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Design Considerations and Factors Influencing Floating Offshore Wind Turbines through Numerical Method and Industrial Practice

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ABSTRACT

The increasing demand for renewable energy sources has prompted significant interest in exploring offshore wind power. However, most of the studies in the literature are limited to onshore power generation with a lack of long-term data from a wide range of operational wind turbines. This research explores the design considerations and factors influencing the design of Floating Offshore Wind Turbine (FOWT) by providing valuable insights into the key areas that demand attention, thereby facilitating the realization of the full performance of FOWTs. While FOWTs present a promising solution for harnessing wind energy in deep waters, significant challenges need to be addressed. These include the design of foundations that can withstand harsh marine conditions, the development of effective strategies for fabrication, installation, operation, maintenance and decommissioning and the integration of these factors into a comprehensive design framework. The lack of specific guidelines and standards for FOWTs further complicates these issues. This paper aims to explore these challenges in detail and propose innovative solutions to advance the commercialization of FOWTs. In this work, numerical simulations and modelling techniques are employed to analyse the dynamic response of FOWTs under various environmental conditions. The FOWT fabrication, transportation and installation strategies were briefly examined based on the industrial practice and recent academic literature. The numerical results indicated that the numerical method is extremely beneficial during the initial design stage, as it allows for an accurate and comprehensive understanding of the FOWTs' behaviour under various environmental conditions. This study contributes to the field of FOWT by utilizing numerical simulation and industrial operational methods to optimize design considerations, thereby paving the way for efficient and cost-effective harnessing of wind energy in deeper waters.

1. Introduction

Wind energy is crucial in our efforts to combat climate change and meet growing energy needs. While land-based wind turbines are a well-established renewable energy source, researchers now looking to offshore for more power. Floating Offshore Wind Turbines (FOWTs) are a promising new technology that can operate in deeper waters where winds are stronger and more consistent and

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where the seabed is too deep for fixed-bottom foundations [1]. Therefore, to explore offshore wind energy's potential, the United States has initiated a comprehensive study through the National Renewable Energy Laboratory (NREL). With a database of 2,079 projects in 49 countries and a total capacity of 831,991 MW, NREL collaborates with industry leaders, the research community and other government organizations to create a fast, efficient and lasting path toward commercially successful offshore development [2,3]. US, EU and UK are increasingly committed to reducing greenhouse gas emissions to net-zero by 2050 and diversifying their energy portfolios [4]. FOWTs offer a strategic pathway to achieve these objectives under the term ‘Electricity Decarbonization’ [5]. With a clear vision and a roadmap connecting government, private sectors and citizens, the FOWT enhance energy security and mitigate reliance on fossil fuels—a known major contributor to global warming [6].

Shi *et al.,* [7] highlighted that floating platforms are designed to support offshore wind turbines and perceived as a cost-effective and technically viable solution to overcome the limitations posed by deeper water. However, the study lacked a comprehensive examination of optimization techniques to address the issue of excessive motions in floating offshore wind turbines. Mello *et al*., [8] and Shi *et al*., [7] found that the responsiveness of a FOWT can be enhanced by incorporating an auxiliary geometry referred to as a heave plate. A study by Subbulakshmi *et al*., [9] shows that the heave motion in terms of the hull's response amplitude operator (RAO) depends on the ratio between the column diameter, D_C and heave plate diameter, D_{HP}. Yang *et al*., [10] evaluated the effect of varying numbers of columns for FOWT using the OrcaFlex software package which utilizes potential flow theory, concluding that there was no significant difference in the stability performance. A high-fidelity fluid-structure interaction simulation using computational fluid dynamics, CFD on the dynamic motion of a FOWT has been conducted by Tran *et al.,* [11] has shown that CFD is effective to yield more accurate results in which unsteady viscous flow separation, free wakes, vortex shedding and complex interference effects among the rotating blades, hub, nacelle and tower were considered. Esa *et al.,* [12] conducted a CFD analysis on cylindrical structures, determining the drag and lift coefficients for both bare cylinders and those with fairings. The purpose of the fairing is to reduce turbulence caused by fluid separation. They highlighted the design of the vortex-induced vibration (VIV) suppression device must be tailored to the specific type and shape of the structure. Multidisciplinary Design Analysis and Optimization (MDAO) system by Ojo *et al.,* [13] highlighted that such framework can lead to an efficient design process, helping to select the optimal design for a FOWT substructure and significantly reducing the CAPEX (Capital Expenditure) for a FOWT system, which is desirable in the realm of industry. In their detailed analysis, Diaz *et al.,* [14] explored the Levelized Cost of Electricity (LCOE) for three types of FOWTs. Their findings revealed that the tension-legged platform (TLP) emerged as the most expensive solution which this type shall not be studied in this paper. Writer notes that numerous studies have explored FOWT, but a significant portion remains theoretical due to restrictions imposed by intellectual property concerns within the industry. Additionally, the high implementation costs pose challenges for translating research findings into practical applications. Therefore, this study examines design considerations aimed at navigating the engineering of the FOWT, ensuring a balance between innovation, cost-effectiveness and real-world feasibility.

2. Numerical Analysis Methodology

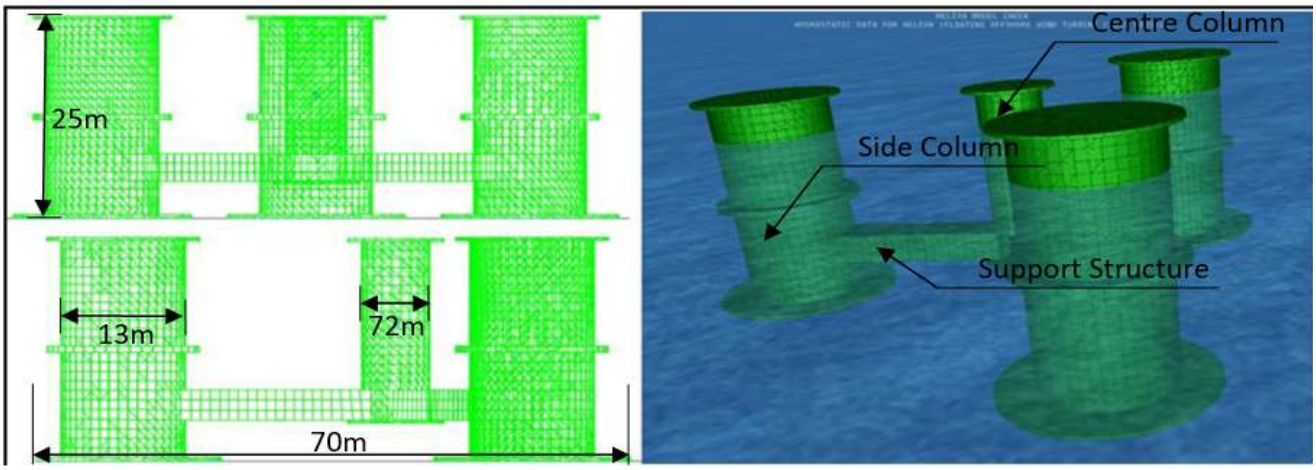
This subsection examines the methodology of designing the FOWT, presented within two scopes of numerical calculation, i.e., hydrostatic stability and hydrodynamic response through wave potential theory. Various numerical tools and optimization approaches are adopted for the conceptual design of the floating structure, aiming to predict the full-scale global dynamic responses of FOWTs accurately, economically and efficiently [15].

Evaluating the movement of a floating offshore structure in waves is an essential part of designing and operating it. Model testing and numerical modelling are two ways to do this evaluation. Model testing involves building a scale model of the structure and testing it in a wave tank, while numerical modelling uses computer simulations and mathematical equations to predict the structure's behaviour in actual sea conditions. Model testing is a powerful tool to obtain high-accuracy results [16], however, such method is expensive and time-consuming compared to numerical modelling, which is more cost-effective and can be easily modified to explore different design options, once validated via physical measurements [10]. Consequently, given that this research emphasizes design considerations during the preliminary design phase, the utilization of simulation-based methodologies emerges as the most optimal approach and elaborated more in this section.

