

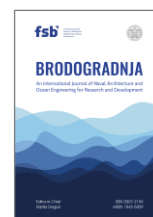


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An International Journal of Naval Architecture and
Ocean Engineering for Research and Development



Effects of wind-wave misalignment on motion responses of a floating wind turbine with a shared-anchor mooring system

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ARTICLE INFO

Keywords:

Floating offshore wind turbine
Wind-wave misalignment
Platform motion response
Shared anchor

ABSTRACT

Wind-wave misalignment significantly affects the dynamic responses of floating offshore wind turbines (FOWTs). A fully coupled aero-hydro-mooring numerical model was established in OrcaFlex for a FOWT with a three-line shared-anchor mooring system. The numerical analysis evaluated three representative sea states (LC1, LC2, and LC3) alongside multiple wind-wave heading combinations. The six-degree-of-freedom (6-DOF) motion responses of the floating platform were systematically investigated using motion trajectories, kernel density estimation (KDE), violin plots, and probabilistic statistical analyses. The results indicated that: (1) the motion responses of the floating platform were jointly governed by the sea state and wind-wave heading. The sea state primarily determined the response intensity and variability, whereas the wind-wave heading governed the motion pattern. Increasing wind-wave misalignment angle shifted platform motion from unidirectional response to multidirectionally coupled motions. This shift led to increasingly dispersed probability distributions. (2) Different motion degrees of freedom exhibited distinct environmental sensitivities. Roll and pitch were primarily controlled by the wind direction, whereas relative wind-wave heading dictated yaw sensitivity. Increasing sea-state severity significantly amplified motion responses without altering their directional response characteristics. (3) Variations in platform motions altered shared-anchor loading characteristics. Higher wind-wave misalignment shifted shared-anchor loads from unidirectional to multidirectional distributions. Consequently, mooring lines underwent continuous load redistribution. These findings clarified the coupled effects of wind-wave misalignment on floating platform motions and shared-anchor loading. This work provides theoretical guidance for designing and assessing shared mooring systems in FOWTs.

1. Introduction

Offshore wind energy offers abundant reserves, a low carbon footprint, high renewability, and reliable operation. Consequently, it has become one of the fastest-growing renewable energy technologies over the last decade [1]. The global cumulative installed capacity is projected to reach 260-290 GW by 2031 [2]. This target represents more than a fivefold increase over current levels. Meanwhile, commercial-scale floating offshore wind farms are expanding to incorporate hundreds of units. This expansion significantly raises the

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manufacturing and installation costs of mooring systems. High costs now impose a severe technical bottleneck on the floating offshore wind sector. Shared mooring systems offer a promising solution for clustered or array-configured floating offshore wind power facilities. This innovation substantially curtails the construction, transportation, and installation costs of mooring systems. Furthermore, it reduces associated expenses for seabed geotechnical surveys. Shared anchoring configurations enhance economic efficiency by decreasing anchor demand by 40 % and reducing overall mooring costs by up to 16 % in wind farms [3]. Nevertheless, shared-anchor systems present several technical challenges. Their coupled dynamic responses are considerably more complex than those of an isolated floating offshore wind turbine (FOWT) [2, 4-6].

Numerous studies have investigated shared mooring lines [7-10] and shared anchors [11-14]. Shared anchors have received significant research attention. This technology reduces anchor quantities and net load magnitudes. Coughlan et al. [15] evaluated a shared anchor layout for a 54-turbine wind farm against a single-turbine baseline. The shared layout decreased mooring costs by up to 36 %. Chen et al. [16] conducted model tests on multiline anchor systems. Their work optimised mooring line diameters to enhance system stability. The optimized configuration reduced marine space footprint by approximately 24 % compared with single-line anchor configurations. Devin et al. [14] and Hallowell Spencer et al. [17] optimised the layout of a 100-turbine farm and concluded that a minor 10 % increase in design anchor capacity yielded an optimal balance. This adjustment-maintained risk levels comparable to single-line configurations and simultaneously reduced overall costs. Overall, shared anchors exhibit strong potential for broad industrial deployment.

Shared anchors exhibit load characteristics distinct from those of traditional single-line anchors. Shared mooring systems incorporate longer mooring lines to mitigate inter-turbine interactions. Consequently, shared-anchor loads, mooring line tensions, and platform motion responses differ substantially from those of traditional FOWTs. For instance, Fontana et al. [18] investigated three-line and six-line anchor systems. Resultant forces on multiline anchors were calculated using vector superposition of line tensions. The line with maximum tension governed the total vector force. Multiline systems exhibited lower resultant forces and lower maximum shared-anchor loads than single-line systems. However, loads on shared anchors are both cyclic and multi-directional. Such loading conditions can reduce anchor holding capacity by up to 86.5 % [19, 20]. Multi-line anchor systems face more complex and severe loading conditions than traditional single-line systems. Multidirectional load interaction and vector summation drive these conditions. Most previous studies focused on mooring lines in shared systems. Research on shared-anchor load characteristics under multi-directional loads remains scarce. In addition, recent studies highlighted synthetic fiber ropes for shared mooring systems. Their compliant and nonlinear stiffness influences restoring behaviour, load distribution, and dynamic responses of shared mooring systems [21-23]. Therefore, these effects warrant further investigation.

Wind and waves are generally non-collinear across different wind speeds [24]. High wind speeds induced minor misalignment. Conversely, low wind speeds yielded significant misalignment. Increasing wind speed or significant wave height narrowed the spread of wind-wave heading misalignment [25]. Maximum misalignment correlated with stable atmospheric conditions. Typical misalignment remained within 30°. Occurrences exceeding 60° accounted for less than 5 % [26-28]. Varied wind-wave load combinations directly altered the motion responses of FOWTs [29]. For instance, Guo et al. [30] investigated the motions of a TLP platform under a 90° wind-wave misalignment. Their study demonstrated significant amplification of surge and pitch responses. Ali et al. [29] evaluated the dynamic responses of a 3.6 MW TetraSpar FOWT in realistic offshore environments. Their study incorporated the influence of wind-wave misalignment. Varied misalignment angles induced asymmetric platform motions, lateral drift, and rotational instabilities. Similarly, Jia et al. [28] investigated the hydrodynamics of a 5 MW barge-type FOWT platform during a two-mooring-line failure scenario under misaligned conditions. Xue et al. [31] numerically analyzed the hydrodynamic, aerodynamic, and wake responses of an FOWT. Their investigation tested five wind-wave misalignment angles (0°, 15°, 30°, 45°, and 60°). Platform responses varied significantly across misalignment angles. Increasing wave headings reduced both the equilibrium positions and response amplitudes of both surge and pitch. Mooring-line tensions also responded dynamically to changes in wind-wave misalignment. This behavior indicated load redistribution across the mooring system. Consequently, accounting for directional

effects remains essential in mooring-system design. Overall, mismatched headings impose critical dynamic effects on FOWTs relative to collinear conditions. Existing literature demonstrated frequent wind-wave misalignment under realistic sea conditions. This directional discrepancy substantially affects platform dynamics.

In this study, three representative sea states (LC1-LC3) and various wind-wave heading combinations were considered to systematically investigate the effects of wind-wave misalignment on the six-degree-of-freedom platform motions and the loading characteristics of the shared anchor. Special emphasis was placed on the evolution of platform motion patterns and the corresponding load redistribution among the three mooring lines under varying environmental conditions. The primary contribution of the present study lies in extending the analysis of wind-wave directional effects from platform motions and individual mooring-line responses to the load-transfer characteristics of a shared-anchor system. Specifically, this work clarified how different wind-wave directional combinations induced load redistribution among the three mooring lines. This, in turn, modified the magnitude, directionality, variability, and critical directional conditions of the resultant force acting on the shared anchor. These findings provide deeper insights into the directional load-transfer mechanism, which cannot be fully characterised by examining individual mooring-line tensions alone. The remainder of this study is structured as follows. Section 2 details the numerical methodology, Section 3 presents the simulation results, and Section 4 concludes the study.

2. Numerical methodology

2.1 Wind Turbine, Floating Platform, and Mooring System

This study adopted the National Renewable Energy Laboratory (NREL) 5-MW reference wind turbine mounted on the OC4-DeepCwind semisubmersible floating platform [32]. This turbine represents a standard utility-scale baseline and is widely used in offshore wind energy research. Figure 1 illustrates the overall layout of the floating wind turbine system. Table 1 details the key design specifications [33].

Table 1 Main parameters for the NREL 5-MW wind turbine

Parameter	Value
Rating	5 MW
Rotor Orientation, Configuration	Upwind, 3 Blades
Rotor diameter	126 m
Hub Height	90 m
Cut-In, Rated, Cut-Out Wind Speed	3 m/s, 11.4 m/s, 25 m/s
Rotor Mass	110,000 kg
Nacelle Mass	240,000 kg

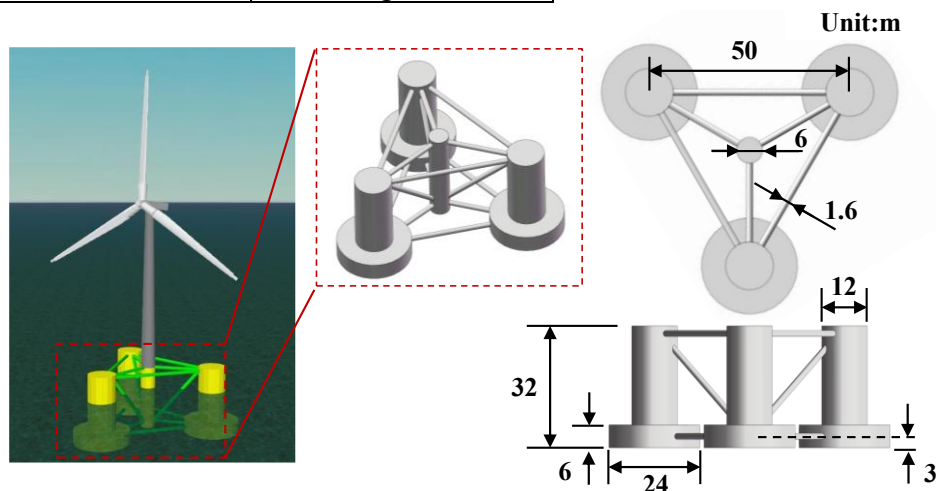


Fig. 1 Schematic diagram of the OC4-DeepCwind semi-submersible platform

Table 2 lists the specific parameters for the mooring lines. The mooring lines were composed of 185-mm Grade R3 studless chains. The inter-turbine spacing was set to a minimum of 7 rotor diameters ($7D$) [34–37]. This separation distance minimized turbine interactions and facilitated aerodynamic wake recovery.

Table 2 Parameters for the mooring lines

Parameter	Value
Mooring system	Catenary
Mooring line type	Studless chain
Water depth	70 m
Line length	800 m
Chain nominal diameter	0.185 m
Mass per unit length of a chain	691.35 kg/m

The NREL 5-MW reference wind turbine did not reflect current state-of-the-art capacity levels. Nevertheless, this system was selected for the present investigation. The combination of the NREL 5-MW turbine and OC4-DeepCwind semisubmersible platform served as a well-established benchmark system. Extensive model parameters and validation data were documented for this configuration. Consequently, model verification was streamlined. This setup enabled a consistent and reproducible analysis of wind and wave heading effects.

Figure 2 presents the overall system arrangement. The wind turbines, the floating platform, and the shared anchor (highlighted in red) constituted the primary research objects. F_1 , F_2 , and F_3 denote the tension forces transmitted to the shared anchor by the three mooring lines at their anchor-end connection points. Vector summation of these three forces yielded the resultant load on the shared anchor, F_{multi} . The adoption of a catenary mooring configuration allowed the omission of vertical components and load inclinations at the anchor. Only the horizontal components of the anchor-end tensions were considered.

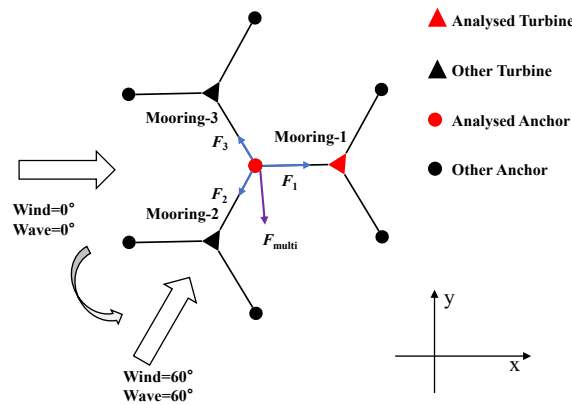


Fig. 2 Three-turbine shared anchor configuration

2.2 Coupled dynamic model

2.2.1 Aerodynamic model

Aerodynamic loading on the floating wind turbine was determined in OrcaFlex using Blade Element Momentum (BEM) theory. Each blade was divided into multiple elements. Aerodynamic force on individual elements was calculated independently by coupling blade element theory with momentum theory.

The relative inflow velocity for each blade element is given by:

$$V_{rel} = \sqrt{V_n^2 + V_t^2} \quad (1)$$

where V_n and V_t denote the normal and tangential components of the relative inflow velocity, respectively.

The lift and drag on each blade element are calculated as follows:

$$dL = \frac{1}{2} \rho_a V_{rel}^2 c C_L dr \quad (2)$$

$$dD = \frac{1}{2} \rho_a V_{rel}^2 c C_D dr \quad (3)$$

where ρ_a is the air density, c denotes the chord length at the local blade section, C_L and C_D are the lift and drag coefficients, respectively, and dr is the blade element length.

Aerodynamic forces on each element were decomposed into axial and tangential components. Integration of these forces over the blade span yielded the total rotor thrust and aerodynamic torque. Momentum theory was applied to iteratively update the axial and tangential induction factors. Prandtl tip-loss correction and high-induction corrections were incorporated to improve prediction accuracy under high-thrust operating conditions. Instantaneous platform motions drove continuous updates of aerodynamic loads in time-domain simulations. This framework enabled a fully coupled dynamic analysis of the aerodynamic, hydrodynamic, and mooring systems.

2.2.2 Hydrodynamic model

The first-order hydrodynamic loads on the floating platform were evaluated using linear potential-flow theory. The fluid was assumed to be incompressible, inviscid, and irrotational. Consequently, the velocity potential satisfies the Laplace equation.

$$\nabla^2 \phi = 0 \quad (4)$$

The equation of motion for the floating platform is expressed as follows:

$$(M + A)\ddot{x} + B\dot{x} + Cx = F_{wave} + F_{wind} + F_{moor} \quad (5)$$

where M , A , B , and C represent the structural mass matrix, added mass matrix, radiation damping matrix, and hydrostatic-restoring matrix, respectively. F_{wave} , F_{wind} , and F_{moor} represent the wave-excitation, aerodynamic, and mooring restoring force, respectively.

The potential-flow boundary element method yielded the frequency-dependent hydrodynamic quantities. These parameters comprised the wave excitation forces, added mass, and radiation damping.

Viscous effects are significant in slender structural members. Morison's equation was applied to correct the hydrodynamic load prediction. C_M and C_D denote the inertia and drag coefficients, respectively.

$$F_M = \rho C_M V \dot{u} + \frac{1}{2} \rho C_D A |u| u \quad (6)$$

The dynamic analysis incorporated first-order wave excitation alongside second-order difference-frequency wave-drift loads evaluated via Newman's approximation. Wave-drift damping was also considered. These second-order wave-drift loads accounted for the mean drift effect and slowly varying excitation. Consequently, such loads potentially drove low-frequency platform motions and induced tension variations in the mooring lines and shared anchors.

2.2.3 Mooring line model

The dynamic response of the mooring system was modelled in OrcaFlex. Each mooring line was discretized into discrete lumped masses connected by massless elastic segments. The mathematical formulation accounted for axial tension, gravitational force, buoyancy, hydrodynamic loading, and seabed interaction. This framework enabled dynamic analysis under large displacements and deformations.

The governing equation of motion for each node is expressed as follows:

$$M\ddot{x} = F_T + F_H + F_G + F_B + F_C \quad (7)$$

where M is the nodal mass matrix, F_T is the axial tension, F_H is the hydrodynamic force, F_G is the gravitational force, F_B is the buoyancy force, and F_C denotes the seabed reaction force.

2.2.4 Coupled time-domain solution

Aerodynamic, hydrodynamic, current, and mooring restoring loads were solved simultaneously in the time domain using OrcaFlex. Environmental loads were calculated at each time step based on the instantaneous state of an FOWT. These loads were subsequently applied to the platform. The resulting six-degree-of-freedom (6-DOF) platform motions were subsequently utilized to update the aerodynamic loads, hydrodynamic forces, and mooring-line tensions for the next time step. This iterative procedure captured the simultaneous interaction among the aerodynamic, hydrodynamic, structural, and mooring systems. Consequently, a fully coupled time-domain dynamic analysis was achieved.

The equations of motion were solved using the implicit time-domain scheme in OrcaFlex. Specifically, the implicit Newmark integration method ensured high numerical stability for strongly coupled nonlinear dynamic systems. This approach is widely established for analyzing floating offshore structures. The simulations incorporated fully coupled dynamics without simplified one-way coupling assumptions. Complex interactions among wind, waves, currents, mooring lines, and platform motions were comprehensively evaluated.

Simulations for each environmental condition lasted 7200 s with a constant time step of 0.1 s. The initial 3600 s contained numerical initialisation transients and was discarded. The remaining 3600 s provided the dataset for statistical evaluation. Identical random seeds were employed for generating the turbulent wind field and irregular wave realisations. This practice ensured direct comparability across all wind-wave heading combinations. The final dataset supported all statistical analyses, including platform trajectories, kernel density estimation (KDE), violin plots, shared-anchor resultant forces, and maximum response statistics.

2.3 Model Validation

A mesh independence analysis was performed to establish an optimal balance between computational efficiency and numerical accuracy. Three hydrodynamic panel models containing 6,496, 7,985, and 9,376 panels were constructed to evaluate mesh convergence. Surge, heave, and pitch RAOs were calculated and compared across various wave periods. Figure 3 showed nearly identical response curves for all three discretisation schemes. The numerical predictions exhibited negligible dependence on mesh density. The results demonstrated stability at panel counts between 6,496 and 9,376. A mesh consisting of 7,985 panels offered an optimal balance between computational cost and accuracy. Consequently, this configuration was adopted for all subsequent simulations.

