Design study of offshore floating wind and photovoltaic power generation platform

Siqi Chen[1, *, †], Zijia Wang[2, †] and Wenxin Yang[3, †]

[1]School of Architecture, Xi'an Jiaotong-Liverpool University, Shuzhou, China

[2]School of Civil Engineering, HeFei University of Technology, Hefei, China

[3]School of Civil Engineering, Southwest Jiaotong University, Chengdu, China

*Corresponding author: Shiqi.Chen22@student.xjtlu.edu.cn

[†]These authors contributed equally.

Abstract. The oceans contain a huge amount of clean energy, of which wind and solar are the largest reserves and the easiest to access. In consideration of the many factors affecting traditional offshore semi-submersible platforms, the design of an offshore semi-submersible platform that can overcome the harsh marine environment and work efficiently is based on overcoming the many problems of low stability, low efficiency, and poor economy of existing semi-submersible platforms. The text, therefore, builds on previous designs to design an offshore floating platform that combines a floating wind turbine with photovoltaic power generation. Firstly, the paper combines various design concepts, proposes a model concept for the floating platform and the corresponding structural dimensions, designs the ballast system, and selects the materials for each part. The paper concludes with a simple calculation of the stability, loads, and cost of the structure. The overall high initial stability (GM) of the structure is greater than zero, the wind and wave loads are estimated to be 350,000 N and 50 million N respectively, and the cost is about 58,500,000 RMB per kW. The research offers a new approach to the future development of new green energy sources in the ocean and has implications for the design of new integrated concepts for floating platforms. The paper concludes by looking forward to the design of a more stable, economical, and efficient offshore floating power platform that will provide a new way of maximizing the exploitation of offshore energy for human society.

Keywords: semi-submersible platform, floating fans, photovoltaic, stability design, load calculation.

1. Introduction

The oceans contain a huge amount of clean energy, and the global reserves of ocean energy amount to 150 billion KW [1]. The exploitation of ocean energy can not only solve the problem of resource shortage faced by most countries, but also is an important way to achieve energy saving and emission reduction, and realize the goal of "carbon neutrality". With the further exploration of wind energy, traditional fixed wind turbine construction technology and operation and maintenance costs are no longer sufficient to support their work in the deep sea. Studies have shown that floating generators can withstand more treacherous marine environments. At the same time, the harsh environmental conditions at sea pose a major challenge to the design, manufacture, and operation of offshore wind turbines [2]. For offshore wind turbines, low failure rates and high reliability are required due to the difficulty and high cost of maintenance. The cost of floating platforms is usually influenced by a variety of factors, which mainly include uncertainty, difficulty in forecasting, and high fluctuation with market changes and time [3].

The stability of floating platforms is not only influenced by the volume and shape and size of the platform itself, but also by the superstructure and other factors. The change of load on the floating platform, the work of equipment, or even the installation and transportation process of the floating platform can cause the change in floating platform discharge, the center of gravity, and the floating center. If the initial stability of the design is poor, the stability of the platform will be reduced or even lost in the process of manufacturing, transportation, and installation [4]. The offshore wind power needs to be subjected to the repeated effects of wind and wave loads for a long period during the design life, so a rough calculation of the size of both will be made in this paper. For the cost design of offshore floating structures, local labor costs, local material prices, and costs of various assemblies need to be considered, especially on the cost budget of photovoltaic devices. Since PV devices are characterized by a wide variety of categories, high consumption, and high technicality [5]. Therefore, more consideration needs to be given to the needs when selecting PV equipment.

In this paper, designers combine the semi-submersible platform with wind power generation and photovoltaic power generation as a whole under the premise of combining the assumed sea conditions to achieve the maximum utilization of offshore green energy resources. This paper presents the structural composition of the floating platform and the stability analysis under the requirements of the sea state. In terms of wind load calculation, the API wind spectrum is used for simple data analysis and calculation of wind turbine forces due to the large uncertainty in the wind spectrum description by the NPD wind spectrum during gust studies [6]. After considering the requirements of both computational use and accuracy, the linear wave theory was finally used to perform a rough calculation and analysis of the wave loads on the building [7]. In terms of cost calculation, the cost per KW was finally completed by budgeting the prices of various materials, etc. Finally, the results of the floating platform design are sub-summarized by combining feasibility, safety, economy, and innovation.