2.1 Hydrostatic Stability

FOWT operate in complex environments influenced by wind, wave and marine currents. Stability is vital for both safety and efficient power generation. A lack of stability can cause issues like capsizing, increased movement and even sinking of the turbine. Scicluna *et al.,* [17] assessed the stability of a self-aligning FOWT by adjusting the ballast configuration, aligning with international standards [18]. It's worth noting that misalignment or excessive motion can diminish power efficiency due to sensitivity to wind conditions [19]. Stability is key for safe operation, reduced environmental impact, decreased downtime and extending the turbine's lifespan. This study uses the MOSES software for simulations to ensure FOWTs remain stable in all conditions

In this investigation, the commercial software MOSES was employed to ensure the hydrostatic stability of the FOWT hull is in accordance with established industry benchmarks [18,20,21]. As shown in Figure 1, MOSES facilitates a comprehensive analysis of FOWT by rigorously detailing its geometric attributes, computing its buoyant characteristics compared with weight distribution and other metrics such as the metacentric height (GM). This software offers insights into the FOWT's dynamic response under the influence of external perturbations, notably wind and wave actions, by examining parameters like heel and trim angles.



(a) Mesh model in MOSES (b) 3D visualization in MOSES

Fig. 1. Hydrostatic stability analysis using MOSES software (a) Mesh model (b) 3D visualization

Via MOSES, stability determinants, exemplified by the righting arm curve, are meticulously scrutinized, as delineated in Table 1. The acquired data pertaining to mass, volume displacement and the loci of the centre of gravity presented a similarity with the empirical findings of Coulling's seminal work [22,23] on the OC4 DeepCwind semisubmersible. Such preliminary insights were subsequently refined to enhance the primary dimensions of the columns, ancillary support structures and heave plates, aligning with the optimization paradigms presented in [9,17,24] and in adherence to required criteria [25,26]. As the results, the hull manifested augmented hydrostatic stability, boosting the structure's resilience against potential capsizing scenarios.

Table 1
Hydrostatic properties

		COG wrt 0,0,0			Inertia wrt to COG		
Object	Mass (t)	x(m)	y(m)	z(m)	Ixx (t.m2)	Iyy (t.m2)	Izz (t.m2)
Platform	9,785.10	0.0	0.0	9.2	5.48E+06	5.48E+06	7.31E+06
Tower	270.64	0.0	0.0	64.3	1.53E+05	1.53E+05	1.97E+03
Nacelle	240.00	0.0	0.0	110.3	3.50E+02	5.41E+03	2.61E+03
Rotor & hub	110.00	-5.5	0.0	111.0	1.95E+04	1.95E+04	3.91E+04
Total	10,405.73	0.0	0.0	13.9	9.76E+06	-1.97E-12	1.35E+04

2.2 Hydrodynamic Response through Wave Potential Theory

Wave potential theory plays a crucial role in offshore hydrodynamics, especially when analysing floating structures. It helps in designing the hull by estimating the hydrodynamic forces and moments on the structure due to wave-induced fluid motion, as highlighted in studies by Molin [27], Newman [28] and Pinkster [29]. By understanding these forces and moments, the hull's design can be optimized to reduce wave load impact and enhance the structure's overall performance. To calculate this hydrodynamic properties, numerical method is implemented by computing the diffraction and radiation forces and movements on offshore structures. An approach called the boundary element method (BEM) [30] to tackle potential flow equations, explaining the diffraction and radiation of waves around the structure. Essentially, BEM suggests that the wave field's velocity potential can be represented as a mix of basic functions defined on the boundary of the structure. Applying the boundary conditions gives us equations that can be solved to find the basic functions' unknown values. These values then help in determining the wave-induced forces and movements on the structure. As Papilon *et al.,* [30] indicated, simplifying certain assumptions can make the mathematical process more manageable and speed up computational tasks. This simplification is vital for the potential flow theory, which involves varying degrees of modelling complexity, as depicted in Figure 2.

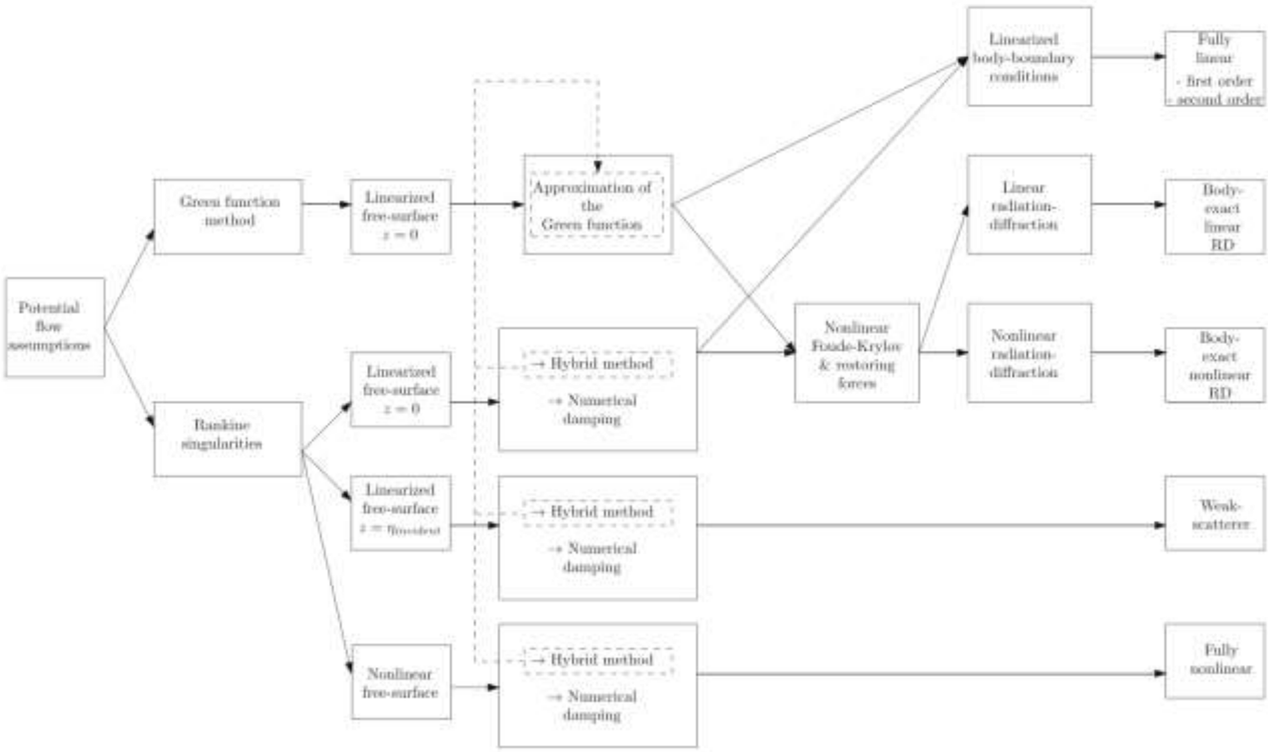


Fig. 2. Potential models in boundary element method [30]

In this work, the OrcaWave commercial code was adopted which allows the user to input the structure's geometry, the properties of the surrounding water and the wave conditions. The code then calculates the diffraction and radiation coefficients and provides the results of the structure's time-domain and frequency-domain wave loads and motions [31]. For the wave radiation numerical calculation, the wave-induced forces and motions on the structure are calculated by accounting for how the structure radiates waves, as shown in Eq. (1) below:

$$\emptyset = \emptyset_I + \emptyset_S + \emptyset_R \tag{1}$$

Here, the first-order complex potential $\emptyset$ is a sum of the potential of the incident wave $\emptyset_I$, wave scattered and diffraction potential that is due to the presence of a fixed obstructing body, $\emptyset_S$ and radiation potential, which is known due to the motion of the body in the fluid, $\emptyset_R$. For an incident wave with complex amplitude A (A is a height with dimensions of length), frequency ω, wave number k and wave heading β, the potential is given by Eq. (2):

$$\emptyset I(X) = \frac{igA}{\omega} f((kZ) e^{-ik(X\cos\beta + Y\sin\beta)} \tag{2}$$

The radiation potential, $\emptyset_R$ is separated into six components per rigid-body degree of freedoms (heave, surge, heave, roll, pitch, yaw), denoted as j (1 to 6), as shown in Eq. (3):

$$\emptyset R = i\omega \sum_j \xi_j \emptyset_j \tag{3}$$

Once the diffraction and radiation forces are calculated, the analysis results are presented in tables, graphs and plots of the wave-induced forces and motions on the structure. These results can be used to design and optimize the structure to withstand the forces and motions caused by waves.