Figure 4 compares the hydrodynamic RAO characteristics of the OC4 floating platform in surge, heave, and pitch under wave headings of 0°, 30°, 60°, and 90°. The numerical results were validated against data reported by Liu [38]. The maximum mean errors for surge, heave, and pitch were -4.67, 1.05, and -3.36 %, respectively. These limited discrepancies confirmed the model's accuracy in predicting platform motion responses. Detailed validation procedures were documented in a prior study [39].

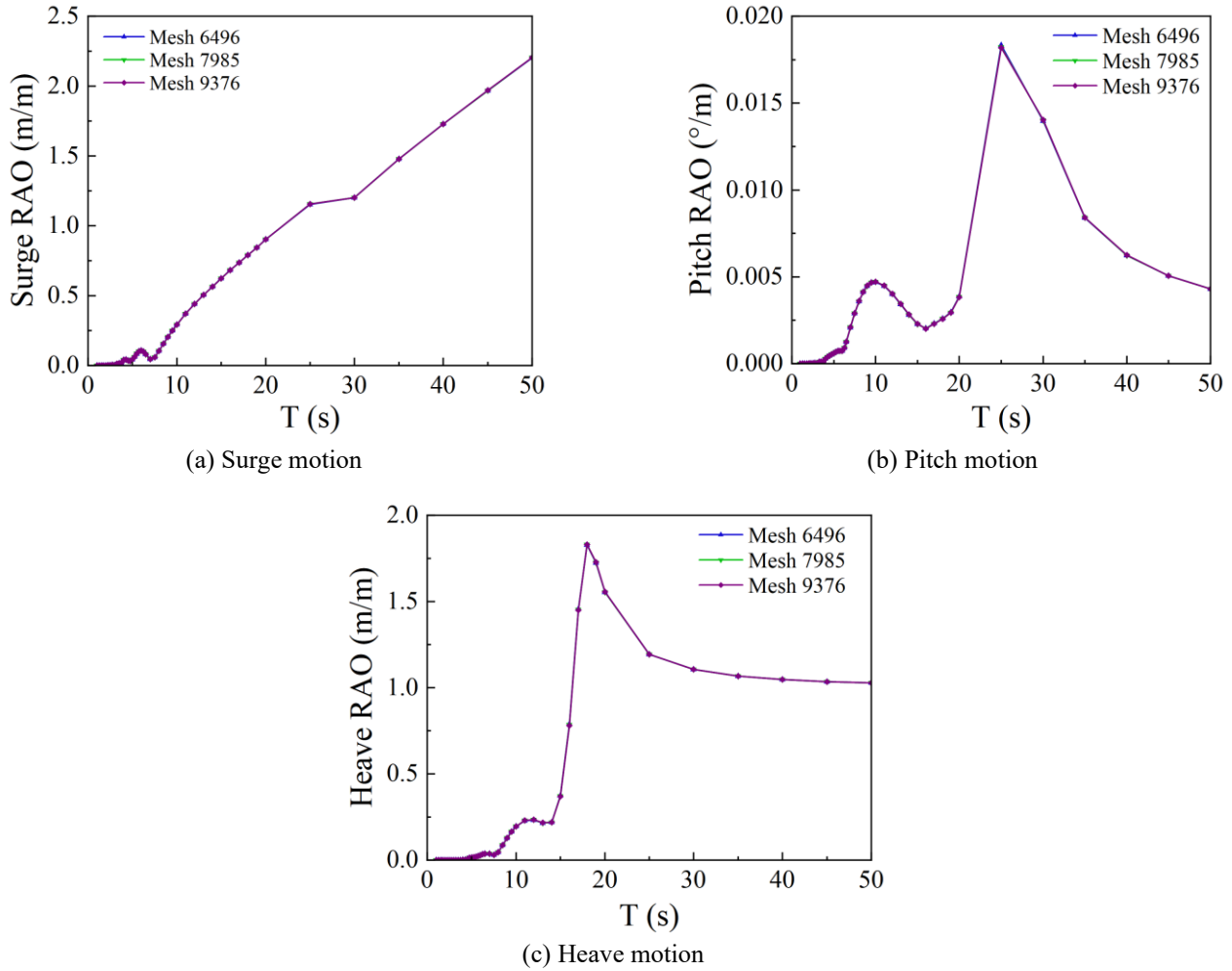
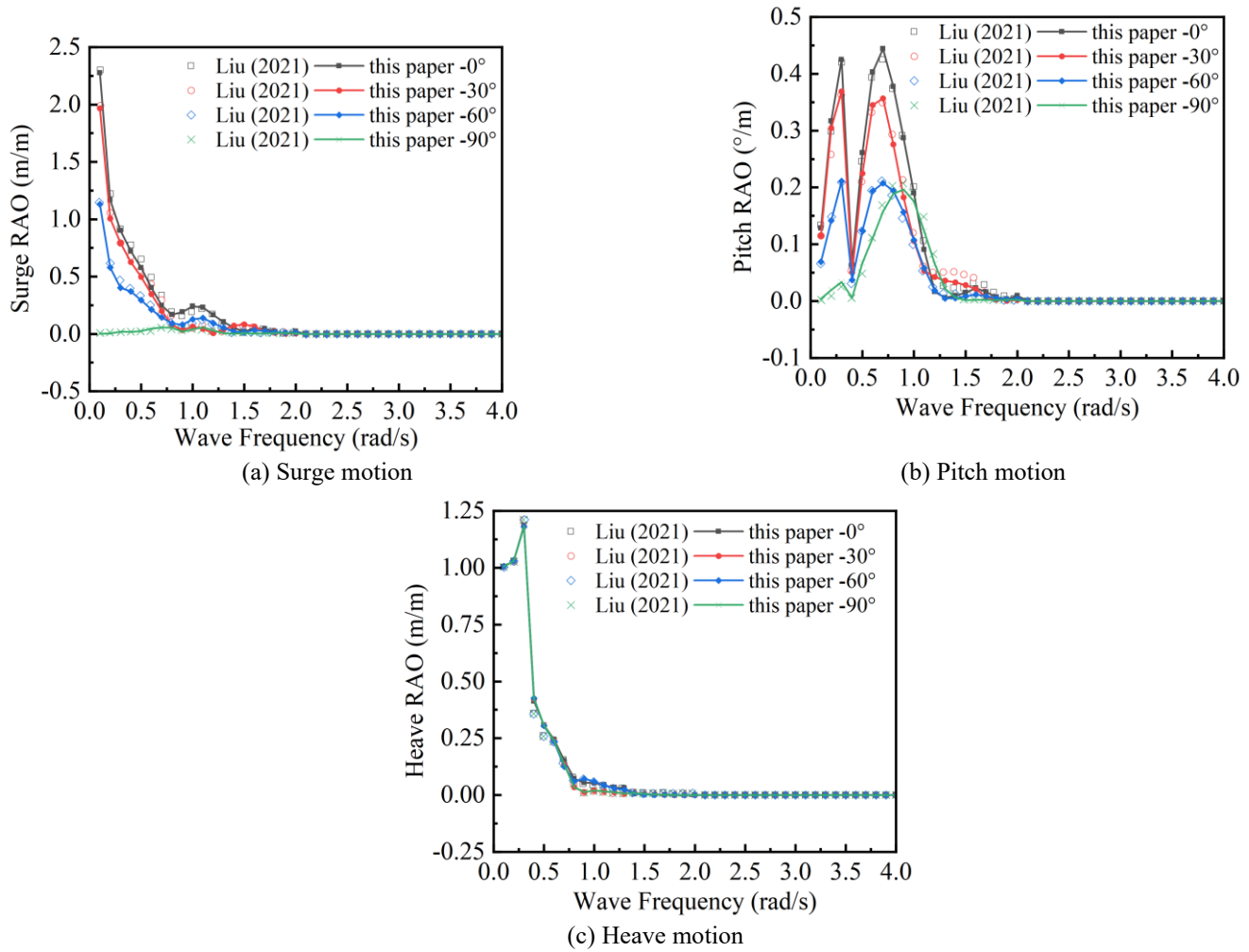
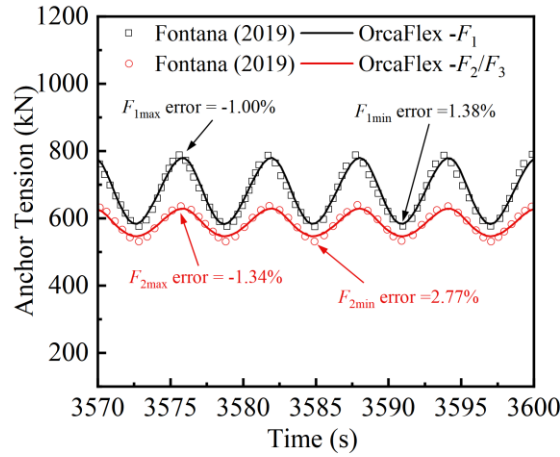


Fig. 3 Mesh independence verification: (a) surge motion; (b) pitch motion; (c) heave motion

The coupled FOWT model was evaluated by reproducing the turbine and mooring configuration from Fontana et al. [36]. Environmental loading was applied at 0° . Figure 5 compares the numerical predictions with the reference data, where F_1 , F_2 , and F_3 denote the tensions in mooring lines 1, 2, and 3, respectively (Figure 2). The numerical predictions aligned closely with the reference results. The maximum tension deviation at peaks and troughs was 2.77 %. The overall errors were 0.3 % for F_1 and 0.04 % for both F_2 and F_3 . This high level of agreement confirmed the predictive reliability of the coupled FOWT model. Furthermore, the resultant shared-anchor force was derived directly from the vector summation of these validated anchor-end mooring-line tensions. Independent validation of the resultant force was therefore unnecessary.

2.4 Load Case Design

Environmental conditions at a water depth of 70 m were categorized into three distinct sea states. Load cases LC1, LC2, and LC3 corresponded to a Normal Sea State (NSS), a Severe Sea State (SSS), and an Extreme Sea State (ESS), respectively (Table 3) [40]. The wind turbine operating conditions for these load cases were summarised as follows. LC1 and LC2 represented normal operating conditions, in which the wind turbine maintained active power production. LC2 represented the most severe environmental condition within the normal operating range. The rotor operated normally and the generator remained connected. The turbine control system automatically adjusted the blade pitch to regulate the rotor speed and aerodynamic loads. In contrast, LC3 represented the parked survival condition under extreme environmental loads. The rotor was locked and the generator was disconnected from power production. All three blades were positioned at a feathering angle of 90° to minimise aerodynamic loads on the turbine.

**Fig. 4** Validation of the platform RAOs [39]**Fig. 5** Mooring line tension validation**Table 3** Parameters for the selected sea states [40]

Sea state	Wind speed (m/s)	H_s (m)	T_p (s)	Current (m/s)
LC1	11.4	2.5	6.5	0.8
LC2	25	6.7	12.4	1.5
LC3	55	13.3	15.5	1.97

The turbulent wind field was generated in OrcaFlex based on the API wind spectrum model. Irregular waves were modeled using the JONSWAP spectrum. The wind turbine was evaluated in a parked survival

state under extreme environmental conditions. Full blade feathering was implemented. The pitch angle was fixed at 90° in accordance with the IEC standard and turbine design documentation [33, 41].

Table 4 summarizes three environmental load cases (calculation results are provided in Tables A1-A6 in the Appendix A). Each load case comprised sixteen wind-wave heading combinations. The maximum angular separation between wind and waves reached 90° . This separation exceeded typical engineering practice. Large wind-wave misalignment angles were selected to investigate the motion response of the floating platform under pronounced wind-wave heading mismatches. The first and second values in the paired notation (e.g., 0° , 30°) represented the wind heading and wave heading, respectively. Additionally, the current direction consistently aligned with the wave heading across all load cases.

Table 4 Matrix of the simulated load cases

Sea state	Case number	Wind/wave heading	Wind/wave misalignment
LC1, LC2 and LC3	1	(0° , 0°)	0°
	2	(30° , 30°)	0°
	3	(60° , 60°)	0°
	4	(90° , 90°)	0°
	5	(0° , 30°)	30°
	6	(0° , 60°)	60°
	7	(0° , 90°)	90°
	8	(30° , 0°)	30°
	9	(30° , 60°)	30°
	10	(30° , 90°)	60°
	11	(60° , 0°)	60°
	12	(60° , 30°)	30°
	13	(60° , 90°)	30°
	14	(90° , 0°)	90°
	15	(90° , 30°)	60°
	16	(90° , 60°)	30°

Collinear wind and wave propagation yielded a unified environmental loading direction. Environmental conditions in non-collinear propagation depended on the wind heading, wave heading, and the corresponding wind-wave misalignment angle.

The total simulation duration for each load case was 7,200 s. The initial 3,600 s accounted for start-up transients and were excluded from analysis. Statistical evaluation utilized the remaining 3,600 s for analysis. A time step of 0.1 s yielded approximately 36,000 time-history samples for each load case during the statistical period. The analysis evaluated mean and maximum values of platform motions and shared-anchor forces. Furthermore, probability density distributions, kernel density estimates, and violin distributions were calculated using these steady-state data.

The same random seeds were assigned to all load cases for the generation of turbulent wind fields and irregular-wave time histories. This standardization ensured direct comparability across different wind headings, wave headings, and sea states. This approach minimized the interference from different stochastic realisations and enabled consistent evaluation of environmental effects. Multiple random-seed simulations were omitted for individual load cases. Consequently, the statistical results were used to identify response trends and relative differences among the investigated environmental conditions. They did not quantify confidence intervals across different stochastic realisations.

3. Results and Discussion

3.1 Influence of Aligned Wind and Waves

3.1.1 Platform Motion Responses

Figure 6 presents the joint and marginal probability density distributions of platform surge and sway under different sea states and wind-wave headings. Sea state and wind-wave heading jointly governed the horizontal motion responses. Specifically, the wind-wave heading dictated the directional pattern of the horizontal motion, whereas the sea state mainly controlled the response intensity and variability. Environmental variations significantly altered the joint probability density distribution. Key parameters - including distribution shape, principal axis orientation, and high-density region location - exhibited notable changes. These variations demonstrated the pronounced directional dependence of the platform's horizontal motions.

When the wind-wave heading was 0° , the joint probability density concentrated along the surge direction, while the sway response remained near zero. Surge motion thus governed the platform response. When the common wind-wave heading reached 30° , the distribution transitioned from a nearly one-dimensional pattern into an inclined elliptical shape. The high-density region extended along the diagonal direction. These results indicated that both surge and sway contributed substantially to horizontal motion. These motions exhibited a strong correlation and coupling effect. As the wind-wave heading further increased to 60° , the joint probability density extended along the environmental loading direction. This extension indicated a stronger apparent correlation between surge and sway. When the wind-wave heading reached 90° , the high-density region shifted toward the sway direction, whereas the surge response decreased significantly. This shift indicated a gradual transition of the dominant horizontal motion from surge to sway. This behaviour was primarily attributed to the redistribution of longitudinal and transverse load components under changing headings. The altered dominant excitation direction modified the horizontal motion pattern of the platform. Rotation of the loading direction redistributed aerodynamic and hydrodynamic load projections onto the surge and sway axes. Consequently, the mooring system exerted restoring forces in both horizontal directions. These forces induced increasingly coupled surge-sway motions and progressively rotated the probability density distribution.

The transition from LC1 to LC3 expanded the joint probability density distribution and broadened the marginal probability density distributions. The high-density region gradually spread from the centre toward the periphery. This spatial shift indicated significant increases in motion amplitude and variability under higher sea state. This trend was particularly pronounced under 30° and 90° wind-wave headings. These headings exhibited substantially larger joint probability density coverage alongside distinct low-probability regions. Consequently, severe sea states promoted larger instantaneous horizontal displacements and increased platform motion uncertainty. The joint probability density exhibited a relatively regular elliptical shape under the 30° wind-wave heading. This pattern demonstrated a stable coupling relationship between surge and sway. Conversely, the distribution was predominantly elongated along the sway direction under the 90° wind-wave heading. Transverse environmental loads primarily governed the horizontal motion. Consequently, sway became the dominant dynamic response.