2. Method

2.1. Design of semi-submersible wind photovoltaic power generation platform

Since the designed platform is located in the working water with a maximum water depth of 50m and other marine conditions, the semi-submersible platform is more suitable for this water than the SPAR platform in the floating platform. Therefore, this design adopts the DeepCwind three-float semi-submersible platform foundation of the OC4-5MW offshore floating wind turbine system, taking into account the factors affecting manufacturing, installation, transportation, structure, and the target sea conditions [8]. The platform foundation is connected to the photovoltaic panels, fans, and towers designed to meet the rated power to form a whole. Finally, CAD is used to establish a three-dimensional model of the floating structure.

2.2. Stability calculations

In the calculation of the initial stability, it is mainly calculated whether the center of gravity of the semi-submersible platform is lower than the floating center and whether the center of gravity of the floating platform as a whole is lower than the metacenter. There is a very close relationship between the size of the initial stability and the center of gravity G, metacenter M, and the center of buoyancy B of the offshore structure. The specific relationship is shown in the following equation (1). The center of gravity and the center of buoyancy can be calculated by equations (2) and (3), respectively.

$$GM = BM - BG \tag{1}$$

$$y = \frac{\sum M_i y_i}{M} \tag{2}$$

$$h = \frac{\Sigma h_i v_i}{v} \tag{3}$$

where, the GM is the initial stability height, the BM is the initial stability radius, and the BG is the distance between the center of buoyancy and the center of gravity (Fig. 1).

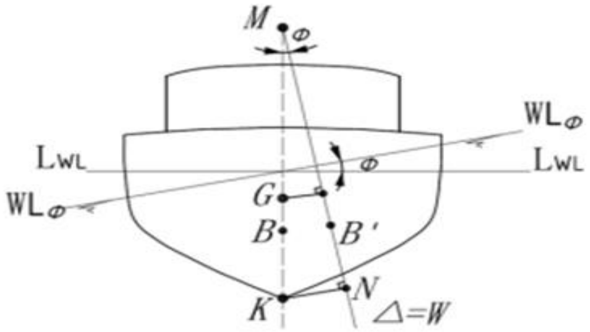

Fig. 1 Geometric characteristics of the inclined ship [9]

When the ship tilts at a certain angle $\emptyset$, when the waterline surface is moved from LL to WW, the position of the center of gravity G, the size of the buoyancy, and the magnitude of the gravity have not changed, only the position of the buoyant B is moved to the point B' position to the tilted side because the ship is tilted. Gravity and buoyancy form a moment at this time, and a set of force coupling moments opposite the inclined direction are M_R=Δ•GZ (GZ is the distance between gravity and buoyancy), which is called the recovery moment of the ship. Therefore, under the inclination angle of the initial stability, the initial stability equation can be expressed as equation (4). To determine whether the initial stability of the ship is qualified, it is necessary to calculate whether GM is greater than 0 (equations (5)-(6)).

$$MR = \Delta \cdot GZ = \Delta \cdot GM \cdot SIN\emptyset = \Delta \cdot GM \cdot \emptyset \tag{4}$$

$$|BB'| = 2|g_1 O|\frac{\nu_1}{\nabla} \tag{5}$$

$$|BM| = \frac{|BB'|}{\phi} \tag{6}$$

where, BB' is called the floating center curve, the O point is the coordinate origin, the g_1 is the distance from the inlet volume center to the origin, and the ∇ is the floating platform drainage volume.

2.3. Load calculation

2.3.1 Wind load

In this paper, the wind load on the structure is calculated using the API wind spectrum and the calculation equation is equation (7).

$$\mathrm{p} = 0.613\mathrm{C_H C_S V^2} \tag{7}$$

where, C_H is the height coefficient considering the wind pressure variation along the height, C_S is the shape coefficient considering the influence of the shape of the winding member.