With the ability to input wave and current conditions, environmental loads and control systems that impact the structure, the time-domain analysis simulation is executed using OrcaFlex code, incorporating numerical methods, such as finite difference and finite element methods, to model the dynamic behaviour of the system precisely [32]. On the other hand, Pols *et al.*, [22] suggested that the unaccountable fluid viscosity in the numerical modelling led to overpredicted motions near the resonant frequencies, which needed an additional roll damping, *E*, as an input.

OrcaFlex default convention has been employed to represent the response of the floating platform to wave and wind loads. This convention involves using the response amplitude as a proportion of the wave amplitude. The response is expressed in length units for surge (motion along the x-axis), sway (motion along the y-axis) and heave (motion along the z-axis) and degrees for roll (rotation around the x-axis), pitch (rotation around the y-axis) and yaw (rotation around the z-axis). Mathematically, this expression is given by the following Eq. (4):

$$x = R\, a \cos(\omega t - \phi) \tag{4}$$

Here, x is vessel displacement in 6 degrees of freedom responses, a, ω are wave amplitude in unit length and frequency in rads or seconds. R, ϕ are the response amplitude operator, RAO magnitude and phase. The software then simulates the dynamic response of the structure over time, providing the results in the form of time-domain wave loads, motions and other performance characteristics. Ultimately, these outputs are used to design and optimize the structure and its associated systems and to perform reliability and safety analyses.

Potential flow theory considers the flow around a body to be incompressible, inviscid and irrotational, with negligible surface-tension effects. Figure 3 shows the 3D panel model created in OrcaWave software for the hydrodynamic database calculation. The hydrodynamic loads that usually affect the response of floating wind turbines consist of two parts: first-order wave loads and second-order wave loads. The following necessary data for mooring design simulations are:

i. First-order motion transfer functions (RAOs)
ii. First-order excitation forces,
iii. Added mass/damping coefficients,
iv. Second-order wave loads (QTF),
v. Wind force coefficients
vi. Current force coefficients

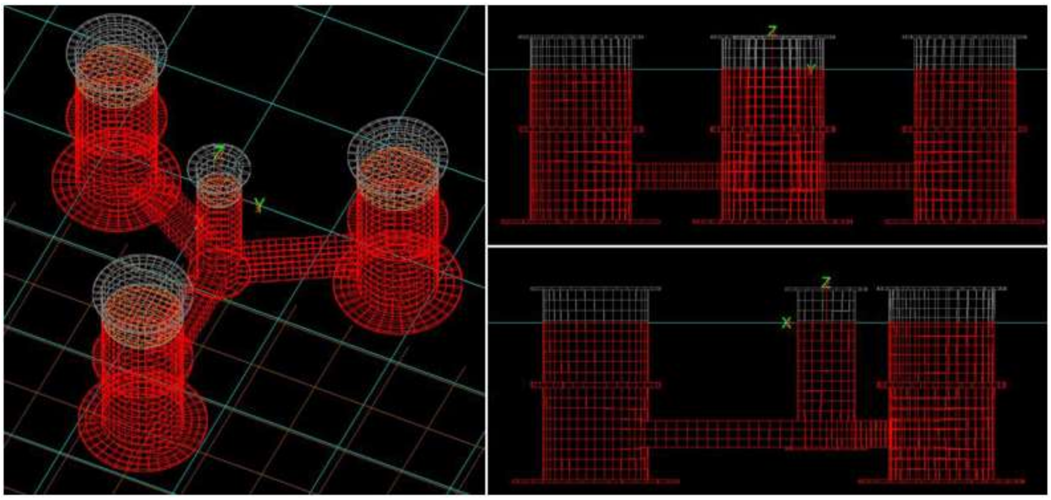


Fig. 3. FOWT panel model in OrcaWave

2.3 Mooring Selection

The mooring system is an essential component of offshore structures, including FOWT. The mooring system consists of a mooring line, anchor and connectors, which are used for station keeping of a ship or floating platform in all water depths. The mooring line for the structure is made of chains and is connected to the anchor at one end and the hull's fairlead at the other end. The mooring lines are modelled to achieve the correct non-linear stiffness behaviour at the fairlead connection points.

The FOWT hull design consideration in this study caters the extreme conditions (ULS and ALS) by fulfilling the requirements for partial safety factors according to standard industrial practices [18,33]. Two components of characteristic line tension are considered for the partial safety factors:

i. T_C–*mean*: the characteristic mean line tension, due to pretension and mean environmental loads. The mean environmental loads are caused by average wind, current and wave drift forces.
ii. T_C–*dyn*: the characteristic dynamic line tension induced by low-frequency and wave-frequency motions (not including mean value).

Characteristic strength S_C of the chain segments was obtained from the specified minimum breaking strength, *SMBS*, given by the following Eq. (5):

$$S_C = 0.95\ SMBS \tag{5}$$

The station-keeping system was designed to the specified minimum safety factors, γ, listed in Table 2 and Table 3. Partial safety factors for the strictest consequence class, *i.e.*, Consequence Class 2, were considered. DNV-GL [33] states that for mooring systems without redundancy, the minimum required safety factors for ULS are to be increased by a factor of 1.2. On top of the ULS design requirements from DNVGL for steel components and grouting an extra load factor of 1.3 was added to the mooring loads.

Table 2
Minimum allowable partial safety factors-ULS

Consequence Class	Limit State	Partial Safety Factor on Mean Tension (γ_{mean})	Partial Safety Factor on Dynamic Tension (γ_{dyn})
2	ULS	1.4*1.2*1.3 = 2.18	2.1*1.2*1.3 = 3.28

To check the robustness of the system, we analyse case studies which considers a minimum of 50-year return period environmental conditions. These cases were regarded as ALS conditions and the basic requirement for safety factor were assumed to be 1.00. In addition, an extra redundancy factor of 1.2 will be used (as for ULS). The required minimum safety factors are then listed in Table 3.

Table 3
Minimum allowable partial safety factors-ALS

Consequence Class	Limit State	Partial Safety Factor on Mean Tension (γ_{mean})	Partial Safety Factor on Dynamic Tension (γ_{dyn})
2	ALS	1.0*1.2 = 1.2	1.0*1.2 = 1.2

The following design equation, Eq. (6) will have to be fulfilled:

$$S_C - T_C\text{-}mean \cdot \gamma_{mean} - T_C\text{-}dyn \cdot \gamma_{dyn} \geq 0 \quad (6)$$

For this study, the mooring line properties for the preliminary study are shown in Table 4, by referring to the study conducted on OC4 DeepCwind semisubmersible [34].

Table 4
Mooring line properties

Parameter	Property	
	Unit	Full Scale
Type	-	Studless chain, grade R4
Nominal outer diameter	m	76.6
Number of Mooring Lines		3
Angle Between Adjacent Lines		120
Unstretched Mooring Line Length	m	540
Equivalent Mooring Line Mass Density	kg/m	113.35
Equivalent Mooring Line Mass in Water	kg/m	108.63
Equivalent Mooring Line Extensional Stiffness	MN	753.6
Hydrodynamic Drag Coefficient for Mooring Lines		1.1
Hydrodynamic Added-Mass Coefficient for Mooring Lines		1

During the mooring design stage, two types of fatigues were considered. The fatigue safety factor is a factor of safety applied during mooring component design to account for uncertainties, while fatigue life is a prediction of how long a component can withstand cyclic loading conditions before needing replacement or maintenance due to fatigue-related damage. The fatigue safety factor of 8 were adopted according to DNV [33], meaning that the fatigue life shall be a minimum of 8 times the design life, i.e. 8 x 25 = 200 years.