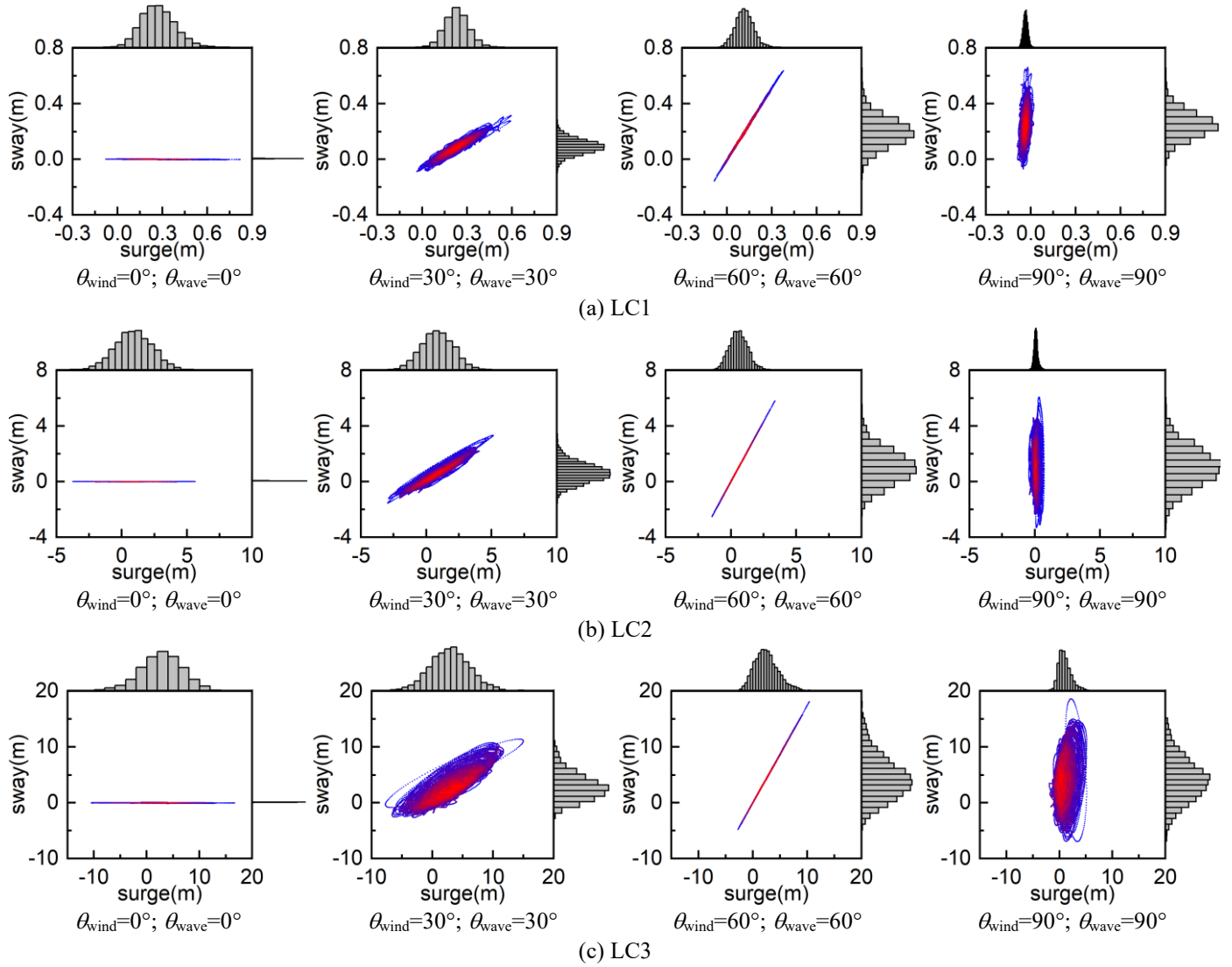


Fig. 6 Sway and surge motion responses of the platform under different sea states

Figure 7 shows the statistical distributions of platform roll, pitch, and yaw across various sea states and wind-wave headings. Overall, the rotational motions were jointly governed by the sea state and the wind-wave heading. The wind-wave heading primarily determined the rotational motion pattern, whereas the sea state mainly controlled the response intensity and variability. The three rotational degrees of freedom exhibited distinct response characteristics under different wind-wave headings. These results demonstrated the pronounced directional dependence of the platform's rotational motions.

The pitch response dominated the platform's rotational motion at a 0° wind-wave heading. When the common wind-wave heading reached 90° , roll gradually became the dominant rotational response. This transition stemmed from shifts in the environmental loading direction. Such directional changes redistributed excitation moments along the platform's principal rotational axes. Consequently, different rotational degrees of freedom exhibited distinct sensitivities to variations in the wind-wave heading.

The transition from LC1 to LC3 increased both the amplitudes and dispersions of the rotational responses. This trend demonstrated that more severe sea states amplified platform motions, enhanced response variability, and elevated the risk of extreme rotational events. In addition, the yaw response exhibited greater dispersion under the 30° and 90° wind-wave headings than under the 0° and 60° headings. This pattern revealed a higher sensitivity to the environmental loading direction. This behaviour primarily stemmed from asymmetric environmental loads on the floating platform and variations in the mooring restoring moment.

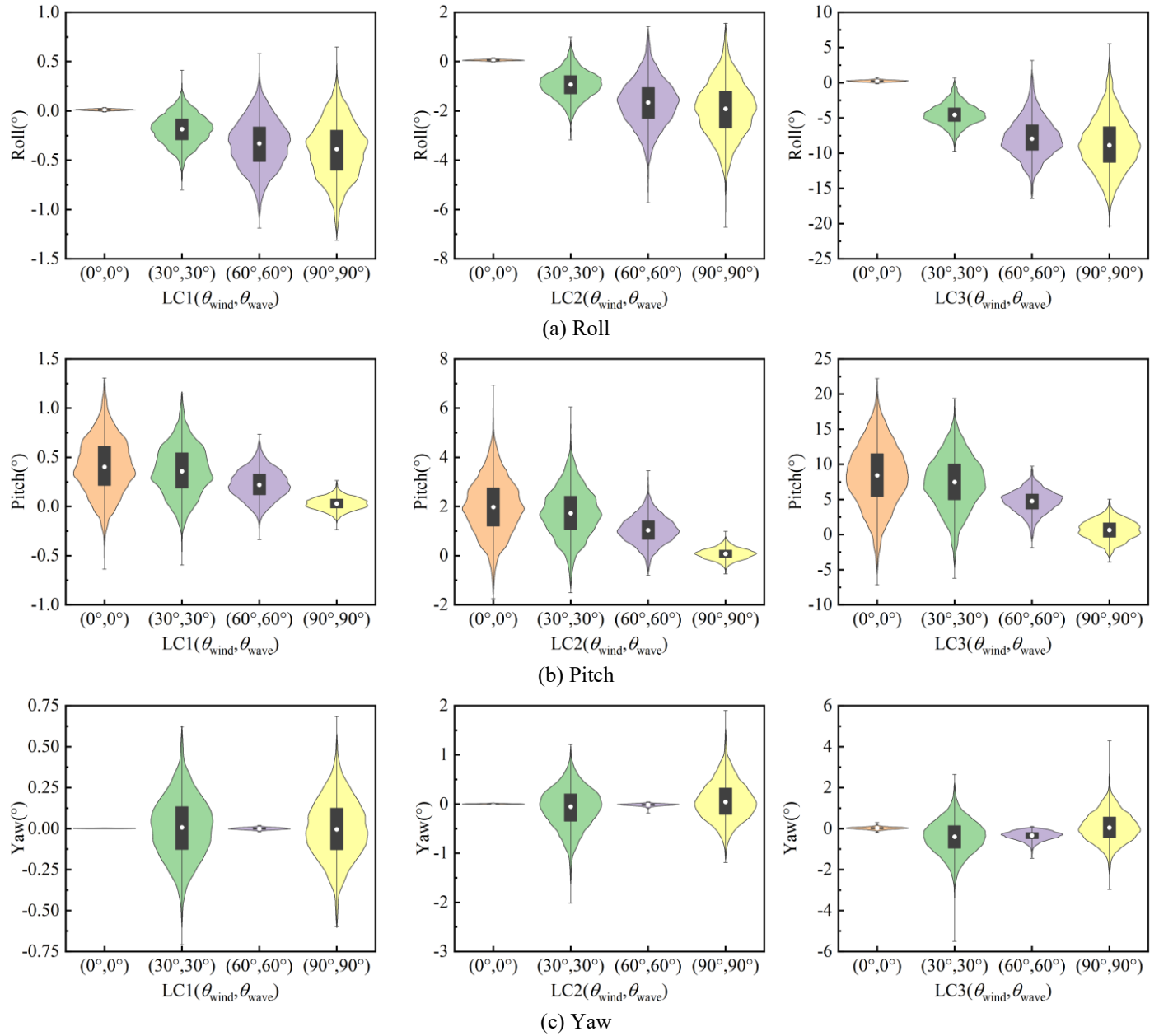


Fig. 7 Rotational motion responses of the floating platform

The preceding analysis demonstrated a strong dependence of floating-platform motion responses on environmental loading conditions. The observed responses were jointly determined by the absolute wind heading, the absolute wave heading, and their relative misalignment angle. The misalignment angle alone was insufficient to govern these responses. Therefore, a parametric study was conducted under the representative sea state LC1 to isolate the respective influences of wind and wave headings on rotational responses. Figure 8 presents the results for a fixed 0° wave heading and varying wind headings. Figure 9 presents the results for a fixed 0° wind heading and varying wave headings. Peak absolute roll, pitch, and yaw responses served as evaluation metrics for direct comparison.

Figures 8(a) and 9(a) present the roll responses. An increase in either wind or wave heading generally amplified the roll response. However, the wind heading produced a considerably greater increase than the wave heading. Thus, roll motion exhibited higher sensitivity to variations in wind direction. This behaviour primarily stemmed from increased transverse aerodynamic loads at higher wind headings. The elevated transverse load increased the overturning moment about the platform's longitudinal axis. Consequently, larger roll motions occurred. Meanwhile, the oblique environmental loading reduced the symmetry of restoring forces within the shared mooring system. This loss of symmetry further amplified the roll response.

Figures 8(b) and 9(b) present the pitch responses. An increase in wind heading from 0° to 90° caused a progressive reduction in the pitch response. In contrast, wave heading variations exerted a minor influence. A noticeable increase occurred only at a 90° wave heading. These results demonstrated the dominant role of wind direction over the pitch response. The wave direction exerted a secondary impact. This behavior occurred because the aerodynamic thrust acted primarily along the rotor axis and therefore dominated the pitching moment. Furthermore, wave heading variations primarily redistributed the lateral hydrodynamic loads. Consequently, these variations exerted minimal influence on the longitudinal pitching response.

Figures 8(c) and 9(c) present the yaw responses. Wind heading variations produced only minor changes in the yaw response, whereas the wave heading exerted a pronounced directional influence. Yaw remained minimal under 0° and 60° wave headings. The alignment between the wave propagation and the mooring-system restoring direction restricted the yaw moment. In contrast, the larger angle between the wave propagation direction and the mooring layout under 30° and 90° wave headings caused a more asymmetric distribution of environmental loads. Consequently, the larger yaw moment significantly amplified the yaw response. Meanwhile, oblique environmental loading induced asymmetric restoring stiffness in the shared mooring system. This condition intensified the yaw response. This phenomenon stemmed from a reduction in rotational restraint about the platform's vertical axis.

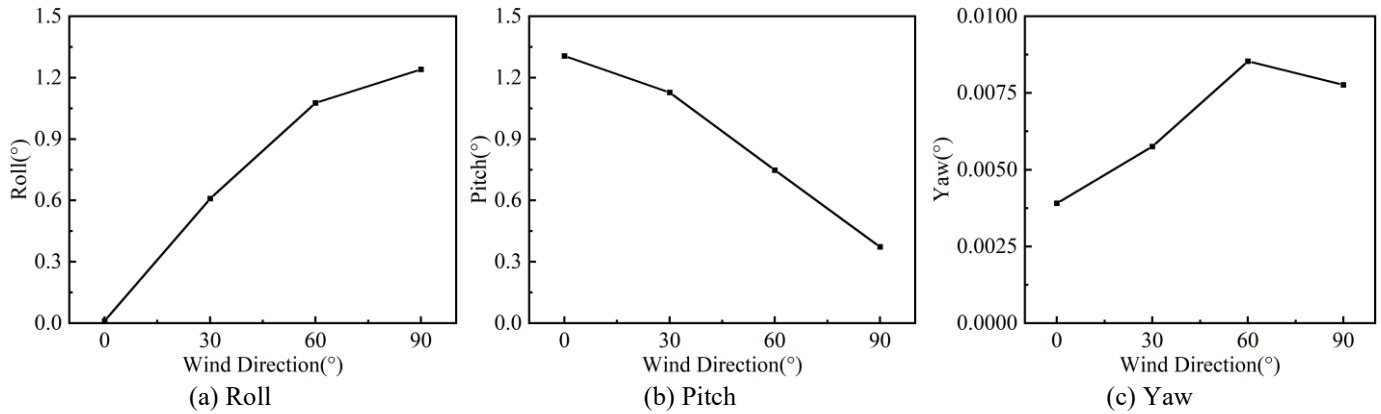


Fig. 8 Wave heading = 0°

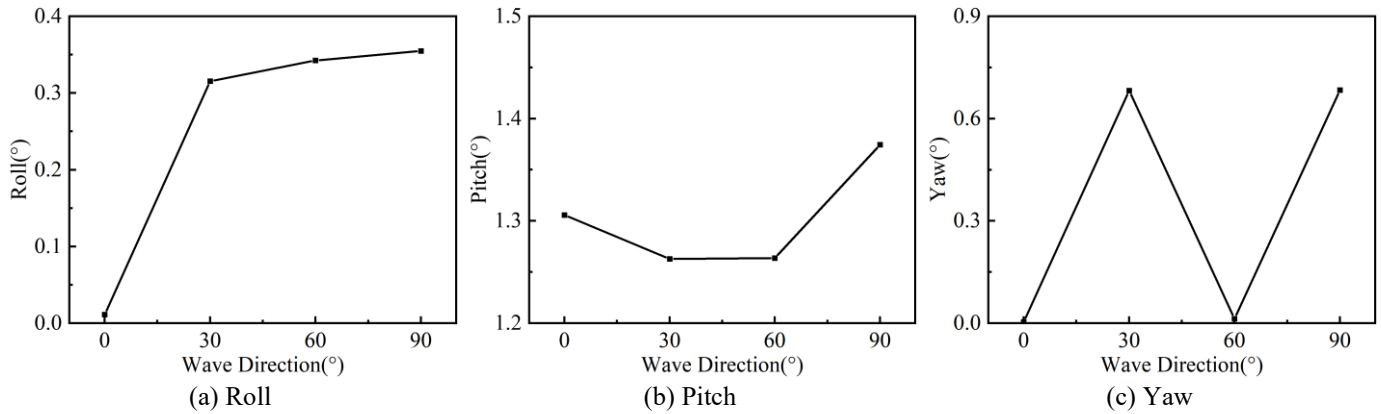


Fig. 9 Wind heading = 0°

3.1.2 Load Analysis of the Shared Anchor

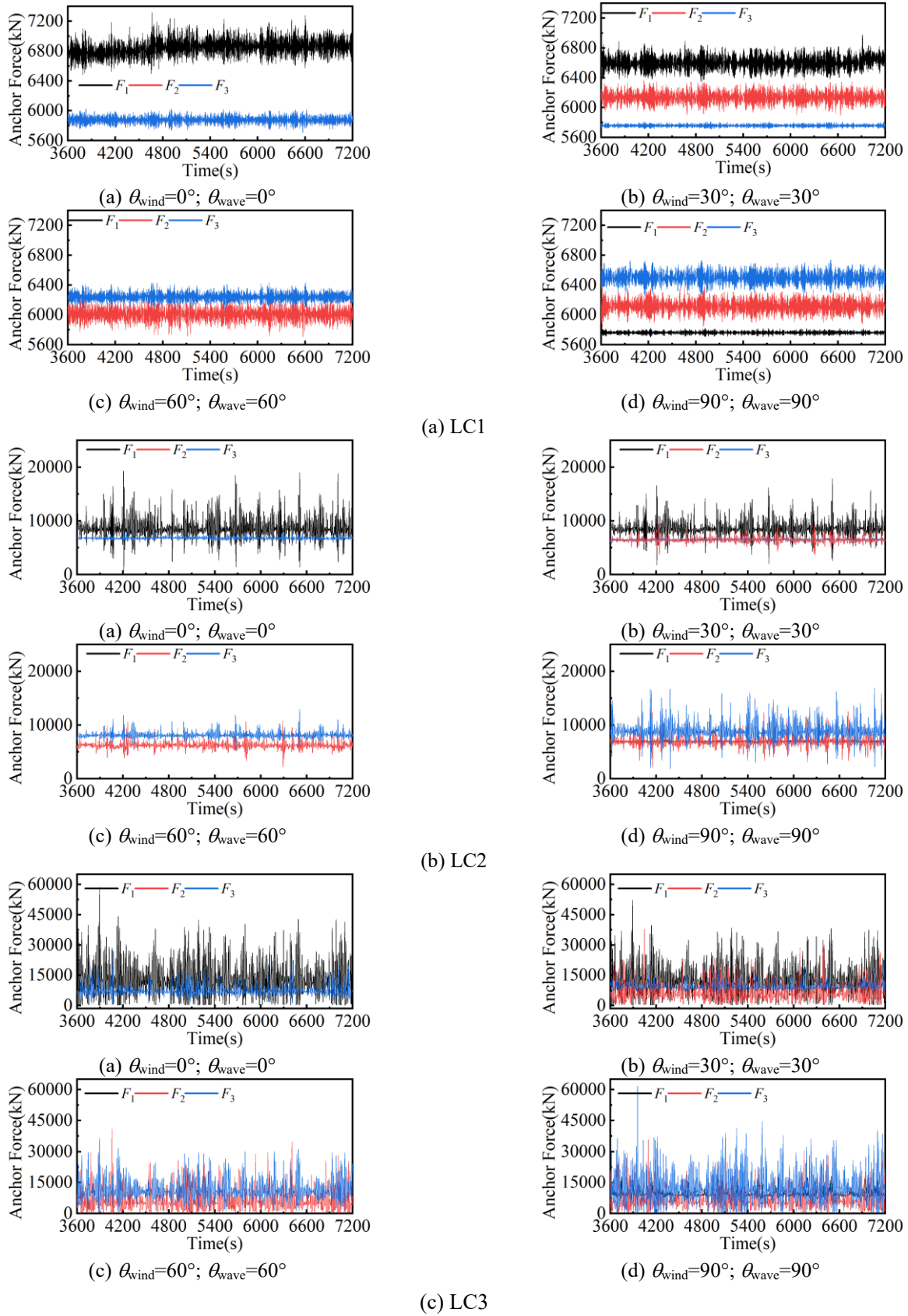
Figure 10 presents the time histories of the three anchor-end mooring-line tensions (F_1 , F_2 , and F_3). Their effective static pretensions under initial equilibrium without environmental loading were 540.34, 576.9, and 576.9 kN, respectively. Figure 11 presents the directional distribution of the shared-anchor resultant load. This calculation followed the vector-based procedure proposed by Fontana et al. [36] and illustrated in Figure 2. The three loading directions of the shared anchor were uniformly arranged at 120° within the horizontal plane. Consequently, the resultant shared-anchor load can be decomposed into three directional components. The combined contributions of these components determined the magnitude and direction of the resultant force. Overall, the horizontal resultant force at the shared anchor was jointly governed by the sea

state and the wind-wave heading. The sea state primarily affected the load magnitude and dynamic fluctuations. In contrast, the wind-wave heading mainly controlled the load distribution among the three directions and the direction of the resultant shared-anchor load.