2.3.2 Wave load

This section mainly uses the dispersion equation, Morrison equation, Reynolds number, and kc number derivative formula to calculate the wave load (equations (8)-(11)).

$$\omega^2 = \mathrm{gktanh}(kd) \tag{8}$$

$$f = f_D + f_I = \frac{1}{2}\rho Du|u|C_D + \frac{\rho\pi D^2}{4}\frac{\partial u}{\partial t}C_M \tag{9}$$

$$\mathrm{Re} = \frac{\mathrm{u_{max}D}}{\nu} \tag{10}$$

$$\mathrm{Kc} = \frac{u_{max}T}{D} \tag{11}$$

2.4. Cost calculation

The cost of marine engineering is to reasonably determine and effectively control the cost involved in the whole life cycle of the entire project, and to enhance the expanded scope of economic benefits under the premise of ensuring the quality and safety of the entire project. Generally speaking, the cost of offshore wind farms is mainly composed of the following parts: equipment purchase costs, construction and security costs, other fees, interest, and the difference between offshore wind power and onshore wind power is mainly reflected in equipment costs, installation fees, and operation and maintenance costs. The cost analysis of this paper mainly considers the investment costs in the project development and construction stage, that is, the equipment cost, the construction and security fee, and other costs, and calculates the corresponding cumulative calculation based on the average level of the current offshore wind power project cost in China.

3. Results and discussion

3.1. Design of a semi-submersible wind photovoltaic power platform

The floating photovoltaic wind turbine consists of three main components: the generator system, the photovoltaic system, and the base platform system. Generator set systems consist mainly of generator nacelles, hubs, fan blades, etc. Photovoltaic systems consist mainly of photovoltaic panels and their supporting platforms. The base platform system consists of supporting towers, floating platforms, etc. The specific models and dimensions are shown in Fig. 2-5.