3. Numerical Analysis Result and Discussion

The impact of the wave, wind and current loads combination was thoroughly examined and the final result is tabulated in Table 5. In the context of FOWT mooring parametric study, the departure angles, denoted as Θ_1, Θ_2 and Θ_3, are crucial factors that determine how the mooring lines are positioned and tensioned. To determine these departure angles, a static simulation process was employed, varying the length of the chain while the mooring anchor radius was kept constant. During this simulation, the mooring line tensions were systematically monitored, effectively exploring various configurations, from taut to catenary mooring configurations. To select the best FOWT design, two critical parameters were considered: dynamic mooring tension and nacelle acceleration. Dynamic mooring tension refers to the varying force exerted on the mooring lines as the wind and waves change, reflecting the real-world conditions FOWT faces during operation. On the other hand, nacelle acceleration measures how much the housing containing the generator and other critical components at the top of the wind turbine vibrates or moves due to external forces. These parameters are evaluated per the guidelines provided by DNV [18,20,21] and it depends on which design configuration minimizes dynamic mooring tension and nacelle acceleration while still meeting the necessary structural and operational criteria. The pressure distribution using CFD on the surface of the rotating blade impacts overall turbine performance [35,36]. However, this factor was not included in the current numerical simulation due to software limitations.

The design significant wave height, H_s is defined by 5m, wave peak period, T_p of JONSWAP spectrum. The dynamic wind is defined as constant value at 20m/s and current speed is 1.5m/s as visualized in Figure 4.

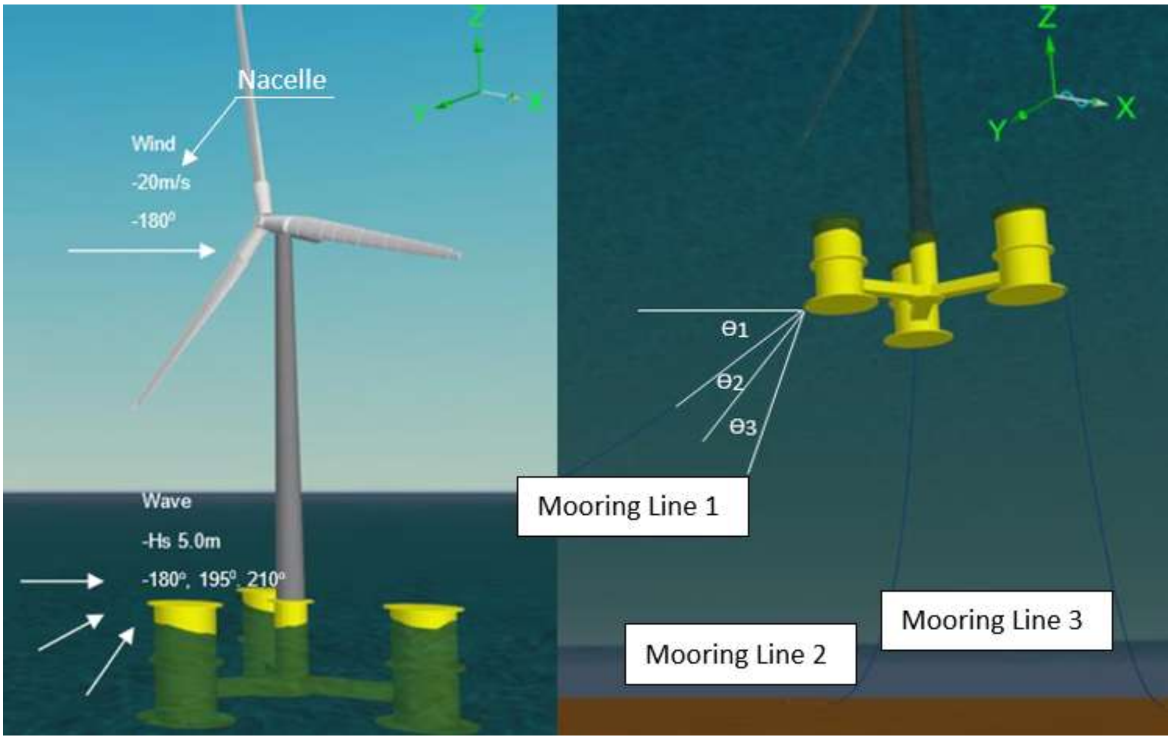


Fig. 4. FOWT visualization in OrcaFlex-time domain analysis

Figure 5 shows the time domain results for mooring line 1, 2 and 3 for 3 configuration of chain departure angle. The manufacturer has specified a minimum breaking load of 444t for the chain. The results indicate that the integrity of all lines will remain intact across the analysed wave directions in Cases 1-3. For all cases, mooring line 1, which runs parallel to the direction of environmental loads, experienced the highest tension compared to the other two lines. Specifically in Case 1, where the chain departure angle is smaller, the maximum tension reaches 74t, which is 27.7% higher than that experienced by the mooring chain with the largest departure angle.

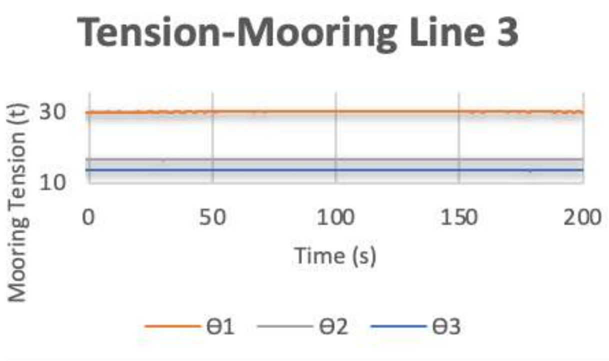


Fig. 5. Mooring line tension for each configuration

While tight mooring can enhance stability by restricting lateral motion and preventing the FOWT from drifting too far from its intended position, the nacelle acceleration for Case 1, visualized in Figure 6, shows the highest value at 0.25m/s but relatively insignificant.

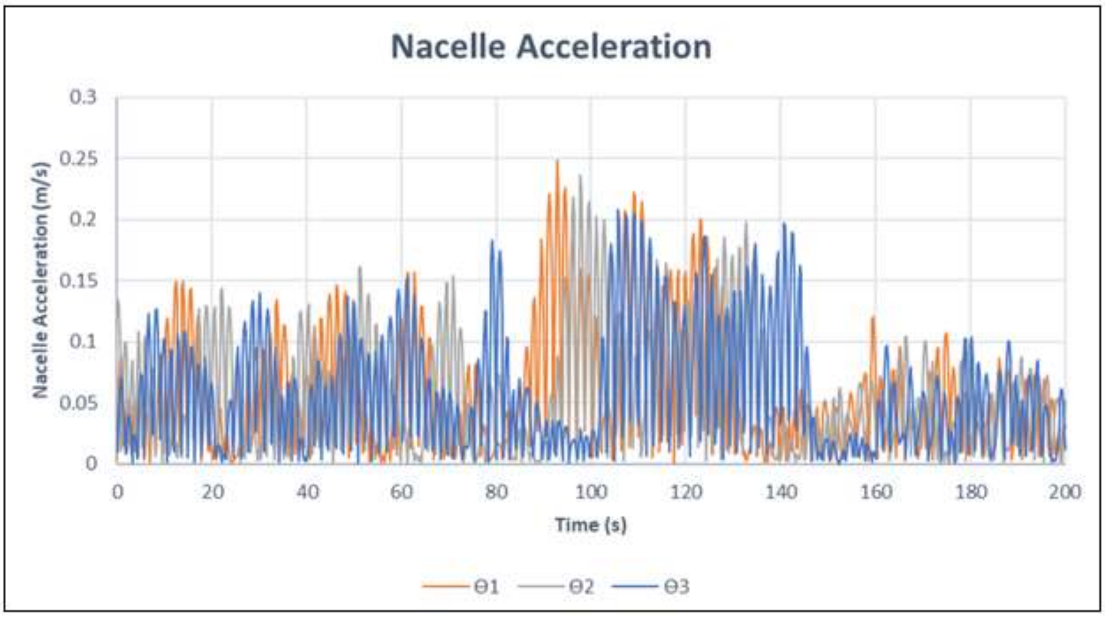


Fig. 6. Nacelle acceleration for each configuration

The overall result is summarized in Table 5.