Figure 10 showed that transitioning the sea state from LC1 to LC3 significantly increased both the mean values and fluctuation amplitudes of all three directional loads. Instantaneous peak loads also increased substantially under higher sea states. Overall, more severe sea states elevated the average load on the shared anchor and intensified dynamic load fluctuations. Consequently, the anchor system experienced more severe cyclic loading. In contrast, the wind-wave heading primarily redistributed loads among the three loading directions. It did not uniformly alter all directional loads. When the wind-wave heading was 0° , the environmental loading direction aligned with the F_1 direction. Thus, F_1 sustained the majority of the load. Components F_2 and F_3 were geometrically symmetric relative to the environmental loading direction. Therefore, these two components exhibited nearly identical load levels. At a 60° wind-wave heading, the environmental loading direction lay between F_1 and F_3 . This orientation produced nearly equal projections along these two directions. Consequently, F_1 and F_3 sustained similar load levels, whereas the load carried by F_2 decreased significantly. These observations demonstrated continuous load redistribution among the three loading directions. This load redistribution resulted from the changing projection of the environmental loading vector onto the three loading axes spaced at 120° intervals. It did not reflect synchronous variations across the three directional loads.

Figure 11 demonstrated the progressive rotation of the resultant force direction alongside the wind-wave heading. The peak probability remained concentrated around the environmental loading direction. Consequently, the environmental loading direction predominantly governed the resultant force direction. Meanwhile, transitioning from LC1 to LC3 substantially increased the magnitude of the resultant shared-anchor load. In contrast, the dominant direction remained essentially unchanged. Consequently, more severe sea states primarily amplified the environmental loading intensity without altering the dominant loading direction.

Figure 12 presents a detailed analysis of the shared-anchor loads. Figure 12(a) showed that the maximum and minimum loads occurred under wind and wave headings of 0° and 60° , respectively. The minimum loads for LC1, LC2, and LC3 were 609.31, 8282.72, and 35797.70 kN, respectively. The corresponding maximum loads were 1459.62, 12962.85, and 54608.89 kN, respectively. The disparity between the minimum and maximum loads remained relatively small for LC1 and LC2. In contrast, LC3 exhibited a significantly larger variation. Furthermore, the shared anchor loads increased markedly with sea state severity. Figure 12(b) illustrates the variation curves of the mean loads on the anchor. The minimum mean loads across different headings for LC1, LC2, and LC3 were 235.22, 1948.41, and 7542.25 kN, respectively. The peak mean loads reached 971.28, 2343.89, and 8931.00 kN, respectively. These results confirmed substantial variations in the loads acting on the shared anchor across different sea states.

**Fig. 10** Time histories of anchor-end mooring-line tensions

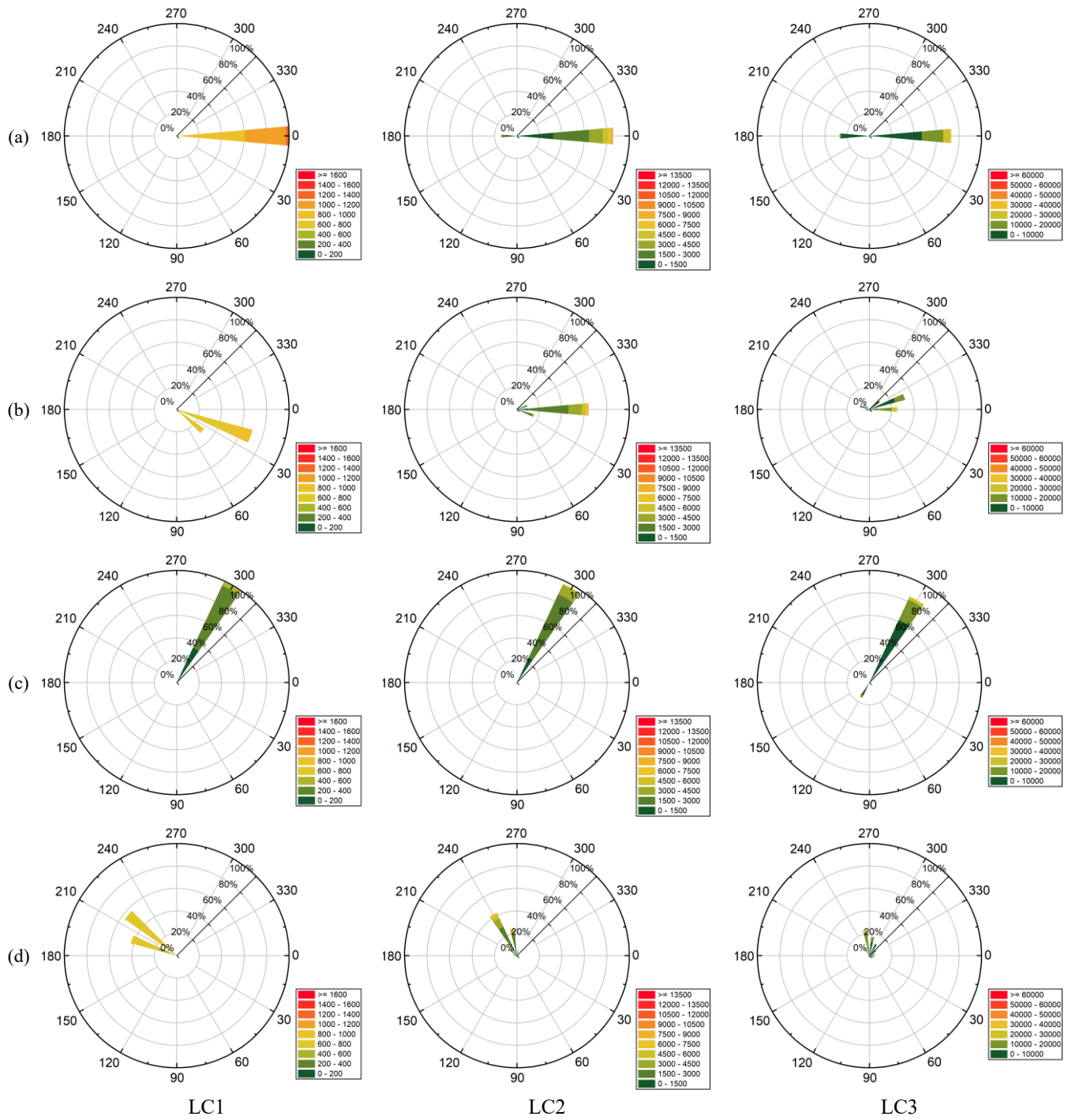


Fig. 11 Directional distributions of the resultant force under different sea states (kN):

(a) $\theta_{\text{wind}} = 0^\circ, \theta_{\text{wave}} = 0^\circ$; (b) $\theta_{\text{wind}} = 30^\circ, \theta_{\text{wave}} = 30^\circ$; (c) $\theta_{\text{wind}} = 60^\circ, \theta_{\text{wave}} = 60^\circ$; (d) $\theta_{\text{wind}} = 90^\circ, \theta_{\text{wave}} = 90^\circ$

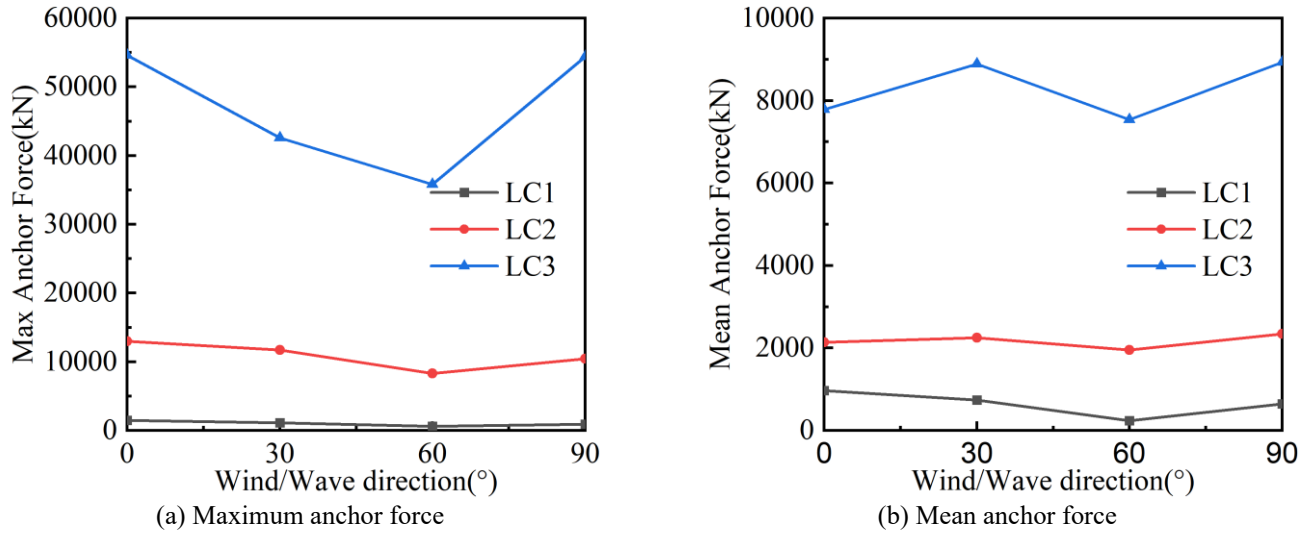


Fig. 12 Maximum and mean anchor forces

3.2 Influence of Misaligned Wind and Waves

3.2.1 Platform Motion Responses

Figures 13-15 present the joint and marginal probability density distributions of platform surge and sway under different sea states and directional combinations. Wind heading, wave heading, and sea state jointly influenced the horizontal motions of the platform. Specifically, wind and wave headings dictated the horizontal motion pattern and surge-sway coupling characteristics. In contrast, sea state mainly governed the response intensity and variability. These combined factors defined the overall horizontal response of the platform.

All three sea states exhibited a consistent evolution pattern in horizontal motions. An increase in wave heading gradually from 0° to 90° progressively altered the principal axis of the joint probability density distribution under a fixed wind heading. The orientation shifted from alignment with the surge axis toward the sway axis. This shift indicated a gradual transition of the dominant horizontal motion from surge to sway. When the wave heading was 0°, the platform motion primarily concentrated in the surge degree of freedom. Increasing the wave heading to 30° and 60° transformed the joint probability density distribution into an elongated elliptical shape. This shift indicated a significant enhancement in the correlation and coupling between surge and sway. The distribution aligned almost entirely with the sway direction at a 90° wave heading. Consequently, sway predominantly governed the horizontal motion of the platform. Meanwhile, wind heading variations further altered the orientation and shape of the joint probability density distribution under a fixed wave heading. Therefore, the horizontal motion pattern depended on the combined effect of wind and wave headings rather than any single factor.

Transitioning sea state from LC1 to LC3 drove the progressive expansion of joint probability density distributions. Concurrently, marginal probability density distributions broadened, and high-density regions enlarged. These trends indicated significant increases in both the amplitudes and variability of the platform's horizontal motions. In particular, surge and sway responses under LC3 exceeded those under LC1 and LC2. Severe sea states considerably amplified horizontal motion responses. Nevertheless, the principal axis orientation of the joint probability density distribution remained essentially unchanged under the same wind-wave combinations. This observation indicated that more severe sea states did not alter the fundamental horizontal motion pattern. Instead, they primarily increased the response magnitude and fluctuation range. Therefore, the sea state mainly controlled the energy input to the floating platform. The wind and wave headings continuously governed the dominant direction of horizontal motions.

Furthermore, the joint probability density distribution evolved from an approximately circular shape into an elongated elliptical or nearly linear form. This evolution reflected variations in the coupling strength between surge and sway. An elongated elliptical distribution indicated a strong correlation between these two

degrees of freedom. Consequently, platform motions occurred primarily along a dominant direction. In contrast, a nearly circular distribution signified a weaker correlation and a more dispersed motion direction. More severe sea states caused the high-density region to expand. This expansion signaled increased uncertainty in platform motions and produced more dispersed motion trajectories.