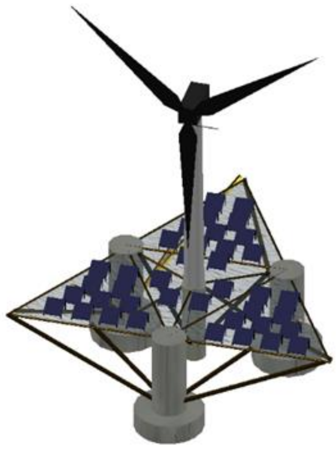

Fig. 2 Floating platform 3D concept drawing

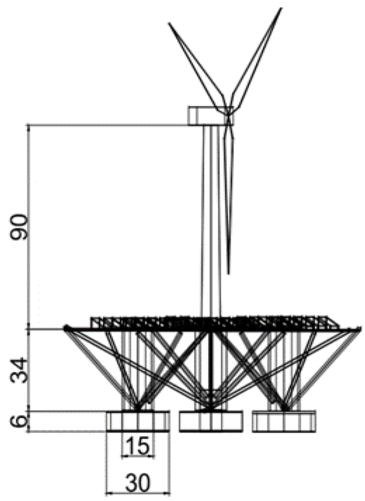

Fig. 3 Front view of floating platform

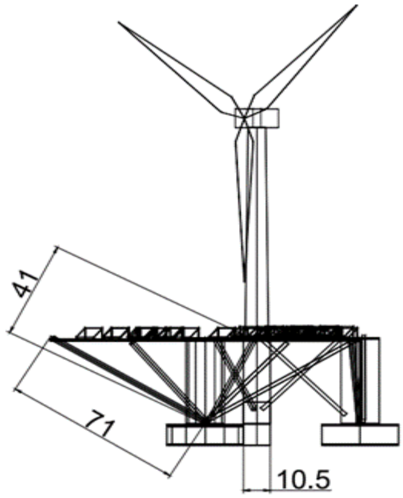

Fig. 4 Left view of floating platform

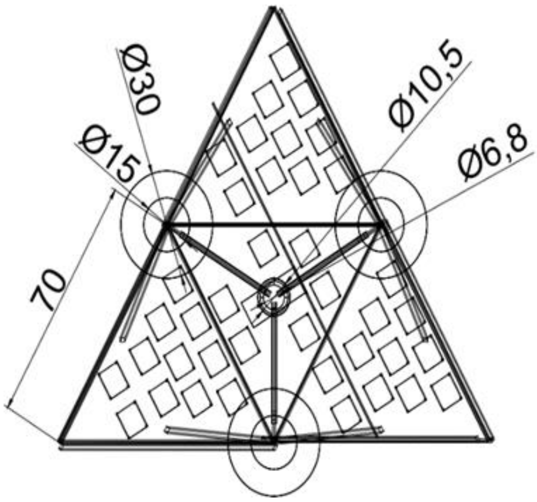

Fig. 5 Top view of floating platform

The specific dimensions are shown in Table 1-3. The wind turbine (MHIVestasV164-10.0MW) and tower parameters are shown in Table 1. Photovoltaic panel design is a design concept that combines the best economic efficiency with the prerequisite of meeting the rated power. We have therefore placed the photovoltaic panels at 30º on a square triangular platform with a side length of 170 m. The specific parameters are shown in Table 2. The main parameters of the semi-submersible platform are shown in Table 3. The used materials are DIN EN 1.4401 austenitic stainless steel. The relevant parameters are shown in Table 4.

Table 1. Wind turbine and tower parameters

Parameter name	Data	Parameter name	Data
Power rating	10. 0MW	Tower height	90 m
Impeller diameter	164 m	Diameter of the lower section of the tower	9.2 m
Blower blade length	80 m	The thickness of the lower section of the tower	0.030 m^2
Single blade weight	35 t	Diameter of the upper section of the tower	7 m
Cabin dimensions	1280 m^2	The thickness of the lower section of the tower	0.020 m^2
Cabin weight	390 t	The total mass of the tower	452,119.322 kg
Swept air area	21,124 m^2		

Table 2. Photovoltaic panel parameters

Parameter name	Data	Parameter name	Data
Weight per square meter of support truss	305.1069645kg/m^2	Total rated power	2,126,600W
Photovoltaic panels per square meter heavy	11.33kg	The total mass of photovoltaic panels	111,034kg
Photovoltaic panel area	9800m^2		

Table 3. Floating platform parameters

Parameter name	Data (m)	Parameter name	Data (m)
Platform height	40	Float diameter	15
Design draught	30	Float height	34
Float pitch	70	Float thickness	0.02
Diameter of the pressurized water bucket	30	Diameter of the center column	10.5
Pressurized water bucket height	6	Height of center column	40
Wall thickness of pressurized water bucket	0.03	Diameter of connection column	1.5

Table 4. Select material parameters

Parameter name	Data	Parameter name	Data
Modulus of elasticity	193 GPa	Density	7,950 kg/m^3
Shear modulus	77 GPa	Elongation	40 %
Yield strength	205 Mpa	Tensile strength	515 MPa

3.2. Initial stability calculation

The design water discharge of the platform is about 28044m3, the draft depth of the platform without ballast is about 3.75 m and the total mass of the platform is about 29,000 t when ballasted. The specific dimensions of the platform are shown in Table 3. For reasons of space, only the initial stability of the platform is calculated in the paper. The center of gravity and the height of the floating center in the following calculations are calculated from equations (2)-(3). The specific parameters used to calculate the high initial stability are shown in Table 5-7. The floating center without upper ballast can be calculate to be 10.91673501 m, according equation (12). The center of gravity without upper ballast can be calculated from equation (13) as 10.61843739 m. As the height of the center of gravity is already less than the height of the floating center, the platform stability condition is satisfied.