Table 5
Time domain summary results

Case	Parameter		Sig. Wave Height	Current Speed	Wind Speed	Max Acc.	Translation			Rotational			Mooring Max. Tension		
							Surge	Sway	Heave	Roll	Pitch	Yaw	M1	M2	M3
			(m)	(m/s)	(m/s)	(m/s2)	(m)	(m)	(m)	(deg.)	(deg.)	(deg.)	(t)	(t)	(t)
1	ϴ1	55^{o}	5	1.5	20	*0.25*	0.76	0.01	0.23	0.01	*0.22*	0.09	*74*	*33*	*33*
2	ϴ2	70^{o}				0.24	*0.81*	0.02	*0.23*	0.01	0.22	0.22	60	17	17
3	ϴ3	85^{o}				0.22	0.78	*0.03*	0.22	*0.01*	0.22	*0.35*	56	14	14

In this context, particular attention is given to the mooring chain configuration at departure angle Θ_3 as tabulated in Table 5, suggested to be the most suitable mooring layout for achieving the delicate balance between stability and performance during the dynamic operation of FOWT. A similar pattern was found in the parametric and experimental study [37].

4. Fabrication, Transportation and Installation

The Hull Block Construction Method (HBCM), developed by Storch *et al.,* [38] is a technique used typically in shipbuilding to fabricate the hull of a vessel in sections or blocks that are subsequently joined together to form the complete hull structure. The innovative aspect lies in incorporating this method into the newly proposed FOWT design in this study. As shown in Figure 7, The HBCM process begins by designing the FOWT hull form, which is then divided into a series of blocks or sections that are constructed separately in a fabrication yard. Each block is built on a horizontal or inclined surface known as a block bed, which provides a stable working platform for the construction process. Typically, blocks are constructed using steel plates and sections that are welded together to form a strong, rigid structure. The block's shape and size are determined by the design and can vary depending on factors such as the size and complexity of the hull, the available construction facilities and the transportation requirements. Once each block is completed, it is transported to the shipyard where the hull is being assembled. The blocks are then lifted into position using cranes and joined together to form the complete hull structure. The joining process involves welding, bolting or a combination of both, depending on the shipyard's preferences and the hull's design requirements.

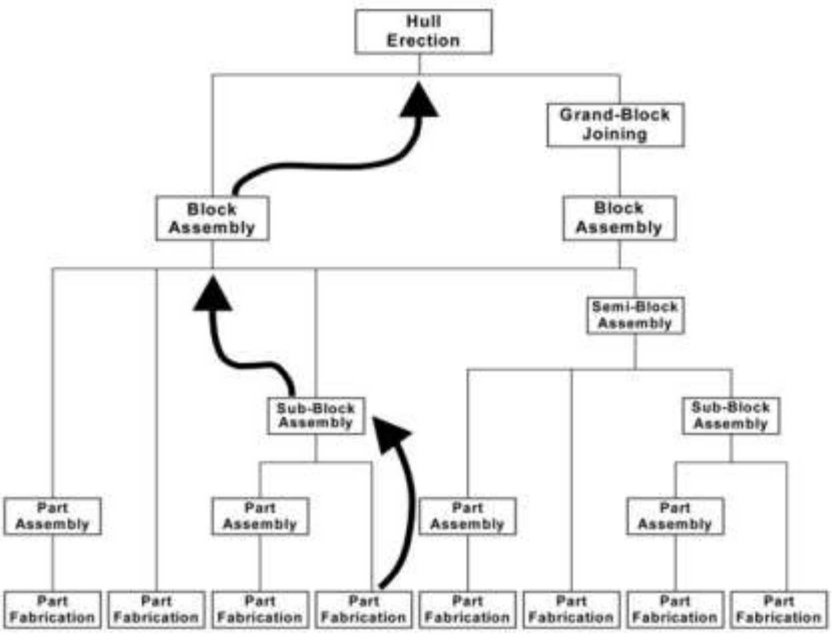


Fig. 7. Hull block construction method (HBCM) [38]

The HBCM method has several advantages over traditional hull building techniques, including improved quality control, increased productivity and reduced construction time [39]. Additionally, the use of prefabricated blocks can reduce the need for skilled labour, which can help to lower construction costs. However, the HBCM method requires careful planning and coordination to ensure that all blocks fit together correctly and that the final hull structure meets the design requirement as per DNVGL [18,20,21]. The fabrication of the hull is simplified and visualized in Figure 8 to Figure 11 using the HBCM.