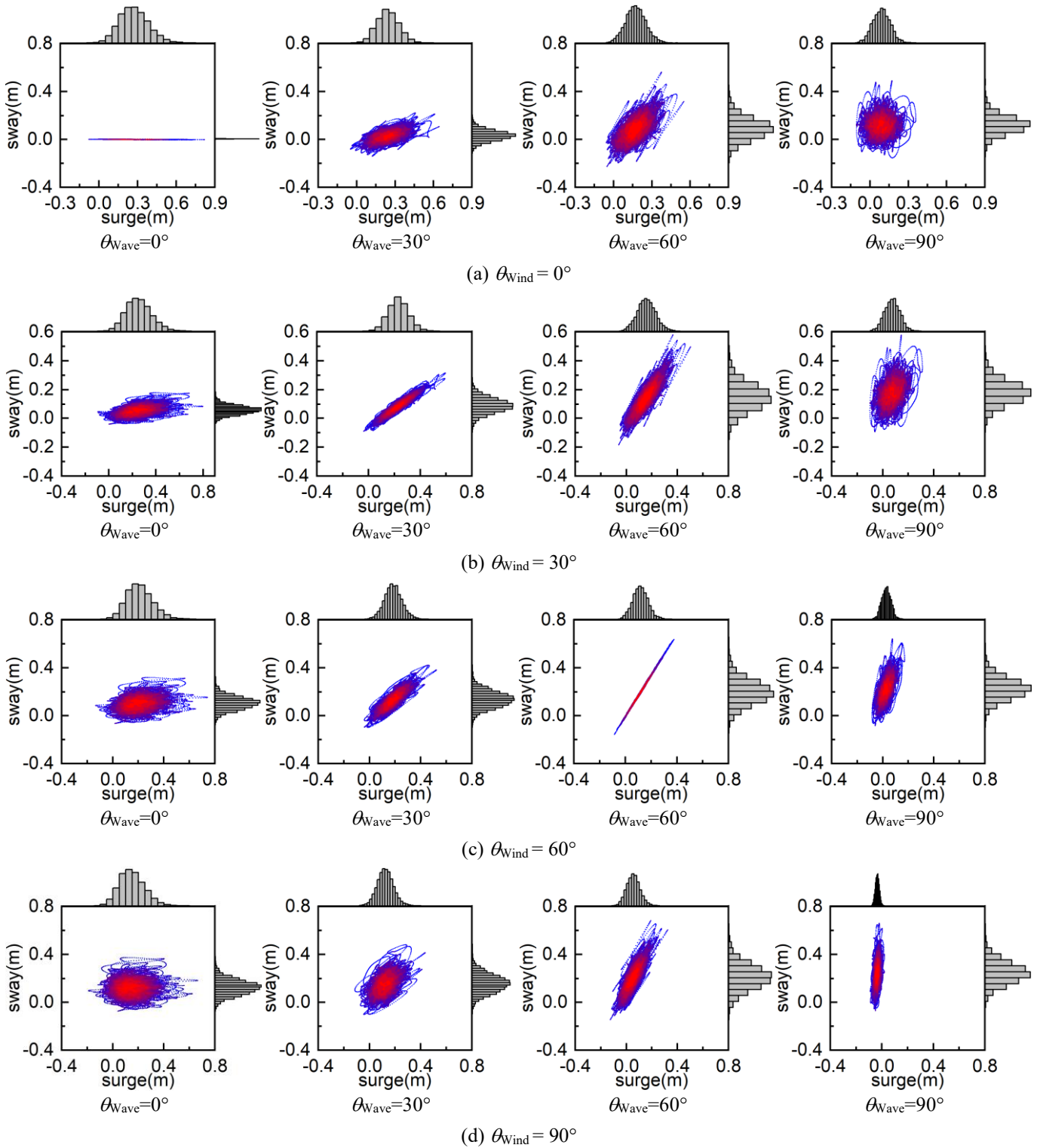


Fig. 13 Surge and sway motions under LC1

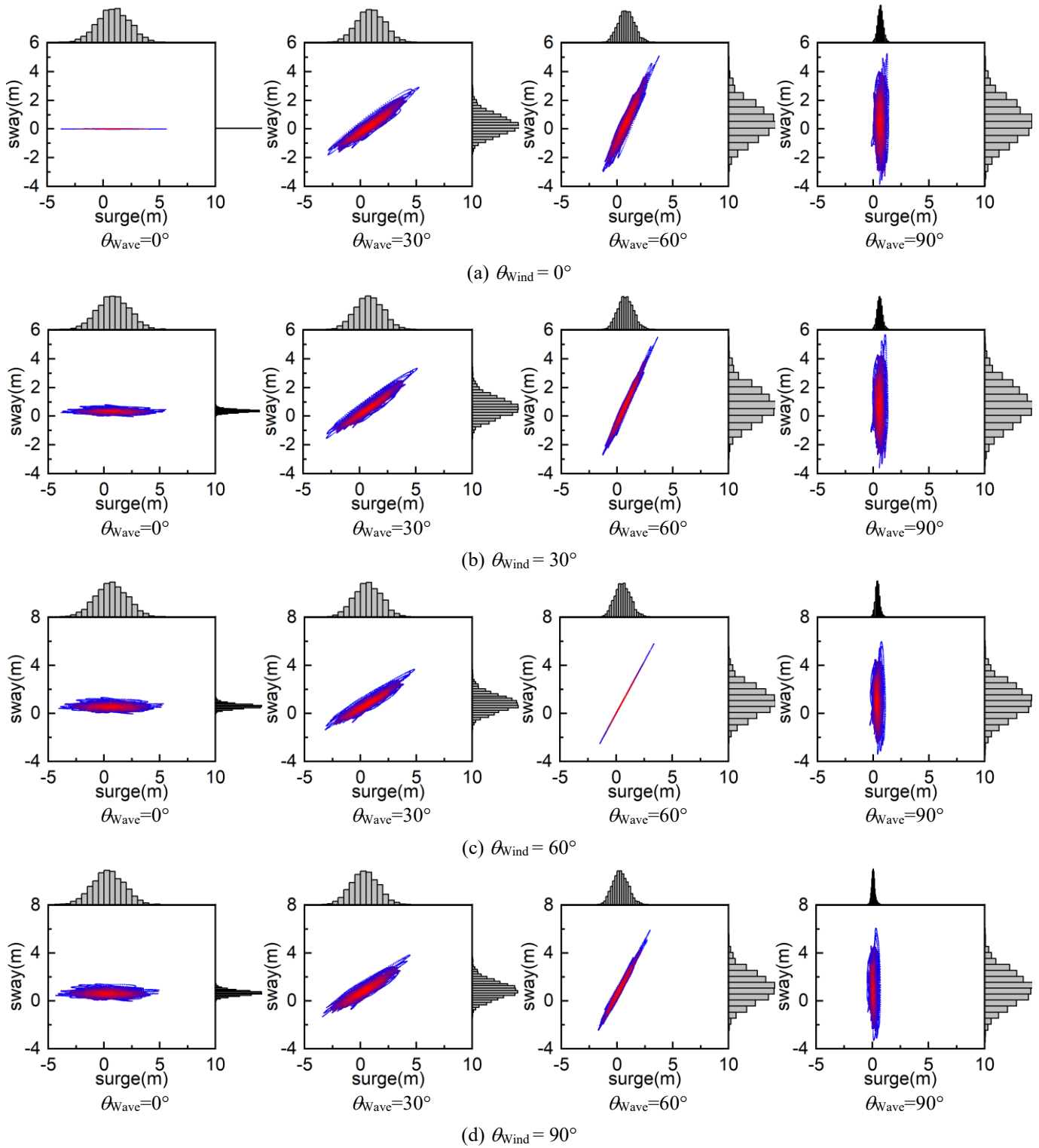


Fig. 14 Surge and sway motions under LC2

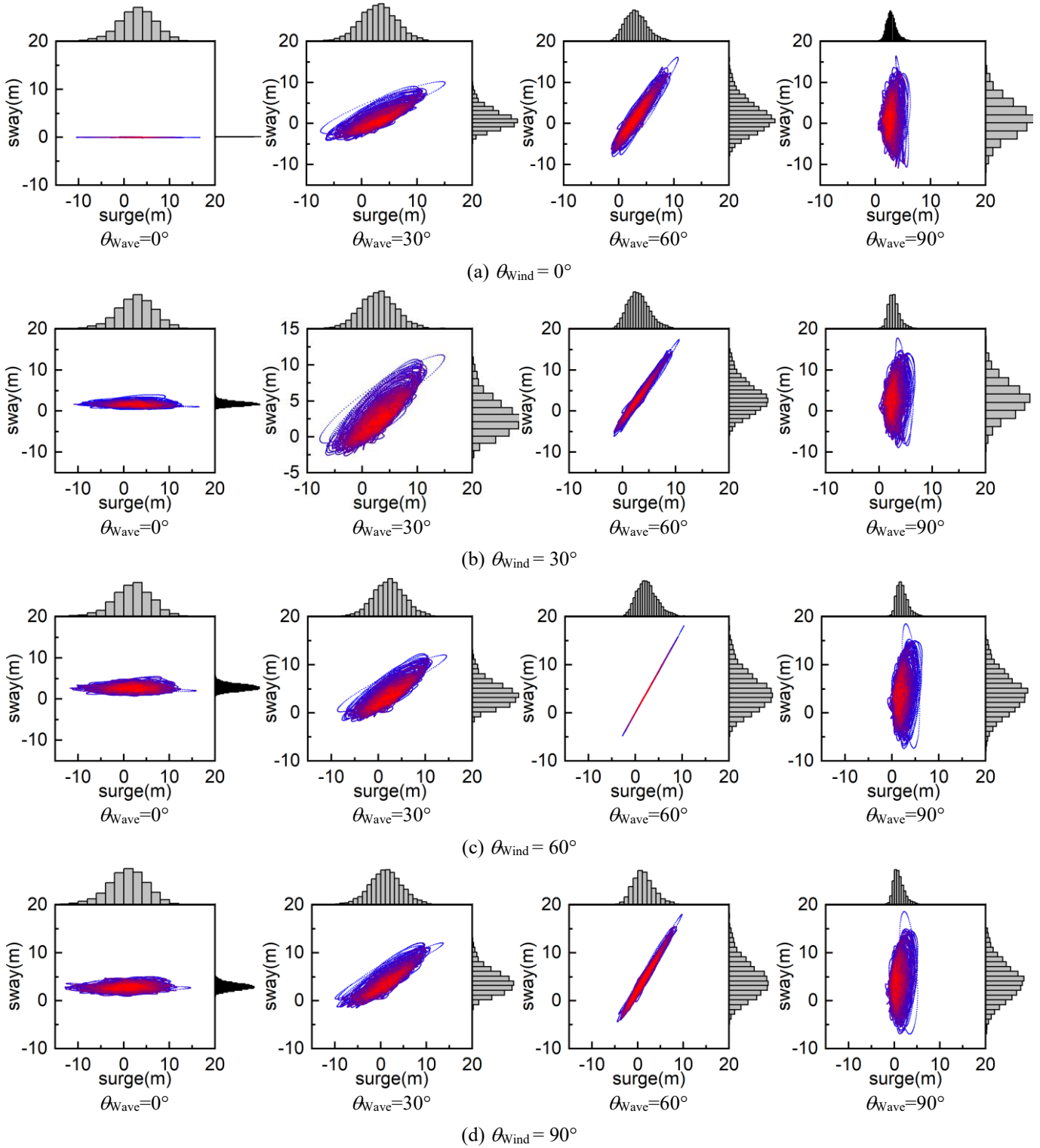


Fig. 15 Surge and sway motions under LC3

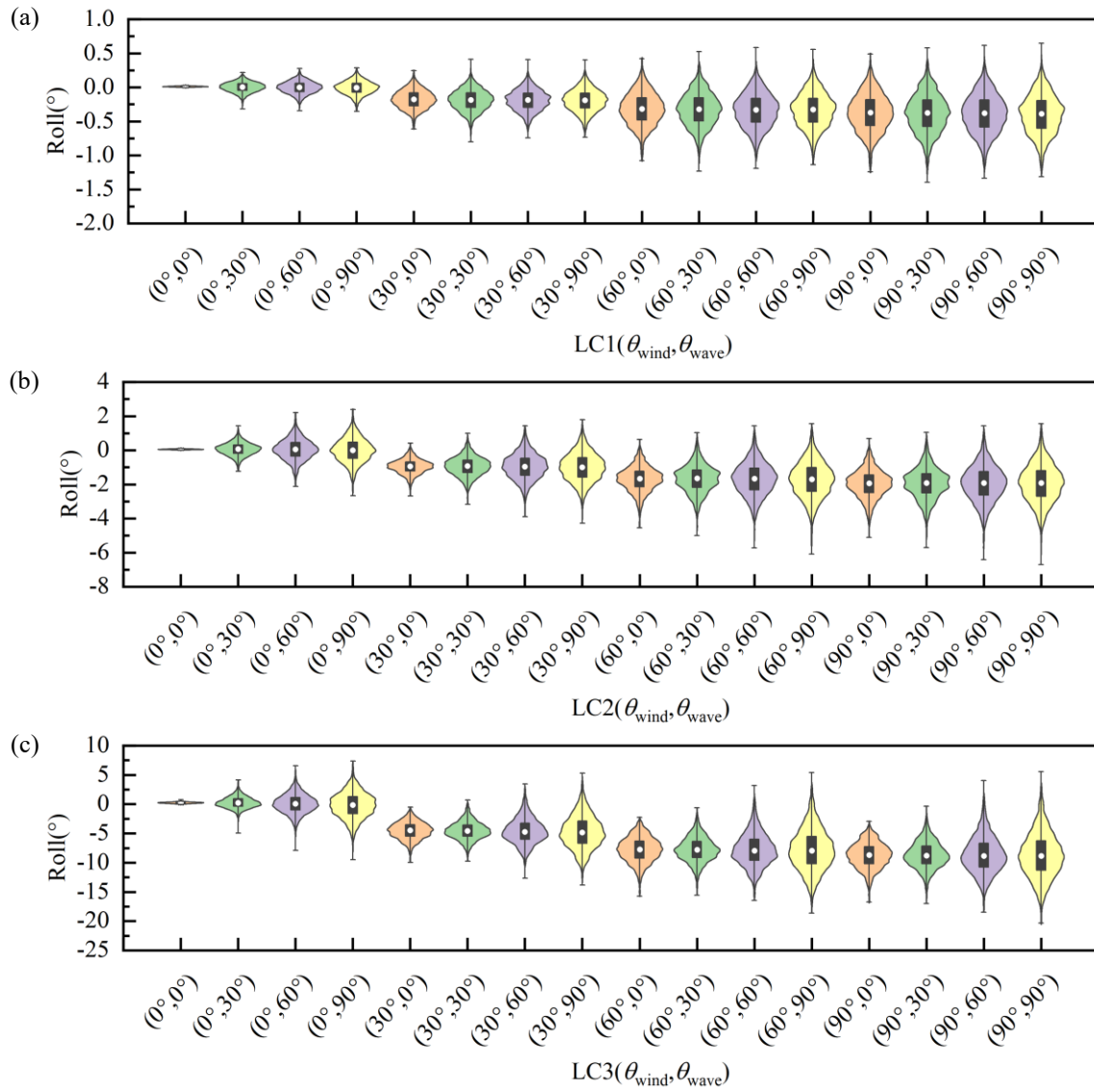
Figures 16-18 present the violin plots for platform roll, pitch, and yaw under various combinations of wind and wave headings across three representative sea states (LC1, LC2, and LC3). Overall, the rotational motions were jointly governed by wind heading, wave heading, and sea state. The three rotational degrees of freedom exhibited distinct response characteristics. The wind heading dictated the platform attitude along the horizontal axes (roll and pitch). The relative wind-wave heading orientation governed the yaw motion about the vertical axis. In contrast, the sea state primarily influenced the response intensity and variability. It did not fundamentally alter the response characteristics of each rotational degree of freedom.

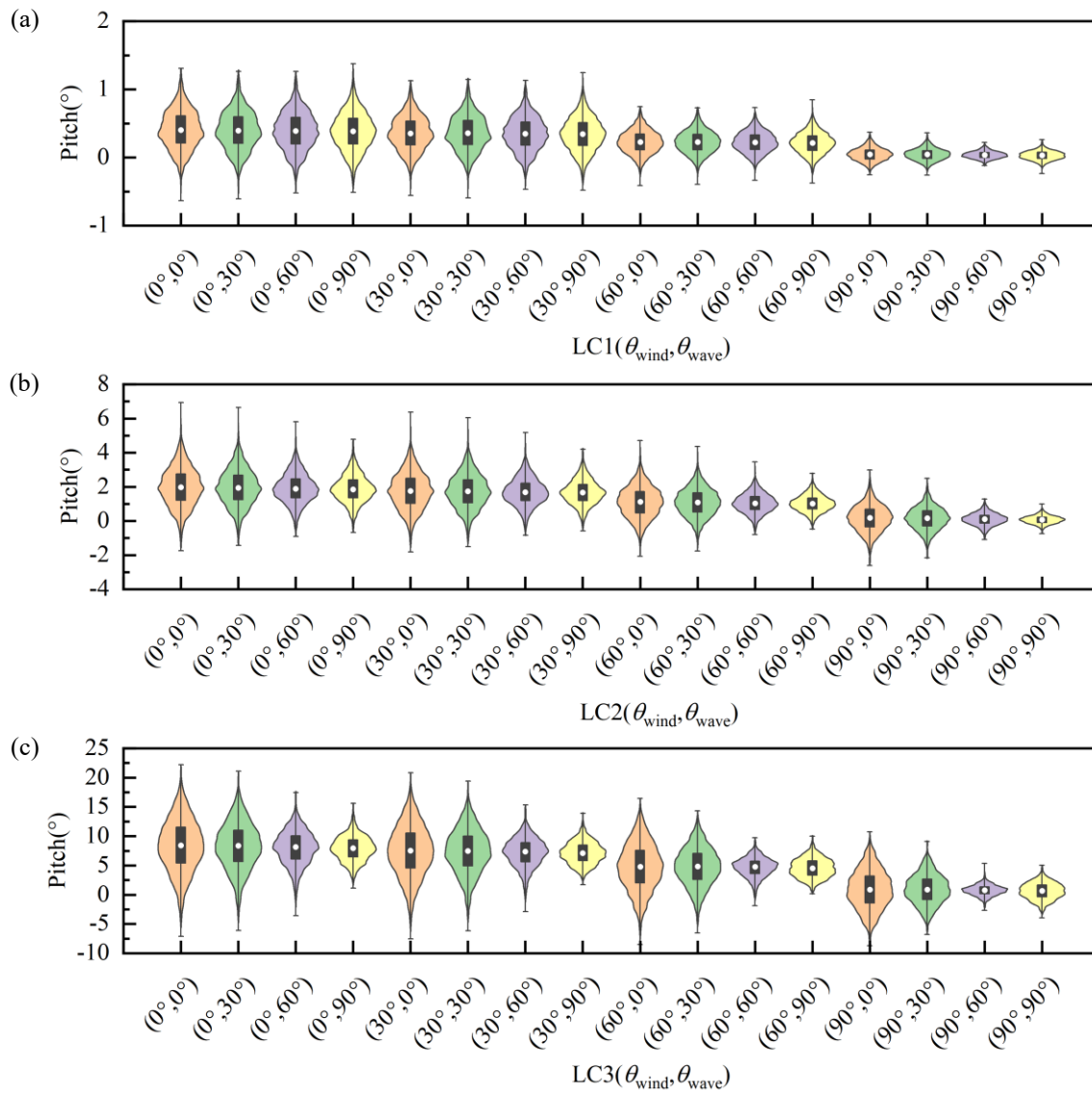
Figure 16 demonstrated a consistent evolution pattern of roll responses across all three sea states. An increase in wind heading from 0° to 90° intensified the absolute roll response. Broader violin distributions further indicated continuous increases in both the motion amplitude and response variability. In contrast, variations in wave heading produced only minor changes. Therefore, the roll response was predominantly governed by the wind direction. This behaviour stemmed from higher transverse aerodynamic force and associated overturning moment at larger wind headings. These forces amplified the rolling moment about the platform's longitudinal axis. The magnitude of roll responses increased significantly from LC1 to LC3, yet the overall variation trend remained unchanged. These results indicated that more severe sea states amplified the environmental energy input without altering the governing mechanism of the roll motion.

Figure 17 showed that pitch responses exhibited an evolution trend opposite to that of roll responses. Higher wind heading reduced the pitch response magnitude. Conversely, wave heading variations induced only minor fluctuations. Consequently, the pitch motion was also controlled by the wind direction. Shifts in wind heading redistributed the longitudinal aerodynamic force and pitching moment. This force redistribution adjusted the platform attitude about the transverse axis. More severe sea states caused a pronounced broadening of the violin distributions. This change indicated higher variability and stronger fluctuations in the pitch response. In contrast, the fundamental directional response pattern remained essentially unchanged.

Figure 18 revealed that yaw responses exhibited characteristics distinctly different from those of roll and pitch motions. Overall yaw amplitudes remained relatively small. However, the yaw response exhibited heightened sensitivity to wind-wave combinations. Greater misalignment between wind and wave headings significantly broadened the violin distributions. This pattern indicated a pronounced increase in the yaw response. In contrast, closer alignment between the wave propagation direction and the restoring mooring direction substantially reduced the yaw response. These observations indicated that individual environmental headings did not solely govern yaw motion. Instead, yaw motion relied on the coupled wind-wave interaction and the restoring effect of the mooring system. Larger offsets between the environmental loading direction and the mooring restoring direction generated greater yaw moments. Consequently, these moments intensified the overall yaw response.

Transitioning the sea state from LC1 to LC3 broadened the violin distributions across all three rotational degrees of freedom. The high-probability regions expanded gradually. This expansion reflected continuous increases in platform attitude fluctuations and response variability. Nevertheless, the response patterns of roll, pitch, and yaw remained consistent under identical wind-wave combinations. This observation demonstrated that more severe sea states primarily amplified rotational responses. However, the underlying governing mechanisms remained unchanged. Overall, the rotational responses exhibited a distinct dual-control mechanism. The wind-wave combinations determined the response pattern, whereas the sea state governed the response intensity.