$$h = \frac{\Sigma h_i v_i}{v} = \frac{h_1 v_1 + h_2 v_2 + h_3 v_3}{v_1 + v_2 + v_3} \tag{12}$$

$$y = \frac{\sum M_i y_i}{M} = \frac{M_1 y_1 + M_2 y_2}{M_1 + M_2} \tag{13}$$

Table 5. Parameters related to topless ballast platforms

Parameter name	Data	Parameter name	Data
Design draught	30 m	Drainage volume of pressurized water buckets v_1	17,723.450 m^3
No ballast draft	3.75 m	Float discharge volume v_2	12,723.450 m^3
Drainage volume	28,044.605 m^3	Drainage volume of central column v_3	2,597.704 m^3
Floating center of pressurized water bucket h_1	3 m	Float mass M_1	919,214.293 kg
Floatation center h2	18 m	Mass of pressurized water bucket M2	1,493,916.498 kg
Centre column floating center h_3	15 m	Float center of gravity y_1	3 m
		Pressurized water bucket center of gravity y_2	23 m

Table 6. Parameters related to upper ballast platforms

Parameter name	Data (kg)	Parameter name	Data (m)
Fan mass M_4	495,000	Wind turbine center of gravity h_4	130
Tower mass M_5	452,119.322	Tower center of gravity h_5	82.938
Photovoltaic panel quality M_6	111,043	Photovoltaic panel's center of gravity h_6	40

$$h' = \frac{\Sigma M_i h_i}{M} = \frac{M_4 h_4 + M_5 h_5 + M_6 h_6}{M_4 + M_5 + M_6} \tag{14}$$

The center of gravity with upper ballast can be calculated to be 37.93002694 m, according to equation (14). At this point the height of the center of gravity is higher than the height of the floating center of the platform, then the ballast system needs to be designed in a ballast bucket so that the floating platform is selected for ballasting in plain concrete. The specific ballast forms and data are shown in Fig. 6-7 and Table 7.

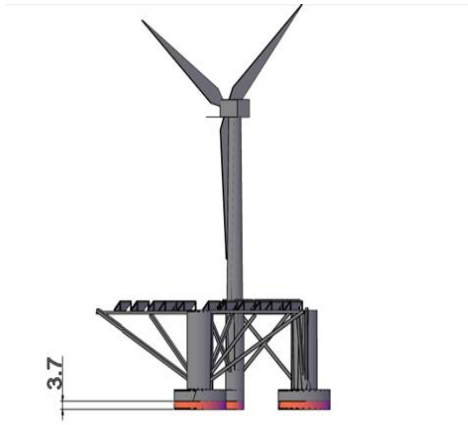

Fig. 6 Front view of floating platform.

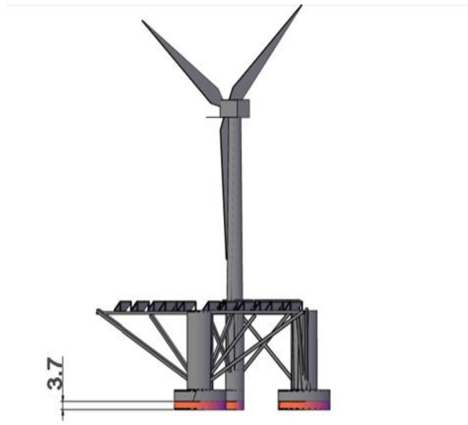

Fig. 7 Side view of floating platform

Table 7. Plain concrete and ballast parameters

Parameter name	Data	Parameter name	Data
Density	2,350kg/m^3	Volume	6,864.840m^3
Height	3.7m	Quality	16,132,374.309kg
Area	2,120.575m^2		

$$h' = \frac{\Sigma M_i h_i}{M} = \frac{M_1 h_1 + M_2 h_2 + M_3 h_3 + M_4 h_4}{M_1 + M_2 + M_3 + M_4} \tag{15}$$

From equation (15), it can be calculated that the center of gravity of the overall structure after ballasting is 7.949339488 m<h has satisfied the initial stability equilibrium condition. Calculation of initial stability height: By importing the 3D model of the built floating platform directly into CAD,

$g_1 O$ is 67.5 m, v1 is 1445.38037 Φ can be calculated by setting the inclination angle, platform draft height, and other parameters. Taking into equations (5) and (6) respectively, BM was 1.163350 m and BG is -2.967395522 m. Further, the GM is greater than 0, therefore this offshore floating platform has good initial stability to meet the working requirement conditions after the ballasting design.