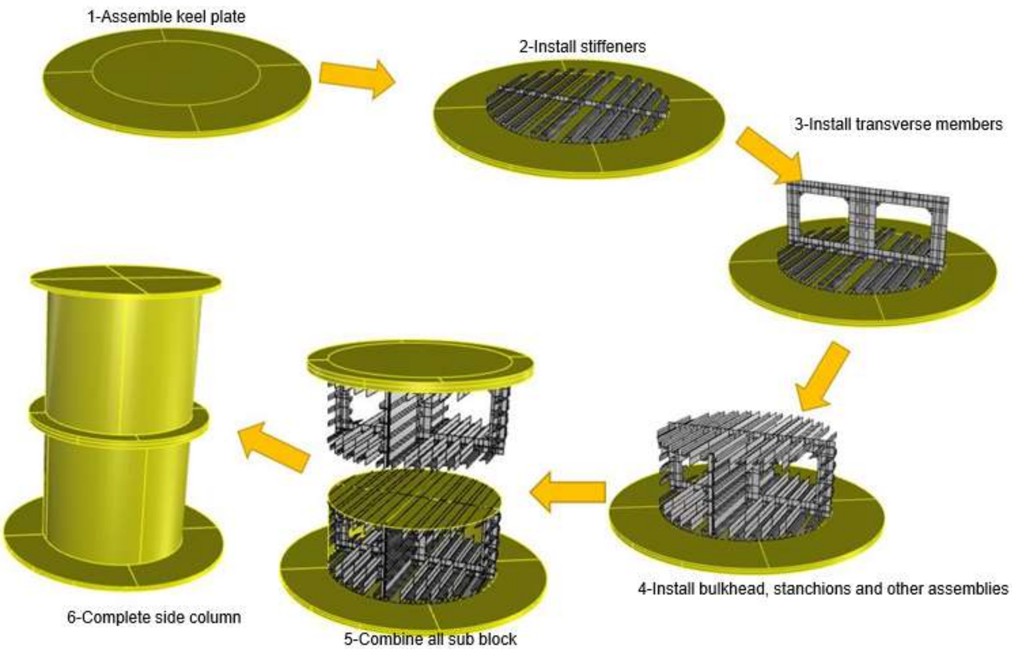


Fig. 8. Side column breakdown structure identification

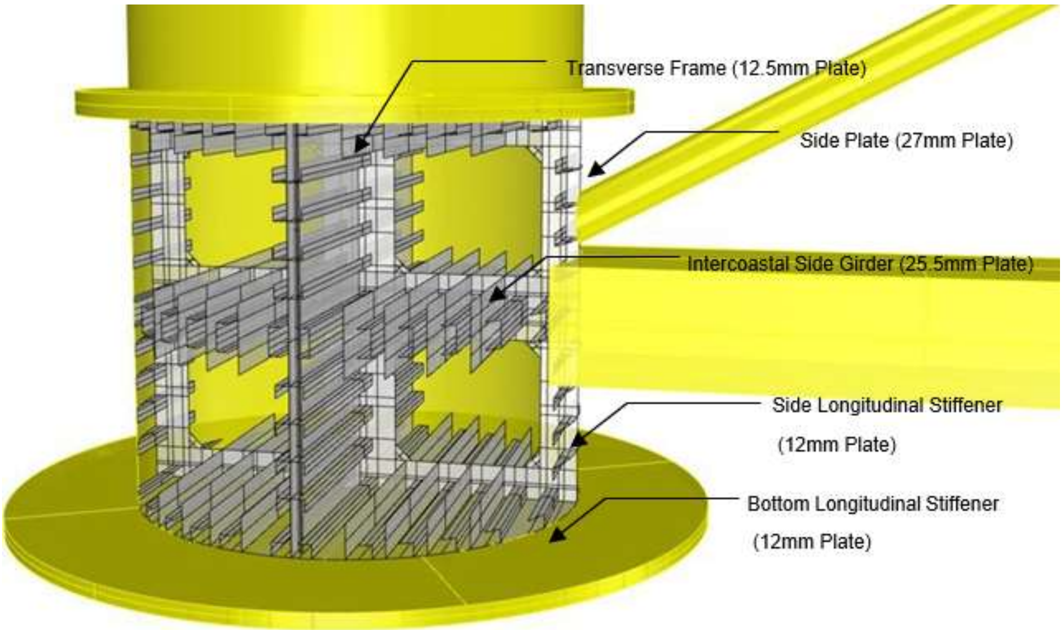


Fig. 9. Scantling model-side column

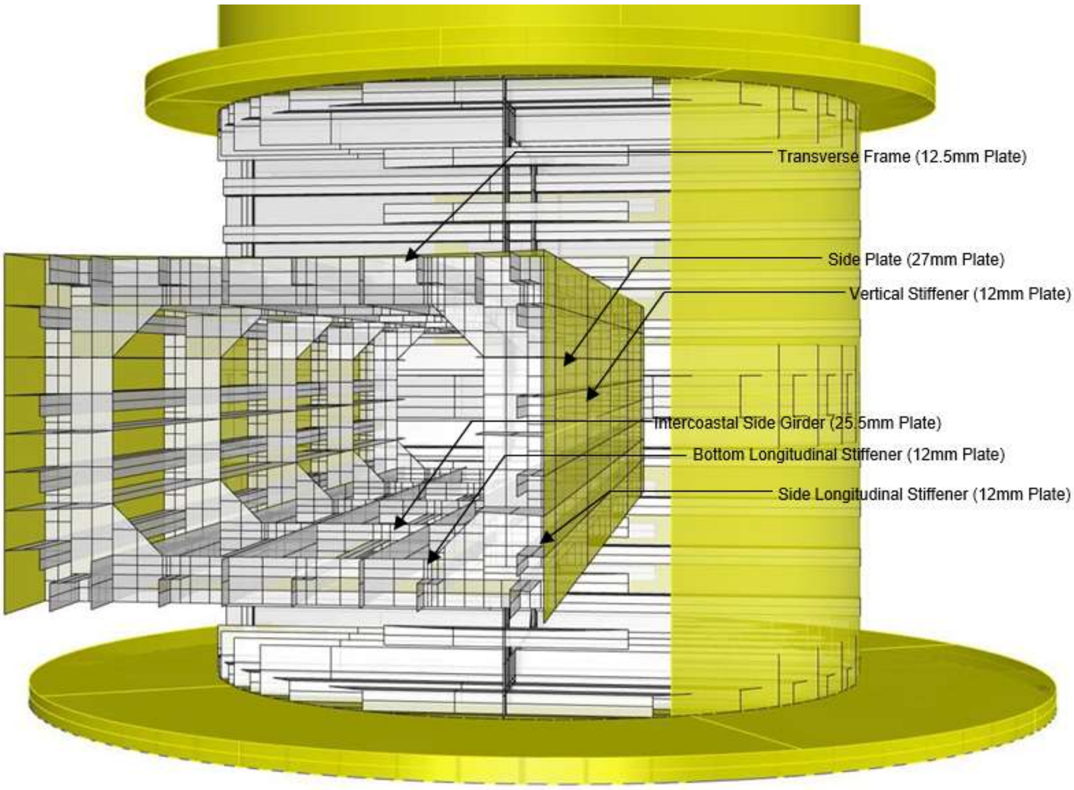


Fig. 10. Scantling model-pontoon

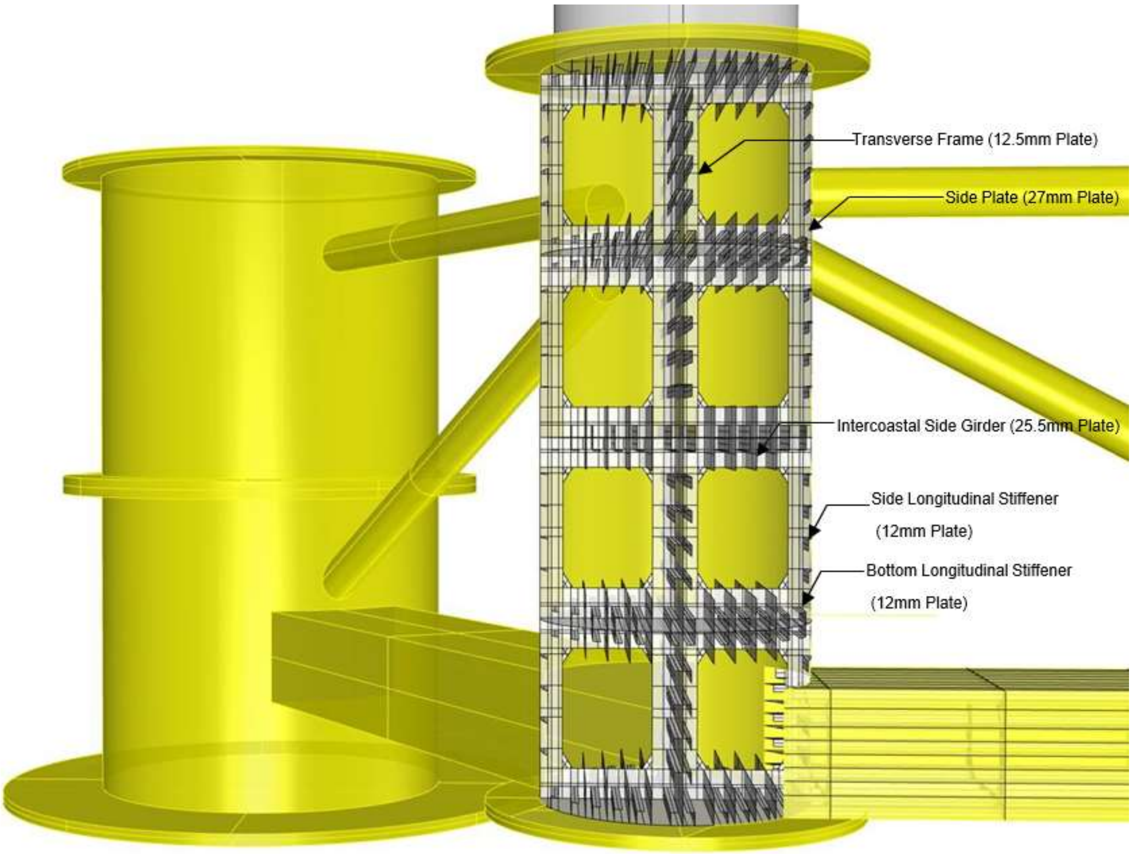


Fig. 11. Scantling model-centre column

Drawing from advanced techniques used in offshore oil and gas platform installations, this study introduces a novel skidding operation for transferring the FOWT hull from the fabrication yard to the transportation vessel, as shown in Figure 12. The process involves creating a robust skid track, meticulously preparing and levelling the skidway and mounting the hull on innovative skid shoes, which are typically reinforced steel plates or beams. These skid shoes facilitate the smooth movement of the hull along the track. The hull is then moved using hydraulic jacks or winches, ensuring precise control over the transfer. This approach carefully balances weight distribution and minimizes structural stress, with rigorous regulation of speed and force to prevent any potential damage, offering a fresh perspective on optimizing large-scale offshore structure handling.