**Fig. 16** Roll responses

**Fig. 17** Pitch responses

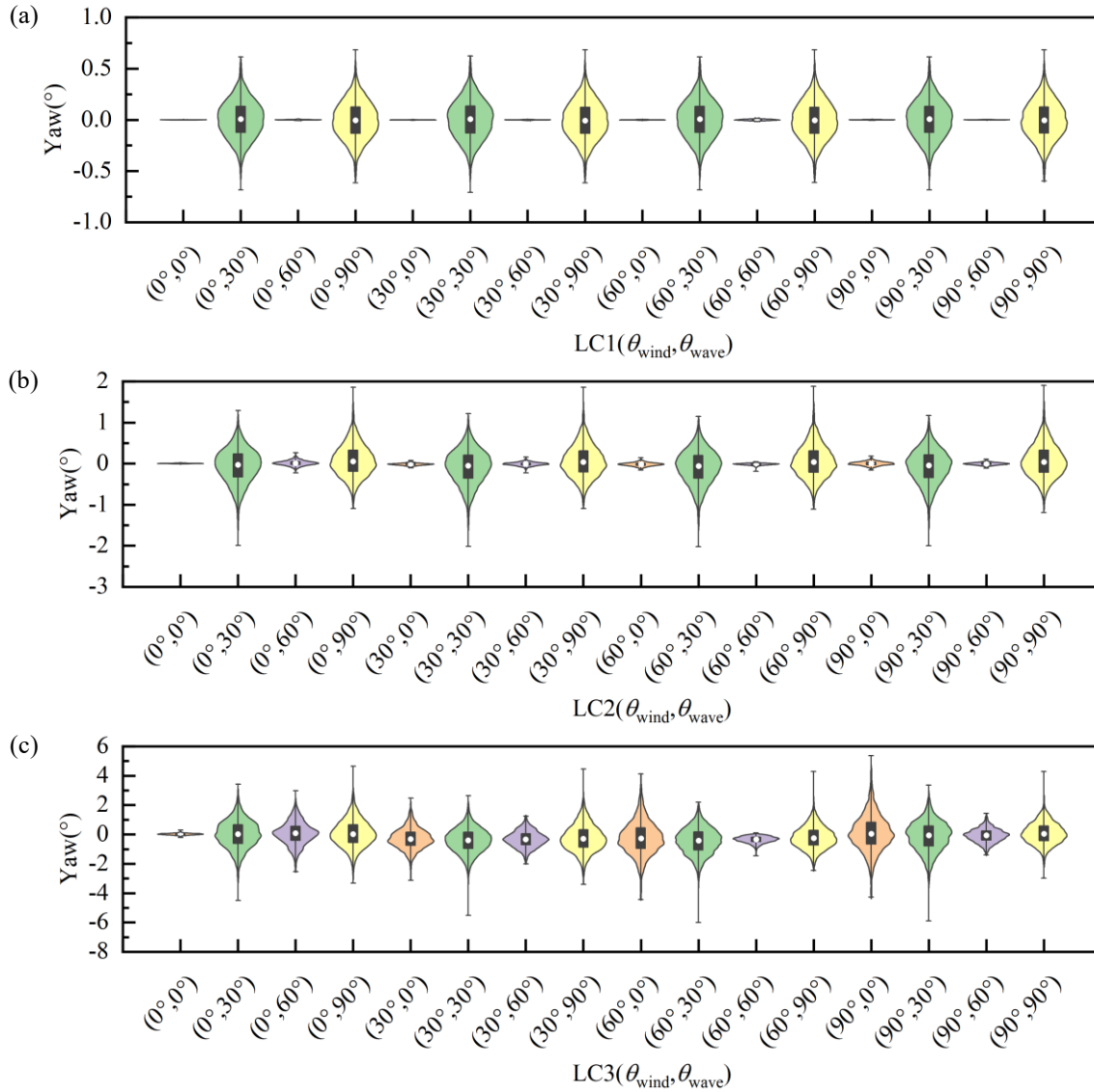


Fig. 18 Yaw responses

3.2.2 Load Analysis of the Shared Anchor

Figure 19 presents the directional distributions of the shared-anchor resultant force under LC2 across six representative wind-wave misalignment cases. Overall, wind-wave misalignment substantially affected shared-anchor loading. Wind-wave alignment concentrated the resultant load predominantly along a single direction. This load behavior exhibited pronounced directionality. Larger wind-wave misalignment shifted the force distribution from a single dominant direction to multiple directions. This transition markedly increased the directional spread. Consequently, wind-wave misalignment altered the magnitude of the resultant force. Furthermore, it reshaped the loading direction and the load transfer mechanism within the shared-anchor system.

Figures 19(a)-(f) demonstrated that continuous variations in the combinations of wind heading and wave heading altered the dominant force direction. This direction rotated progressively away from the environmental resultant force vector. The resultant force aligned closely with the environmental loading direction at small wind-wave misalignment angles. The directional distribution remained compact. Larger misalignment angles induced multiple loading directions. Consequently, dominant and secondary loading directions occurred simultaneously. This behaviour demonstrated pronounced load redistribution among the three directional force components spaced at 120° intervals. Meanwhile, significant load variations existed among the three loading directions. High resultant forces concentrated within a few dominant directions. In

contrast, the remaining directions carried smaller loads. Overall, the shared-anchor system exhibited marked directional non-uniformity in its loading characteristics.

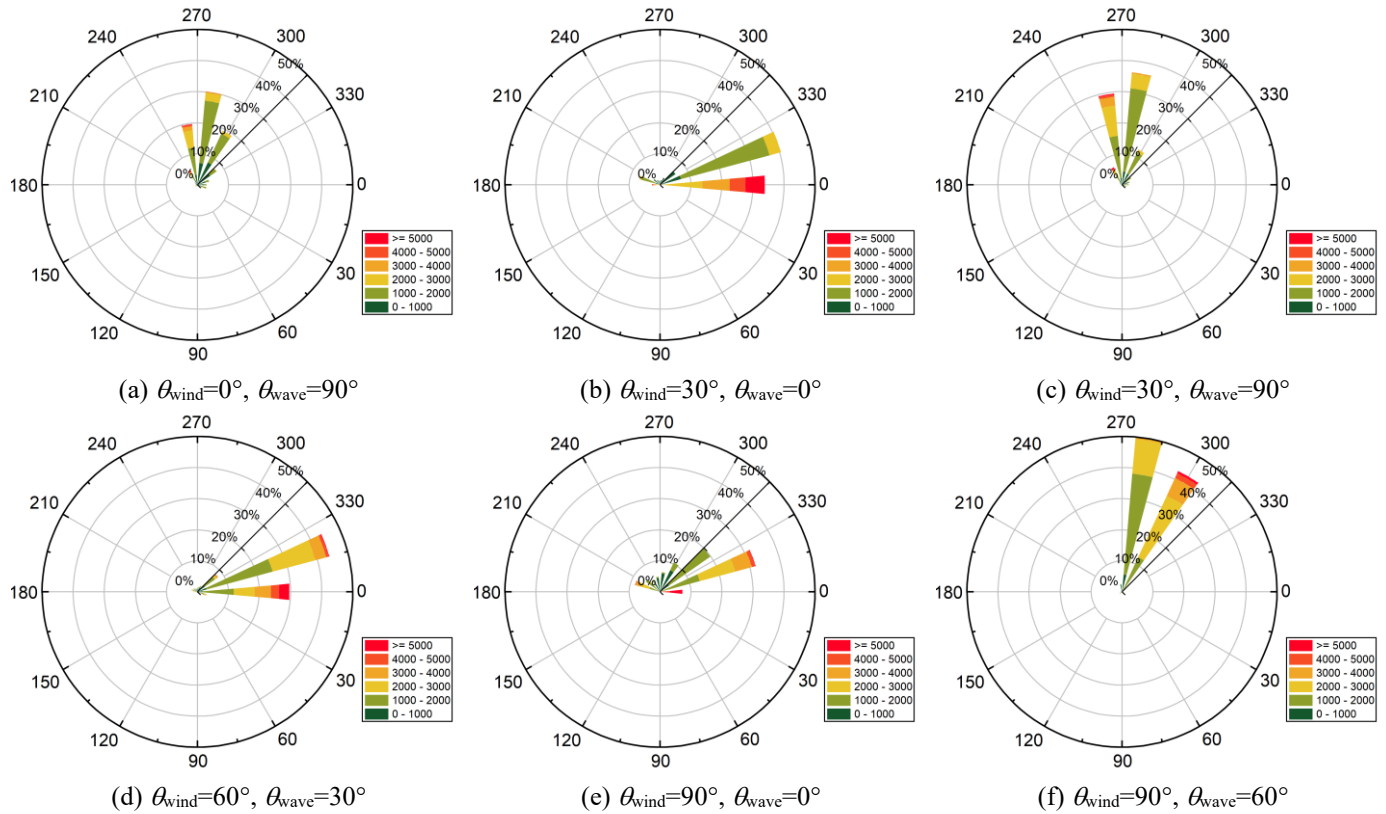


Fig. 19 Directional distributions of the resultant force under LC2

Figure 20 illustrates the maximum, mean, and standard deviation of the horizontal resultant force on the shared anchor under different wind and wave headings in LC1. Overall, the shared-anchor loading exhibited a considerably stronger sensitivity to the wave heading. The wind heading primarily modified the loading variation trend under different wave headings. It determined the corresponding critical loading conditions. This pronounced sensitivity to wave heading stemmed partly from the second-order wave-drift forces in the numerical model. Specifically, the mean drift component drove the mean horizontal offset and therefore affected the mean mooring-line loading. In contrast, slowly varying second-order excitation induced low-frequency variations in platform responses and mooring-line tensions. These combined effects propagated to the shared anchor. Consequently, they governed both the mean loading level and the temporal variability of the resultant force. Meanwhile, the wind heading mainly redistributed the aerodynamic loading direction and consequently altered the critical loading conditions of the shared-anchor system.

Figure 20(a) showed that the maximum resultant force consistently peaked at a wave heading of 0° among the four wave headings. Conversely, the 60° wave heading produced the lowest maximum load. Thus, the wave heading served as the primary determinant of the extreme loading level on the shared anchor. The maximum resultant force decreased with increasing wind heading at 0° and 30° wave headings. In contrast, the peak maximum load occurred at a wind heading of approximately 60° under the 90° wave heading. These observations suggested that different wind-wave combinations led to different critical loading conditions. The wind heading primarily governed the occurrence of the extreme loading rather than its overall magnitude.

Figure 20(b) showed that variations in the mean resultant force generally aligned with those of the maximum resultant force. The 0° wave heading consistently yielded the largest mean load, whereas the 60° wave heading always produced the smallest mean load. However, the mean resultant force exhibited smoother variations across wind headings than the maximum force. Consequently, wind-wave directional coupling exerted a stronger influence on extreme loads than on long-term mean loads.

Figure 20(c) presents the standard deviation of the shared-anchor resultant force to characterise its temporal variability. The results demonstrated a strong dependence on environmental headings. When the

wave heading was 0° , the standard deviation remained relatively high across all investigated wind headings. The standard deviation generally decreased with increasing wind heading at a 90° wave heading. In contrast, a 60° wave heading produced a non-monotonic variation in the standard deviation. These results indicated that wind and wave headings governed not only the mean and extreme levels but also the temporal variability. This variation was partly attributed to slowly varying second-order wave excitation. This excitation drove the low-frequency fluctuations in mooring-line tensions and the resultant force on the shared anchor.

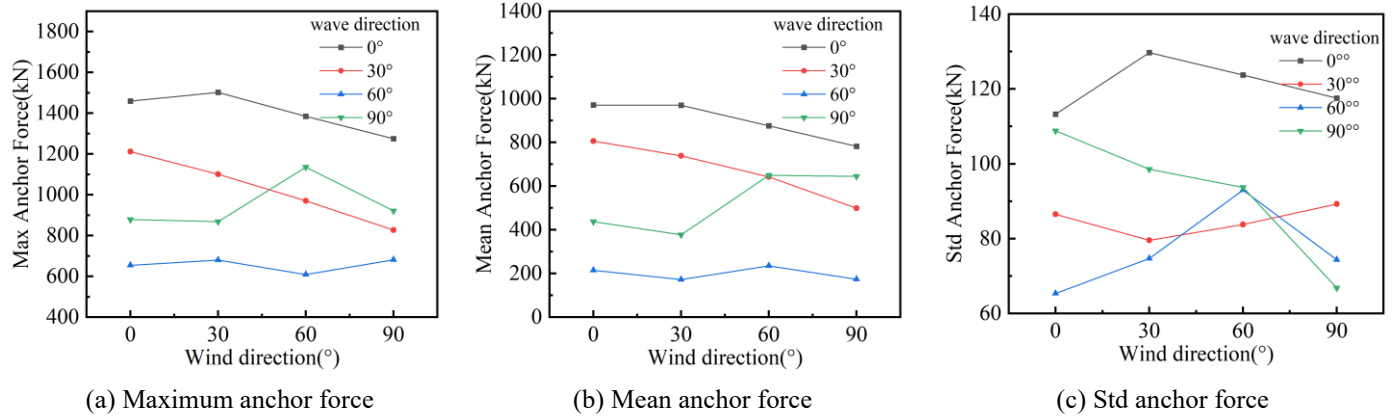
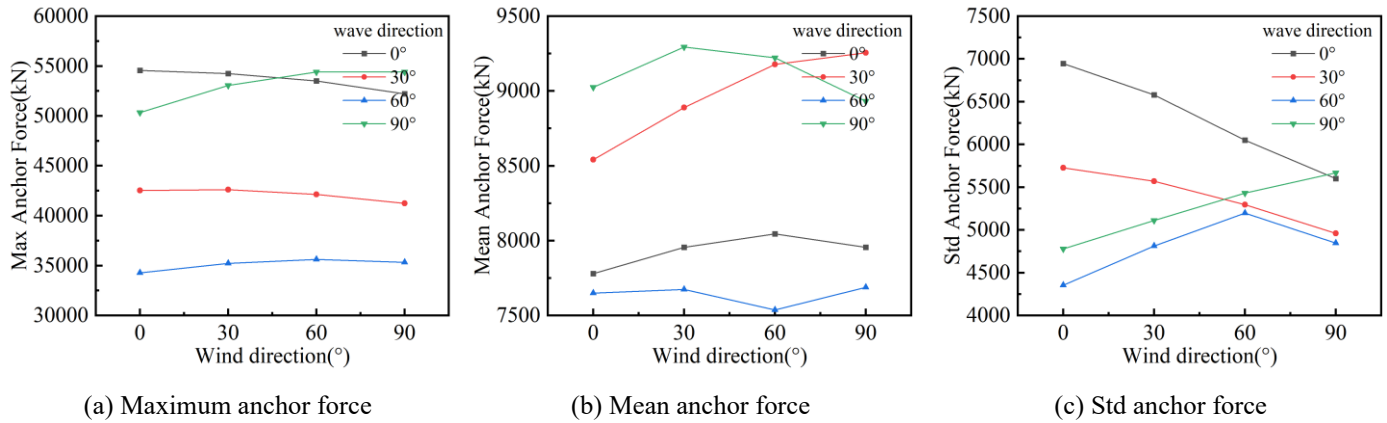


Fig. 20 Anchor force under LC1

Figure 21 presents the maximum, mean, and standard deviation of the horizontal resultant force on the shared anchor under the severe LC3 condition across various wind and wave headings. The shared-anchor loading remained strongly dependent on environmental directional combination in severe sea states. Figure 21(a) showed that maximum resultant forces were generally higher at wave headings of 0° and 90° . Conversely, a 60° wave heading produced the lowest extreme loads across all investigated wind headings. The maximum resultant force generally decreased with increasing wind heading at a wave heading of 0° . An opposite trend occurred in 90° wave-heading cases for wind headings up to 60° . Consequently, the wind-wave misalignment angle alone could not determine the critical extreme loading condition. Instead, this condition depended on specific combinations of absolute wind and wave headings.

Figure 21(b) revealed a distinct directional dependence between the mean resultant force and the maximum force. Specifically, high mean loads occurred at wave headings of 30° and 90° . In contrast, a 60° wave heading produced the lowest mean loading level. Therefore, directional combinations yielding high long-term mean loads did not always align with those producing maximum instantaneous resultant force. Figure 21(c) showed substantial variations in the standard deviation. The standard deviation decreased markedly with increasing wind heading at a wave heading of 0° . Conversely, the standard deviation generally increased at a 90° wave heading. These standard deviation trends aligned closely with changes in maximum resultant force. Thus, environmental directionality influenced both mean loading level and temporal variability. It also governed the extreme response of the shared-anchor resultant force. The pronounced variations in mean, standard deviation, and maximum resultant forces under LC3 were also partly associated with the second-order wave-drift loading considered in the numerical model. This loading mechanism contributed to the mean-drift and low-frequency responses of the floating system.

Table 5 summarises the critical wind-wave directional conditions for platform motions, individual mooring-line tensions, and shared-anchor resultant force. The results demonstrated that no single wind-wave misalignment angle was universally critical across all response quantities. The maximum surge and pitch responses occurred under the aligned (0° , 0°) condition. Conversely, the maximum sway response occurred under the aligned (90° , 90°) condition. The maximum roll and yaw responses occurred under a 90° wind-wave misalignment. These two responses corresponded to different absolute wind and wave headings.

**Fig. 21** Anchor force under LC3

A similar response-dependent behaviour was observed in the mooring system. The maximum tensions in F_1 , F_2 , and F_3 occurred at wind/wave headings of $(0^\circ, 0^\circ)$, $(0^\circ, 60^\circ)$, and $(60^\circ, 90^\circ)$. These headings corresponded to misalignment angles of 0° , 60° , and 30° , respectively. This variation reflected the directional load redistribution among the three mooring lines. Moreover, the maximum shared-anchor resultant force occurred under the aligned $(0^\circ, 0^\circ)$ condition. This condition differed from the critical condition for individual mooring-line tension. Specifically, the shared-anchor resultant force depended on the vector combination of all three anchor-end mooring-line tensions. It did not depend solely on the maximum tension of an individual line. Therefore, critical design conditions must be identified separately for platform motions, individual mooring-line tensions, and shared-anchor loads. These evaluations must account for both the absolute wind and wave headings and their relative misalignments.

Table 5. Wind-wave directional conditions for different response quantities among the investigated load cases

Response quantity	Wind/wave heading	Wind/wave Misalignment	Maximum
Surge (m)	$(0^\circ, 0^\circ)$	0°	16.7
Sway (m)	$(90^\circ, 90^\circ)$	0°	18.59
Roll ($^\circ$)	$(0^\circ, 90^\circ)$	90°	7.34
Pitch ($^\circ$)	$(0^\circ, 0^\circ)$	0°	22.23
Yaw ($^\circ$)	$(90^\circ, 0^\circ)$	90°	5.36
F_1 (kN)	$(0^\circ, 0^\circ)$	0°	58592.80
F_2 (kN)	$(0^\circ, 60^\circ)$	60°	41809.64
F_3 (kN)	$(60^\circ, 90^\circ)$	30°	62073.27
Shared-anchor resultant force (kN)	$(0^\circ, 0^\circ)$	0°	54571.71

4. Conclusions

This study investigated the effects of wind-wave misalignment on the motion responses of an FOWT under different sea states using a fully coupled aero-hydro-mooring numerical model. Platform motion responses across multiple wind-wave heading combinations were systematically analysed. The main conclusions are summarized as follows.

(1) Sea state and wind-wave heading jointly governed the motion responses of the floating platform. The sea state primarily controlled the response intensity and variability, whereas the wind-wave heading determined the platform motion pattern. Greater sea-state severity produced significant increases in both motion amplitude and response dispersion, while the directional response characteristics of the individual motion degrees of freedom remained essentially unchanged.