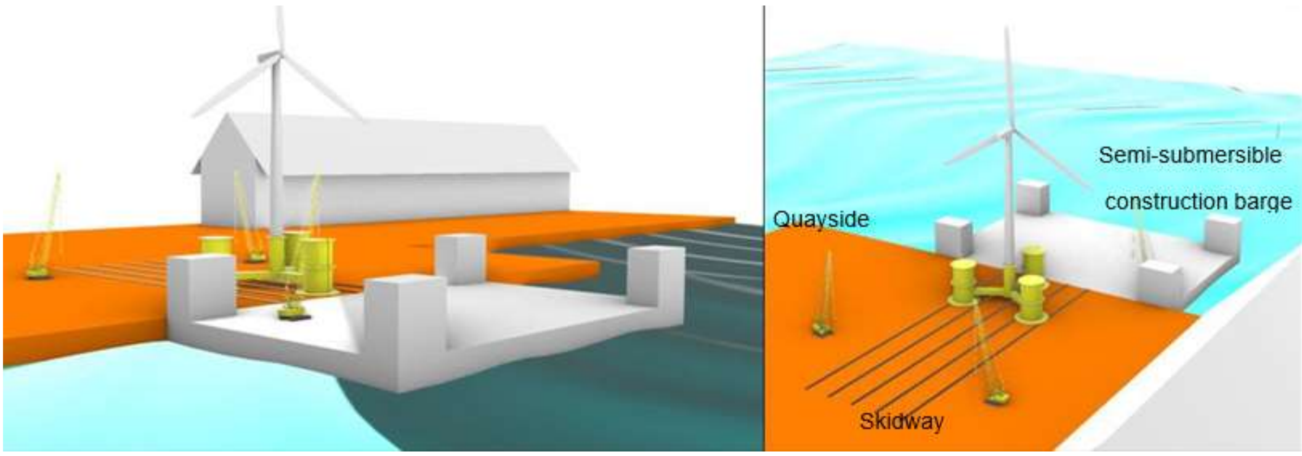


Fig. 12. Skidding/loadout of FOWT hull

Tidal fluctuations can profoundly influence the loadout operation, causing potential misalignment between the shifting height of the transportation vessel and the quay. To address these challenges, it is essential to account for tidal effects and adapt the loadout strategy accordingly. Successful transfer of the structure to the transportation vessel requires meticulous alignment to ensure a smooth operation. Once loaded, the FOWT can be delivered to the installation site using either tugboats, which tow the hull directly or semisubmersible heavy lift vessels, which partially submerge to gently place the FOWT onto the sea surface, as illustrated in Figure 13. While the tugboat approach is typically more cost-effective due to its simpler operational requirements, both methods offer distinct advantages depending on the specific conditions of the transport and installation.

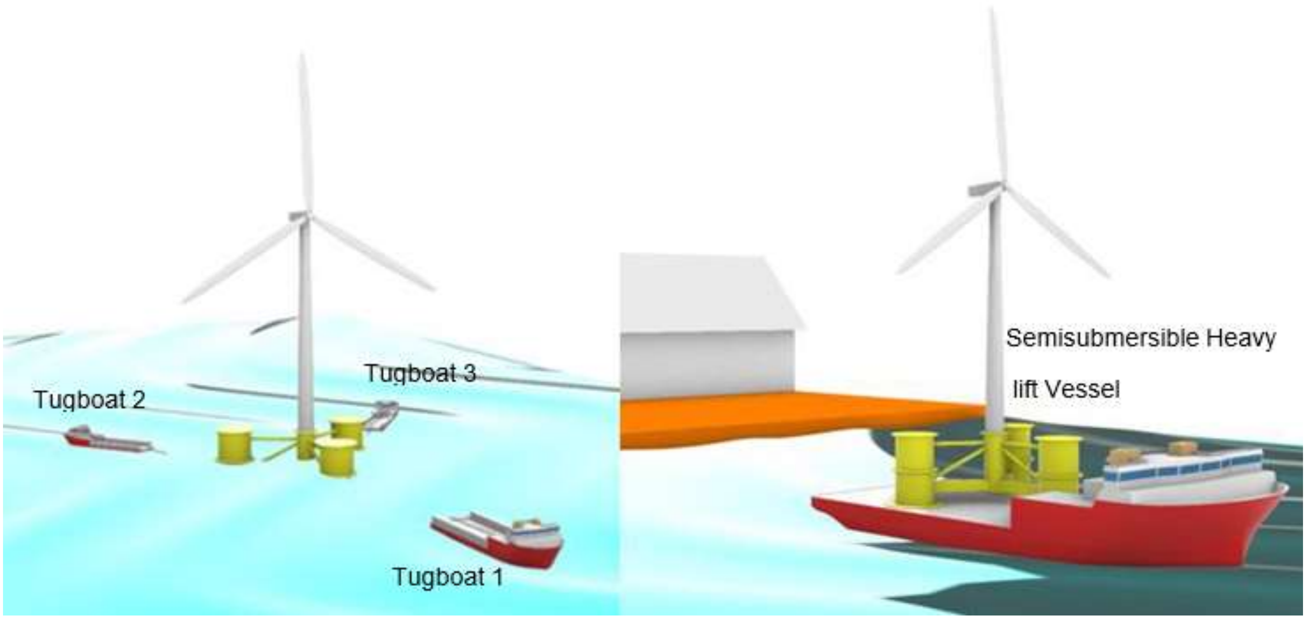


Fig. 13. Transportation of FOWT to the site

The mooring chain hook-up operation connects the mooring line to the anchor and the structure's fairlead for stability and safety. Using the same methodology as adopted by Altuzarra *et al.,* [40] in his FOWT mooring installation planning study, the chain is pre-tensioned using a mooring winch on the hull's top and locked at the chain locker when correctly positioned as per Figure 14. Following this, commissioning involves tests and checks to ensure the mooring chain and systems function correctly, including verifying tension and alignment, inspecting for wear or damage and conducting load tests. Instrumentation may be installed for continuous performance assessment, ensuring the mooring chain can safely anchor the FOWT in its offshore location throughout its lifespan.