(2) A directional mismatch between wind and waves markedly strengthened coupling among platform motion components. A larger wind-wave misalignment angle shifted the dominant horizontal motion from surge dominance to coupled surge-sway dynamics, and ultimately to sway dominance. Rotational responses exhibited distinct sensitivities to environmental loading conditions. Roll and pitch were primarily governed by the wind heading. In contrast, the relative angle between wind and wave headings dictated the yaw response.

(3) No universal critical wind-wave misalignment angle existed across all response quantities. Critical directional conditions varied among platform motions, individual mooring-line tensions, and shared-anchor resultant force. Therefore, the determination of design-critical environmental conditions requires the evaluation of both the absolute wind and wave headings and their relative misalignments.

Several limitations constrain the scope of this study. First, the analysis focused exclusively on a three-turbine shared-anchor floating offshore wind system with a single shared-mooring layout. The effects of turbine arrangements, spacing, and mooring configurations on platform motions and shared-anchor loads require further investigation. Second, all simulations assumed aligned current and wave headings for evaluating wind-wave misalignment effects. More complex environmental conditions involving independent wind, wave, and current directions were not evaluated. In addition, all simulations utilized an identical random seed to facilitate direct comparisons among different load cases. Accordingly, the statistical analysis highlights response trends across environmental conditions rather than quantifying variability over multiple stochastic realisations. Furthermore, the shared-anchor assessment evaluated only the horizontal resultant load. Vertical loading, load inclination, and soil-anchor interaction were excluded. Future studies considering these effects will provide a more comprehensive characterisation of anchor behavior. Subsequent work will extend the current framework to incorporate multiple random-seed simulations, realistic environmental conditions, different shared-mooring configurations, and coupled anchor-soil interaction models. These extensions will enhance the predictive capability and engineering applicability of the proposed numerical approach.

This study focused on the influence of wind-wave headings within a fixed shared-anchor mooring configuration. Consequently, current velocity, mooring-line pretension, line length, and anchor spacing remained constant to isolate the effects of environmental loading directions. These parameters potentially affect mooring restoring characteristics, platform motions, and shared-anchor load distributions. However, their detailed evaluation was beyond the scope of this work. Future research will systematically analyze the sensitivity of coupled dynamic responses to these key design parameters. Such investigation will further verify the robustness and engineering applicability of the present findings.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support provided by the School of Marine Science and Engineering, South China University of Technology. The authors also thank all colleagues who provided valuable discussions and technical assistance during the course of this research.

FUNDING

The first author acknowledges the support from National Natural Science Foundation of China (Grant No. 52671335), Guangdong Basic and Applied Basic Research Foundation (2025A1515012042), the GJYC program of Guangzhou (2024D03J0022), and Guangdong Innovation and Entrepreneurship Team Project (2023ZT10H152), and Postdoctoral Research Project of Guangzhou (L2260580).

APPENDIX A

Table A1. Motion response results of the floating platform (surge / sway)

				Surge (m)					Sway (m)				
				Min	Max	Mean	Std	RMS	Min	Max	Mean	Std	RMS
Aligned Wind and Waves	LC 1	(0°, 0°)	Case 1	-0.08	0.82	0.27	0.11	0.30	-0.01	0.00	0.00	0.00	0.00
		(30°, 30°)	Case 2	-0.04	0.60	0.23	0.08	0.24	-0.09	0.31	0.09	0.05	0.10
		(60°, 60°)	Case 3	-0.08	0.38	0.12	0.06	0.13	-0.16	0.64	0.19	0.10	0.22
		(90°, 90°)	Case 4	-0.09	0.02	-0.04	0.02	0.04	-0.07	0.66	0.24	0.09	0.26
	LC 2	(0°, 0°)	Case 5	-3.75	5.65	0.91	1.40	1.67	-0.02	0.00	-0.01	0.00	0.01
		(30°, 30°)	Case 6	-2.94	5.13	0.85	1.19	1.46	-1.55	3.33	0.57	0.68	0.89
		(60°, 60°)	Case 7	-1.44	3.36	0.58	0.68	0.89	-2.52	5.79	0.98	1.18	1.53
		(90°, 90°)	Case 8	-0.46	0.73	0.08	0.16	0.18	-3.31	6.07	1.01	1.36	1.69
	LC 3	(0°, 0°)	Case 9	-10.48	16.70	2.83	3.83	4.76	-0.16	0.03	-0.06	0.02	0.06
		(30°, 30°)	Case 10	-7.70	15.00	2.88	3.16	4.28	-2.66	11.40	2.73	2.35	3.60
		(60°, 60°)	Case 11	-2.71	10.38	2.44	2.11	3.23	-4.80	18.08	4.20	3.67	5.57
		(90°, 90°)	Case 12	-1.91	5.17	0.99	1.15	1.52	-6.97	18.59	3.90	3.79	5.43
Misaligne d Wind and Waves	LC 1	(0°, 30°)	Case 13	-0.05	0.64	0.24	0.09	0.26	-0.14	0.22	0.03	0.04	0.05
		(0°, 60°)	Case 14	-0.06	0.55	0.17	0.08	0.19	-0.23	0.56	0.09	0.09	0.13
		(0°, 90°)	Case 15	-0.11	0.36	0.09	0.07	0.11	-0.15	0.49	0.12	0.08	0.14
		(30°, 0°)	Case 16	-0.09	0.80	0.25	0.11	0.28	-0.04	0.18	0.05	0.03	0.06
		(30°, 60°)	Case 17	-0.06	0.50	0.16	0.07	0.17	-0.18	0.58	0.15	0.10	0.17
		(30°, 90°)	Case 18	-0.10	0.31	0.07	0.06	0.10	-0.09	0.58	0.18	0.08	0.20
		(60°, 0°)	Case 19	-0.13	0.74	0.21	0.10	0.23	-0.07	0.32	0.10	0.05	0.11
		(60°, 30°)	Case 20	-0.04	0.52	0.18	0.07	0.20	-0.10	0.42	0.13	0.07	0.15
		(60°, 90°)	Case 21	-0.08	0.17	0.03	0.04	0.05	-0.08	0.64	0.22	0.09	0.24
		(90°, 0°)	Case 22	-0.19	0.67	0.15	0.10	0.18	-0.07	0.37	0.12	0.06	0.14
		(90°, 30°)	Case 23	-0.11	0.44	0.12	0.06	0.14	-0.10	0.48	0.15	0.08	0.17
		(90°, 60°)	Case 24	-0.12	0.32	0.05	0.05	0.08	-0.15	0.68	0.21	0.11	0.23
	LC 2	(0°, 30°)	Case 25	-2.90	5.24	0.91	1.20	1.50	-1.81	2.90	0.25	0.69	0.73
		(0°, 60°)	Case 26	-1.27	3.78	0.83	0.71	1.09	-2.97	5.08	0.45	1.18	1.26
		(0°, 90°)	Case 27	-0.16	1.41	0.64	0.23	0.68	-3.86	5.24	0.43	1.35	1.42
		(30°, 0°)	Case 28	-3.83	5.57	0.85	1.40	1.63	-0.04	0.80	0.31	0.12	0.33
		(30°, 60°)	Case 29	-1.28	3.65	0.77	0.69	1.03	-2.71	5.50	0.76	1.18	1.40
		(30°, 90°)	Case 30	-0.20	1.35	0.58	0.22	0.62	-3.60	5.68	0.74	1.36	1.55
		(60°, 0°)	Case 31	-4.04	5.34	0.66	1.40	1.55	-0.05	1.32	0.53	0.19	0.57
		(60°, 30°)	Case 32	-3.14	4.85	0.65	1.19	1.36	-1.37	3.67	0.80	0.70	1.06
		(60°, 90°)	Case 33	-0.30	1.10	0.38	0.19	0.42	-3.39	5.97	0.96	1.36	1.66
		(90°, 0°)	Case 34	-4.31	4.96	0.38	1.39	1.44	-0.04	1.43	0.60	0.21	0.64
		(90°, 30°)	Case 35	-3.39	4.43	0.37	1.18	1.24	-1.33	3.83	0.87	0.71	1.12
		(90°, 60°)	Case 36	-1.69	2.97	0.30	0.68	0.74	-2.47	5.90	1.05	1.18	1.58
	LC 3	(0°, 30°)	Case 37	-7.43	15.09	3.01	3.15	4.35	-4.17	10.22	1.01	2.28	2.50
		(0°, 60°)	Case 38	-1.36	10.79	3.15	1.93	3.69	-8.06	16.11	1.45	3.72	4.00
		(0°, 90°)	Case 39	0.51	6.36	2.92	0.88	3.05	-10.90	16.43	1.08	4.12	4.26
		(30°, 0°)	Case 40	-10.86	16.53	2.63	3.85	4.66	0.33	4.01	1.66	0.53	1.74
		(30°, 60°)	Case 41	-1.58	10.66	3.04	2.00	3.63	-6.16	17.40	3.17	3.70	4.88
		(30°, 90°)	Case 42	0.01	6.81	2.77	1.01	2.95	-8.94	17.78	2.80	4.03	4.91
		(60°, 0°)	Case 43	-11.75	15.88	1.96	3.93	4.40	0.68	5.49	2.69	0.74	2.79
		(60°, 30°)	Case 44	-8.67	14.55	2.27	3.25	3.96	-1.81	12.29	3.76	2.43	4.47
		(60°, 90°)	Case 45	-0.89	6.49	2.15	1.14	2.43	-7.44	18.50	3.82	3.90	5.46
		(90°, 0°)	Case 46	-12.83	14.64	0.78	4.06	4.13	0.87	5.03	2.80	0.69	2.89
		(90°, 30°)	Case 47	-9.91	13.69	1.11	3.40	3.58	-1.53	12.08	3.84	2.39	4.52
		(90°, 60°)	Case 48	-4.46	9.74	1.30	2.23	2.58	-4.43	18.03	4.25	3.59	5.56

Table A2. Motion response results of the floating platform (roll / pitch)

				Roll (°)					Pitch (°)				
				Min	Max	Mean	Std	RMS	Min	Max	Mean	Std	RMS
Aligned Wind and Waves	LC1	(0°, 0°)	Case 1	-0.01	0.03	0.01	0.01	0.01	-0.64	1.31	0.41	0.28	0.50
		(30°, 30°)	Case 2	-0.80	0.41	-0.19	0.15	0.24	-0.60	1.14	0.36	0.25	0.44
		(60°, 60°)	Case 3	-1.19	0.58	-0.34	0.25	0.42	-0.34	0.73	0.22	0.15	0.27
		(90°, 90°)	Case 4	-1.31	0.65	-0.40	0.29	0.49	-0.24	0.26	0.03	0.06	0.07
	LC2	(0°, 0°)	Case 5	-0.02	0.15	0.06	0.02	0.06	-1.74	6.93	1.99	1.14	2.30
		(30°, 30°)	Case 6	-3.17	0.99	-0.94	0.57	1.10	-1.51	6.05	1.75	1.00	2.01
		(60°, 60°)	Case 7	-5.72	1.43	-1.68	0.96	1.93	-0.81	3.46	1.05	0.57	1.19
		(90°, 90°)	Case 8	-6.72	1.55	-1.94	1.12	2.24	-0.75	0.99	0.07	0.23	0.24
	LC3	(0°, 0°)	Case 9	-0.16	0.75	0.25	0.12	0.28	-7.17	22.23	8.38	4.49	9.51
		(30°, 30°)	Case 10	-9.73	0.71	-4.52	1.53	4.77	-6.21	19.41	7.43	3.78	8.34
		(60°, 60°)	Case 11	-16.43	3.17	-7.75	2.81	8.24	-1.87	9.74	4.67	1.64	4.95
		(90°, 90°)	Case 12	-20.34	5.54	-8.71	3.82	9.51	-3.91	5.02	0.63	1.41	1.55
Misaligned Wind and Waves	LC1	(0°, 30°)	Case 13	-0.32	0.22	0.00	0.07	0.07	-0.61	1.26	0.40	0.28	0.49
		(0°, 60°)	Case 14	-0.34	0.27	0.00	0.09	0.09	-0.52	1.26	0.39	0.28	0.48
		(0°, 90°)	Case 15	-0.35	0.28	-0.01	0.10	0.10	-0.51	1.37	0.38	0.28	0.47
		(30°, 0°)	Case 16	-0.61	0.24	-0.18	0.13	0.22	-0.56	1.13	0.36	0.25	0.44
		(30°, 60°)	Case 17	-0.74	0.41	-0.19	0.15	0.24	-0.47	1.13	0.35	0.24	0.43
		(30°, 90°)	Case 18	-0.73	0.40	-0.19	0.16	0.25	-0.48	1.24	0.34	0.25	0.42
		(60°, 0°)	Case 19	-1.08	0.42	-0.32	0.24	0.39	-0.41	0.75	0.23	0.17	0.28
		(60°, 30°)	Case 20	-1.23	0.52	-0.32	0.24	0.41	-0.39	0.73	0.23	0.16	0.28
		(60°, 90°)	Case 21	-1.14	0.56	-0.33	0.25	0.42	-0.38	0.85	0.21	0.16	0.26
		(90°, 0°)	Case 22	-1.24	0.49	-0.37	0.27	0.46	-0.25	0.37	0.05	0.10	0.11
		(90°, 30°)	Case 23	-1.39	0.58	-0.38	0.28	0.47	-0.26	0.36	0.04	0.09	0.10
		(90°, 60°)	Case 24	-1.33	0.62	-0.38	0.28	0.48	-0.12	0.22	0.04	0.05	0.06
	LC2	(0°, 30°)	Case 25	-1.24	1.42	0.06	0.38	0.38	-1.43	6.64	1.97	1.07	2.24
		(0°, 60°)	Case 26	-2.12	2.21	0.05	0.61	0.62	-0.90	5.81	1.92	0.88	2.11
		(0°, 90°)	Case 27	-2.65	2.40	0.00	0.71	0.71	-0.68	4.77	1.89	0.81	2.06
		(30°, 0°)	Case 28	-2.68	0.42	-0.95	0.42	1.04	-1.81	6.36	1.77	1.08	2.07
		(30°, 60°)	Case 29	-3.89	1.43	-0.95	0.75	1.21	-0.83	5.18	1.71	0.80	1.88
		(30°, 90°)	Case 30	-4.28	1.80	-0.99	0.84	1.30	-0.58	4.20	1.68	0.73	1.83
		(60°, 0°)	Case 31	-4.55	0.63	-1.69	0.73	1.84	-2.06	4.71	1.10	0.91	1.43
		(60°, 30°)	Case 32	-4.99	1.03	-1.68	0.82	1.86	-1.76	4.35	1.09	0.82	1.36
		(60°, 90°)	Case 33	-6.08	1.55	-1.71	1.04	2.00	-0.47	2.78	1.02	0.49	1.13
		(90°, 0°)	Case 34	-5.11	0.69	-1.97	0.82	2.13	-2.63	2.99	0.17	0.78	0.80
		(90°, 30°)	Case 35	-5.69	1.05	-1.94	0.90	2.14	-2.15	2.50	0.15	0.66	0.68
		(90°, 60°)	Case 36	-6.42	1.43	-1.94	1.04	2.20	-1.09	1.29	0.10	0.35	0.37
	LC3	(0°, 30°)	Case 37	-4.95	4.14	0.28	0.97	1.01	-6.14	21.07	8.29	4.01	9.21
		(0°, 60°)	Case 38	-7.87	6.57	0.09	1.66	1.66	-3.56	17.47	8.02	2.93	8.54
		(0°, 90°)	Case 39	-9.50	7.34	-0.18	2.20	2.21	1.14	15.63	7.91	2.12	8.19
		(30°, 0°)	Case 40	-9.94	-0.51	-4.53	1.46	4.76	-7.58	20.83	7.45	4.37	8.64
		(30°, 60°)	Case 41	-12.64	3.46	-4.57	2.18	5.06	-2.89	15.33	7.23	2.46	7.63
		(30°, 90°)	Case 42	-13.79	5.29	-4.73	2.82	5.50	1.72	13.89	7.16	1.89	7.41
		(60°, 0°)	Case 43	-15.71	-2.25	-7.78	2.13	8.06	-8.51	16.42	4.76	4.01	6.22
		(60°, 30°)	Case 44	-15.54	-0.64	-7.75	2.12	8.03	-6.56	14.34	4.78	3.26	5.79
		(60°, 90°)	Case 45	-18.60	5.43	-7.77	3.53	8.54	0.16	10.02	4.57	1.64	4.86
		(90°, 0°)	Case 46	-16.73	-2.94	-8.75	2.19	9.02	-8.73	10.72	0.92	3.31	3.44
		(90°, 30°)	Case 47	-16.98	-0.36	-8.67	2.28	8.96	-6.82	9.09	0.92	2.52	2.69
		(90°, 60°)	Case 48	-18.47	4.04	-8.63	3.13	9.18	-2.64	5.38	0.76	0.91	1.18

Table A3. Motion response results of the floating platform (yaw)