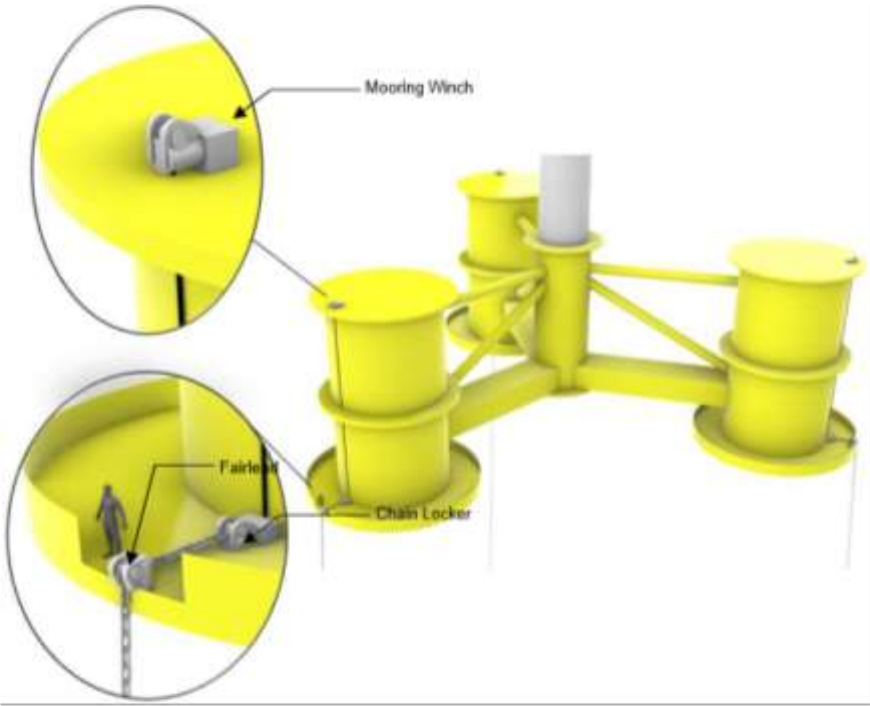
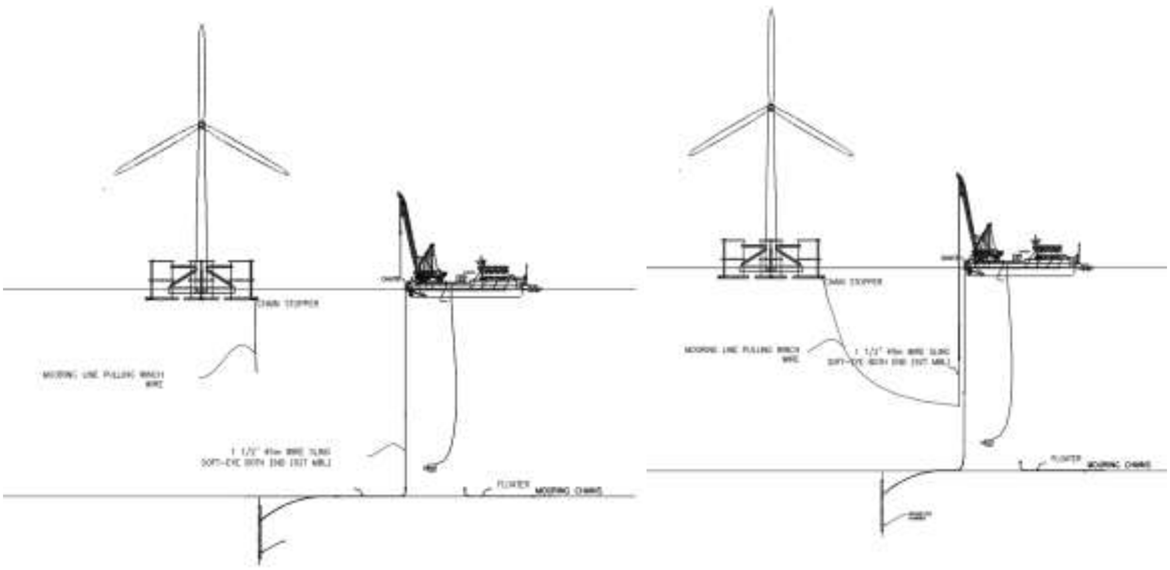
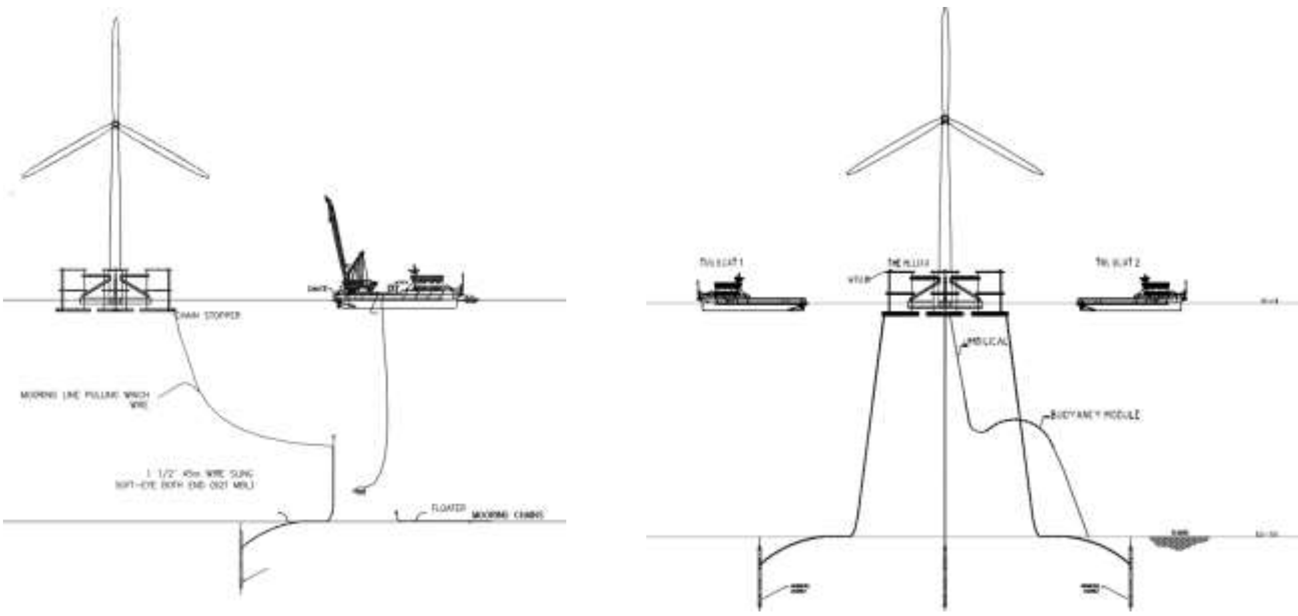


Fig. 14. 3D visualization of mooring hook-up

As illustrated in Figure 15, the innovative construction method for mooring the Floating Offshore Wind Turbine (FOWT) involves a carefully orchestrated process. The FOWT hull is initially centred over a pre-installed mooring chain, with a mooring-pulling wire lowered from the hull. A vessel's winch then retrieves the mooring chain, drawing from established oil and gas industry practices [41]. A Remotely Operated Vehicle (ROV) is employed to connect the winch wire to the hull's pulling wire. The chain is pulled taut and secured to the FOWT hull's chain stopper. Meanwhile, two tugboats position the hull precisely as the chain is drawn, facilitating the connection of the first chain to the chain locker on the hull's deck. This process is repeated for each subsequent chain. After all chains are attached and secured, a thorough survey evaluates the chain's pre-tension and the draft of the FOWT hull. The procedure concludes with the installation of the FOWT umbilical, marking the successful completion of the mooring hook-up.



(a) (b)



(c) (d)

Fig. 15. Mooring hook-up operational storyboard

5. Conclusions

5.1 FOWT Hull Numerical Assessment

Presented in this paper are the exploration of the key influencing aspects of the design of Floating Offshore Wind Turbines (FOWTs). Firstly, the relevant literature and the recent FOWT structural design have been investigated. We drew initial inspiration for the hull platform design from the OC4 DeepCwind semisubmersible works in the literature.

The selected concept, which is the semi-submersible, has been chosen for refinement. Static and hydrodynamic numerical simulations were conducted to optimize the preliminary design of OC4 DeepCwind, involving modifications to the main design parameters. Additionally, a time domain mooring analysis of the FOWT was performed to assess chain strength under the most severe environmental loads. Additionally, for the heave plate design, we focused on optimizing its effectiveness by adjusting the ratio between the heave plate diameter and the column diameter. Above all, the FOWT has been thoroughly designed to adhere to the requirements specified by existing regulations.

The essential elements of FOWT design were examined, encompassing both hydrostatic stability and hydrodynamic performance, utilizing time domain dynamic analysis. The novelty of this study lies in its thorough analysis of the combined effects of wave, wind and current loads on FOWT through a detailed examination of mooring chain configurations and departure angles. By systematically varying these angles and assessing their impact on dynamic mooring tension and nacelle acceleration, the research offers new insights into optimizing mooring system performance under real-world conditions. This approach not only enhances understanding of how different configurations affect stability and operational efficiency but also provides practical recommendations for achieving an optimal balance between structural integrity and performance. These findings will prolong the mooring chain's lifetime and enhance electrical generation from the FOWT by improving its stability, ultimately referred as a guideline of designing FOWT.

However, a limitation of our study is in its reliance on a simplified wave theory, which overlooks the fluid-structure interactions, particularly fluid viscosity. Ignoring viscosity can result in overestimating certain motions, especially when drag plays a significant role. For a more holistic understanding of FOWT behaviour in real world scenarios, validation using advanced techniques like Computational Fluid Dynamics (CFD) or actual experimental tests are recommended.

5.2 Fabrication, Installation and Operation Assessment

The distinctive aspect of this study lies in the implementation of the Hull Block Construction Method (HBCM) for constructing FOWT, a method previously renowned primarily within the shipbuilding industry. While this method is effective, alternate methods might be suitable depending on specific project needs. The ideal construction approach should take into account design criteria, available space, capabilities, timing and budget, ensuring alignment with both technical and economic goals. Post-construction, emphasized in our study is the processes of transporting the FOWT hull from the construction site to its offshore destination and anchoring it securely using a mooring chain.

Future work recommendation includes the investigation on the specific risks associated with FOWT installation. Factors such as variable weather conditions, equipment dependability and the intricacies of offshore operations and maintenance all warrant careful consideration.

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