				Yaw (°)				
				Min	Max	Mean	Std	RMS
Aligned Wind and Waves	LC1	(0°, 0°)	Case 1	0.00	0.00	0.00	0.00	0.00
		(30°, 30°)	Case 2	-0.71	0.62	0.00	0.19	0.19
		(60°, 60°)	Case 3	-0.02	0.02	0.00	0.01	0.01
		(90°, 90°)	Case 4	-0.60	0.68	0.00	0.18	0.18
	LC2	(0°, 0°)	Case 5	-0.01	0.03	0.00	0.01	0.01
		(30°, 30°)	Case 6	-2.01	1.21	-0.08	0.42	0.43
		(60°, 60°)	Case 7	-0.18	0.04	-0.02	0.02	0.03
		(90°, 90°)	Case 8	-1.19	1.90	0.07	0.40	0.40
	LC3	(0°, 0°)	Case 9	-0.20	0.31	0.02	0.06	0.06
		(30°, 30°)	Case 10	-5.51	2.65	-0.42	0.83	0.93
		(60°, 60°)	Case 11	-1.45	0.10	-0.35	0.22	0.42
		(90°, 90°)	Case 12	-2.97	4.29	0.08	0.74	0.74
Misaligned Wind and Waves	LC1	(0°, 30°)	Case 13	-0.68	0.61	0.01	0.18	0.18
		(0°, 60°)	Case 14	-0.01	0.01	0.00	0.00	0.00
		(0°, 90°)	Case 15	-0.61	0.68	0.00	0.18	0.18
		(30°, 0°)	Case 16	-0.01	0.00	0.00	0.00	0.00
		(30°, 60°)	Case 17	-0.01	0.01	0.00	0.00	0.00
		(30°, 90°)	Case 18	-0.61	0.68	0.00	0.18	0.18
		(60°, 0°)	Case 19	-0.01	0.01	0.00	0.00	0.00
		(60°, 30°)	Case 20	-0.68	0.61	0.00	0.18	0.18
		(60°, 90°)	Case 21	-0.61	0.68	0.00	0.18	0.18
		(90°, 0°)	Case 22	-0.01	0.01	0.00	0.00	0.00
		(90°, 30°)	Case 23	-0.68	0.61	0.01	0.18	0.18
		(90°, 60°)	Case 24	-0.01	0.01	0.00	0.00	0.00
	LC2	(0°, 30°)	Case 25	-1.99	1.29	-0.06	0.42	0.42
		(0°, 60°)	Case 26	-0.22	0.27	0.01	0.06	0.06
		(0°, 90°)	Case 27	-1.09	1.86	0.08	0.39	0.39
		(30°, 0°)	Case 28	-0.10	0.08	-0.02	0.03	0.03
		(30°, 60°)	Case 29	-0.22	0.16	-0.01	0.04	0.04
		(30°, 90°)	Case 30	-1.09	1.86	0.06	0.39	0.39
		(60°, 0°)	Case 31	-0.16	0.14	-0.02	0.04	0.05
		(60°, 30°)	Case 32	-2.02	1.15	-0.09	0.41	0.42
		(60°, 90°)	Case 33	-1.11	1.88	0.06	0.39	0.40
		(90°, 0°)	Case 34	-0.16	0.18	0.00	0.05	0.05
		(90°, 30°)	Case 35	-2.00	1.17	-0.08	0.41	0.42
		(90°, 60°)	Case 36	-0.11	0.11	0.00	0.03	0.03
	LC3	(0°, 30°)	Case 37	-4.50	3.41	0.01	0.96	0.96
		(0°, 60°)	Case 38	-2.53	2.98	0.08	0.78	0.79
		(0°, 90°)	Case 39	-3.31	4.65	0.07	0.92	0.93
		(30°, 0°)	Case 40	-3.13	2.46	-0.28	0.71	0.76
		(30°, 60°)	Case 41	-2.00	1.25	-0.32	0.55	0.64
		(30°, 90°)	Case 42	-3.39	4.47	-0.25	0.92	0.95
		(60°, 0°)	Case 43	-4.44	4.12	-0.23	1.13	1.16
		(60°, 30°)	Case 44	-6.02	2.20	-0.45	0.90	1.01
		(60°, 90°)	Case 45	-2.45	4.28	-0.21	0.76	0.79
		(90°, 0°)	Case 46	-4.27	5.36	0.11	1.25	1.25
		(90°, 30°)	Case 47	-5.89	3.36	-0.13	1.02	1.03
		(90°, 60°)	Case 48	-1.40	1.45	-0.07	0.46	0.46

Table A4. Statistical characteristics of the mooring-line tensions at the shared anchor (F_1)

				F_l (kN)				
				Min	Max	Mean	Std	RMS
Aligned Wind and Waves	LC1	(0°, 0°)	Case 1	6481.99	7316.26	6848.06	107.71	6848.91
		(30°, 30°)	Case 2	6345.33	6974.98	6604.59	85.81	6605.15
		(60°, 60°)	Case 3	6046.34	6435.55	6242.18	52.79	6242.40
		(90°, 90°)	Case 4	5697.83	5823.64	5761.81	17.27	5761.84
	LC2	(0°, 0°)	Case 5	681.37	19315.74	8563.42	2002.25	8794.37
		(30°, 30°)	Case 6	1710.75	17885.15	8524.29	1530.37	8660.57
		(60°, 60°)	Case 7	5389.00	12977.88	8144.80	593.33	8166.38
		(90°, 90°)	Case 8	6695.18	7310.52	6931.44	81.13	6931.92
	LC3	(0°, 0°)	Case 9	56.30	58592.80	12918.93	8365.69	15390.95
		(30°, 30°)	Case 10	51.70	52222.95	12646.38	7223.37	14563.88
		(60°, 60°)	Case 11	496.75	36150.23	11612.80	4852.42	12585.81
		(90°, 90°)	Case 12	6292.43	17945.06	9629.15	1578.83	9757.72
Misaligned Wind and Waves	LC1	(0°, 30°)	Case 13	6637.05	7323.88	6911.71	91.63	6912.32
		(0°, 60°)	Case 14	6410.67	6930.82	6644.81	67.36	6645.15
		(0°, 90°)	Case 15	6155.67	6422.88	6275.86	39.82	6275.99
		(30°, 0°)	Case 16	6731.64	7638.47	7124.92	117.66	7125.89
		(30°, 60°)	Case 17	6377.05	6868.36	6608.03	64.04	6608.34
		(30°, 90°)	Case 18	6136.33	6372.71	6242.69	32.91	6242.78
		(60°, 0°)	Case 19	6699.54	7578.47	7075.34	114.51	7076.27
		(60°, 30°)	Case 20	6571.80	7137.19	6833.43	87.45	6833.99
		(60°, 90°)	Case 21	6066.80	6231.76	6138.84	21.63	6138.88
		(90°, 0°)	Case 22	6651.92	7499.38	7009.39	111.23	7010.28
		(90°, 30°)	Case 23	6508.60	7056.12	6765.43	87.53	6766.00
		(90°, 60°)	Case 24	6270.04	6714.55	6482.31	58.04	6482.57
	LC2	(0°, 30°)	Case 25	1658.29	18071.05	8584.50	1545.23	8722.45
		(0°, 60°)	Case 26	5482.75	13629.51	8364.35	634.20	8388.36
		(0°, 90°)	Case 27	7140.76	7953.11	7489.42	103.00	7490.12
		(30°, 0°)	Case 28	674.60	19240.58	8496.36	1996.06	8727.67
		(30°, 60°)	Case 29	5517.72	13399.26	8311.56	614.56	8334.25
		(30°, 90°)	Case 30	7050.26	7850.37	7396.16	99.37	7396.83
		(60°, 0°)	Case 31	724.19	19035.15	8318.24	1976.25	8549.77
		(60°, 30°)	Case 32	1724.83	17475.47	8339.95	1507.32	8475.06
		(60°, 90°)	Case 33	6818.56	7520.56	7117.00	87.04	7117.53
		(90°, 0°)	Case 34	713.65	18715.96	8072.90	1934.99	8301.55
		(90°, 30°)	Case 35	1709.76	16933.20	8091.28	1476.94	8224.97
		(90°, 60°)	Case 36	5178.48	12463.56	7905.80	575.29	7926.71
	LC3	(0°, 30°)	Case 37	62.23	51748.61	12779.83	7151.91	14644.88
		(0°, 60°)	Case 38	806.92	36097.18	12492.48	4479.10	13271.17
		(0°, 90°)	Case 39	8660.73	19724.26	11825.99	1571.00	11929.88
		(30°, 0°)	Case 40	32.96	58529.62	12649.14	8344.99	15153.80
		(30°, 60°)	Case 41	948.88	36010.97	12387.74	4651.96	13232.40
		(30°, 90°)	Case 42	8102.50	20923.21	11666.54	1792.55	11803.44
		(60°, 0°)	Case 43	40.30	58237.07	11863.36	8322.76	14491.58
		(60°, 30°)	Case 44	57.41	52339.86	11911.90	7352.77	13998.40
		(60°, 90°)	Case 45	7118.24	20222.13	10879.03	1842.08	11033.88
		(90°, 0°)	Case 46	32.20	57295.12	10711.15	8285.85	13541.87
		(90°, 30°)	Case 47	46.06	51870.46	10723.10	7435.81	13048.93
		(90°, 60°)	Case 48	321.56	35770.20	10330.65	4909.92	11438.05

Table A5. Statistical characteristics of the mooring-line tensions at the shared anchor (F_2)

				F_2 (kN)				
				Min	Max	Mean	Std	RMS
Aligned Wind and Waves	LC1	(0°, 0°)	Case 1	5705.39	6026.90	5874.17	44.62	5874.34
		(30°, 30°)	Case 2	5895.20	6377.18	6137.68	73.16	6138.12
		(60°, 60°)	Case 3	5704.21	6291.48	6006.79	81.09	6007.34
		(90°, 90°)	Case 4	5828.83	6428.41	6115.78	81.21	6116.32
	LC2	(0°, 0°)	Case 5	5725.50	8533.56	6770.85	235.53	6774.94
		(30°, 30°)	Case 6	3622.58	10830.45	6417.77	525.74	6439.26
		(60°, 60°)	Case 7	2179.58	10859.19	6197.60	697.84	6236.76
		(90°, 90°)	Case 8	2079.76	12558.07	6838.84	1013.42	6913.52
	LC3	(0°, 0°)	Case 9	618.49	28454.11	7277.39	2528.43	7704.10
		(30°, 30°)	Case 10	117.16	37920.58	5917.78	4205.19	7259.70
		(60°, 60°)	Case 11	109.66	40978.20	5635.44	4843.42	7430.77
		(90°, 90°)	Case 12	157.30	35844.28	5961.66	4285.01	7341.81
Misaligned Wind and Waves	LC1	(0°, 30°)	Case 13	6034.09	6767.33	6398.20	104.20	6399.05
		(0°, 60°)	Case 14	5868.39	7070.14	6526.09	133.99	6527.46
		(0°, 90°)	Case 15	6103.37	6695.66	6393.74	94.11	6394.44
		(30°, 0°)	Case 16	5882.62	6333.12	6128.77	59.68	6129.06
		(30°, 60°)	Case 17	5862.04	7056.08	6502.66	135.34	6504.07
		(30°, 90°)	Case 18	6069.05	6662.39	6361.71	94.94	6362.41
		(60°, 0°)	Case 19	5893.14	6347.39	6131.94	60.74	6132.24
		(60°, 30°)	Case 20	5985.63	6734.04	6359.20	104.66	6360.06
		(60°, 90°)	Case 21	6057.34	6650.86	6351.06	95.19	6351.77
		(90°, 0°)	Case 22	5901.58	6355.00	6141.52	60.05	6141.82
		(90°, 30°)	Case 23	5994.04	6744.80	6368.47	104.92	6369.33
		(90°, 60°)	Case 24	5861.75	7055.35	6502.30	135.37	6503.71
	LC2	(0°, 30°)	Case 25	3571.36	11045.89	6578.86	548.98	6601.72
		(0°, 60°)	Case 26	2163.43	11228.75	6413.66	734.88	6455.62
		(0°, 90°)	Case 27	4093.42	9903.91	6683.84	569.19	6708.03
		(30°, 0°)	Case 28	5569.70	8213.50	6589.49	228.56	6593.45
		(30°, 60°)	Case 29	2147.43	11015.90	6255.46	708.04	6295.40
		(30°, 90°)	Case 30	4087.22	9609.45	6519.58	541.81	6542.06
		(60°, 0°)	Case 31	5492.39	8120.51	6521.51	229.89	6525.56
		(60°, 30°)	Case 32	3619.66	10771.48	6355.87	520.15	6377.11
		(60°, 90°)	Case 33	4111.94	9503.01	6461.13	528.10	6482.67
		(90°, 0°)	Case 34	5522.67	8250.65	6581.37	235.64	6585.58
		(90°, 30°)	Case 35	3604.89	10875.47	6409.08	531.38	6431.07
		(90°, 60°)	Case 36	2216.89	10876.07	6258.04	709.05	6298.08
	LC3	(0°, 30°)	Case 37	120.99	38013.28	6522.39	4334.63	7831.35
		(0°, 60°)	Case 38	85.17	41809.64	6397.71	5077.66	8167.78
		(0°, 90°)	Case 39	97.86	38360.14	6693.94	4807.01	8241.09
		(30°, 0°)	Case 40	649.24	27715.07	6548.11	2425.46	6982.87
		(30°, 60°)	Case 41	91.19	40972.87	5801.32	4865.80	7571.70
		(30°, 90°)	Case 42	92.40	36933.10	6026.16	4488.05	7513.76
		(60°, 0°)	Case 43	521.60	28068.78	6334.61	2531.52	6821.71
		(60°, 30°)	Case 44	98.87	38118.31	5755.28	4276.99	7170.46
		(60°, 90°)	Case 45	109.22	36043.48	5785.06	4307.86	7212.77
		(90°, 0°)	Case 46	527.81	28942.26	6614.70	2747.12	7162.45
		(90°, 30°)	Case 47	91.56	38789.78	6000.37	4493.09	7496.12
		(90°, 60°)	Case 48	99.56	41361.98	5826.12	4922.93	7627.47

Table A6. Statistical characteristics of the mooring-line tensions at the shared anchor (F_3)

				F_3 (kN)				
				Min	Max	Mean	Std	RMS
Aligned Wind and Waves	LC1	(0°, 0°)	Case 1	5707.54	6028.99	5876.77	44.68	5876.94
		(30°, 30°)	Case 2	5706.72	5812.42	5758.19	15.76	5758.21
		(60°, 60°)	Case 3	6045.37	6436.04	6242.00	52.72	6242.23
		(90°, 90°)	Case 4	6254.30	6736.20	6499.69	74.79	6500.12
	LC2	(0°, 0°)	Case 5	5723.51	8534.41	6772.28	236.20	6776.40
		(30°, 30°)	Case 6	6273.13	6830.23	6505.28	65.67	6505.61
		(60°, 60°)	Case 7	5375.06	12992.62	8146.01	595.63	8167.76
		(90°, 90°)	Case 8	1819.49	16903.63	8858.16	1631.23	9007.10
	LC3	(0°, 0°)	Case 9	613.40	28604.18	7269.70	2567.39	7709.72
		(30°, 30°)	Case 10	5912.95	20743.74	9586.37	1742.75	9743.49
		(60°, 60°)	Case 11	406.44	36500.55	11619.45	4896.52	12609.00
		(90°, 90°)	Case 12	153.58	61744.98	12687.08	7364.66	14669.65
Misaligned Wind and Waves	LC1	(0°, 30°)	Case 13	5912.61	6077.17	5992.09	22.61	5992.13
		(0°, 60°)	Case 14	6238.90	6709.81	6448.10	64.63	6448.42
		(0°, 90°)	Case 15	6394.51	7176.77	6747.10	120.83	6748.18
		(30°, 0°)	Case 16	5895.93	6396.27	6183.23	59.80	6183.52
		(30°, 60°)	Case 17	6271.38	6715.66	6483.63	58.09	6483.89
		(30°, 90°)	Case 18	6481.86	7193.88	6797.73	103.38	6798.51
		(60°, 0°)	Case 19	5962.53	6549.32	6291.48	65.45	6291.82
		(60°, 30°)	Case 20	6045.89	6188.96	6115.21	21.02	6115.24
		(60°, 90°)	Case 21	6551.71	7312.13	6859.68	98.04	6860.38
		(90°, 0°)	Case 22	6002.58	6659.44	6367.39	71.63	6367.80
		(90°, 30°)	Case 23	6126.76	6327.22	6220.77	29.88	6220.84
		(90°, 60°)	Case 24	6378.52	6868.56	6609.42	63.88	6609.73
	LC2	(0°, 30°)	Case 25	6169.68	6665.63	6365.37	65.32	6365.71
		(0°, 60°)	Case 26	4967.38	12101.42	7678.22	561.98	7698.76
		(0°, 90°)	Case 27	4143.52	14276.89	7913.38	954.95	7970.79
		(30°, 0°)	Case 28	5960.67	8994.37	7022.87	250.98	7027.35
		(30°, 60°)	Case 29	5148.85	12559.58	7913.46	578.72	7934.60
		(30°, 90°)	Case 30	4237.15	14839.83	8156.78	986.33	8216.20
		(60°, 0°)	Case 31	6230.24	9439.14	7263.96	270.11	7268.98
		(60°, 30°)	Case 32	6489.78	7227.25	6816.15	96.11	6816.82
		(60°, 90°)	Case 33	4318.82	15281.24	8399.34	1014.81	8460.42
		(90°, 0°)	Case 34	6378.96	9703.02	7434.63	283.80	7440.05
		(90°, 30°)	Case 35	6731.57	7521.24	7061.73	101.55	7062.46
		(90°, 60°)	Case 36	5523.02	13311.69	8311.08	616.17	8333.89
	LC3	(0°, 30°)	Case 37	5424.95	17987.25	8294.58	1393.86	8410.88
		(0°, 60°)	Case 38	284.22	34716.79	8958.73	4757.10	10143.38
		(0°, 90°)	Case 39	159.89	59994.45	9508.87	7513.41	12118.93
		(30°, 0°)	Case 40	641.25	30187.22	8409.96	2803.21	8864.83
		(30°, 60°)	Case 41	314.26	35979.59	10316.67	4929.11	11433.68
		(30°, 90°)	Case 42	154.88	61539.27	10756.37	7645.77	13196.80
		(60°, 0°)	Case 43	718.13	31984.84	9615.90	3013.18	10076.93
		(60°, 30°)	Case 44	6418.39	23255.36	10873.80	1987.56	11053.95
		(60°, 90°)	Case 45	140.84	62073.27	11961.44	7540.68	14139.88
		(90°, 0°)	Case 46	874.69	33412.27	10448.34	3179.19	10921.30
		(90°, 30°)	Case 47	7685.93	23399.61	11670.49	1919.91	11827.35
		(90°, 60°)	Case 48	748.94	36396.76	12401.20	4706.13	13264.12

Note: The static pretensions 540.34, 576.9, and 576.9 kN correspond to the effective tensions of F_1 , F_2 , and F_3 at the shared-anchor end, respectively, obtained from the initial static equilibrium state without environmental loading.

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