3.3. Load calculation

3.3.1 Wind load

The wind load acting on the offshore platform structure can be calculated according to equation (16).

$$\mathrm{F} = \mathrm{p} \times \mathrm{A} \tag{16}$$

where, p is the wind pressure on the surface of the wind-bearing member in N/m^2; A is the projected area of the member perpendicular to the wind direction, in m^2. F is the wind force acting on the member, in N.

The calculation of wind pressure p is usually based on the basic wind pressure value p_0 selected according to a certain standard height and shape, and then corrected for the variation of wind pressure along the height and shape of the winding member. Take g is 9.8m/s^2. γ is the weight density of air, taking γ is 12.01N/m^3, and v is the design wind speed, this takes 20 m/s. Then the wind pressure p can be expressed as equation (7). CH is the height coefficient considering the wind pressure variation along the CS is the shape coefficient considering the influence of the shape of the winding member.

Table 8. Height factor CH [10]

Height above sea level(m)	C_H
0-15.3	1.00
15.3-30.5	1.10
30.5-46.0	1.20
46.0-61.0	1.30
61.0-76.0	1.37
76.0-91.5	1.43
91.5-106.5	1.48
106.5-122.0	1.52
122.0-137.0	1.56
137.0-152.5	1.60
152.5-167.5	1.63
167.5-183.0	1.67
183.0-198.0	1.70

According to the mobile platform data specification of CCS, ABS, and LR (Table 8), a rough calculation is made by taking the CH value in segments. When the wind speed at sea is 20 m/s, the total wind pressure on the offshore building is 349,609.822N. The wind load on the unit is 274.6604723 N/m^3.

3.3.2 Wave load

Via the dispersion equation (8), The calculated wavelength L in this area is about 151.1627289 m [11]. The diameter D of the submerged part of the building is 30m and 15m respectively, satisfying D/L<0.2. Using Morrison's equation (15), the wave force per unit area is analyzed by equation (9) [12]. Via equation (17), the u_{max} can be calculated as 2.513274123 m/s, taken at 10°C seawater motion viscosity coefficient ν is 1.3563×10^{-6} m^2/s, with the two diameters number substituted into the Reynolds number calculation formula (10) and output 5.76439019×10^7 and 2.882195095×10^7 respectively. Compare with Fig. 8, it can be obtained that C_D≈1.

$$u_{max} = \frac{\pi H}{T} \tag{17}$$

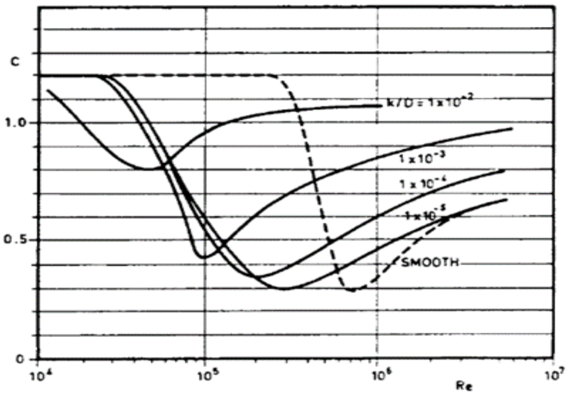

Fig. 8 Relationship between Reynolds number and C_D [13]

Calculate by equation (11). The values of Kc are 0.837758041 and 1.675516082, both of which are less than 3, so C_A is 1, and C_M is 2 due to $C_A+1=C_M$ [13]. Because the diameter of the float and the diameter of the pressure bucket are different, resulting in the coefficient shown in Table 9. When calculating the velocity and acceleration of water points, Wheeler-stretching is adopted due to its flexibility, which is shown in equations (18)-(19). The force of the wave load on the unit can be shown as equation (20). The integral equation in the longitudinal direction is as equation (21). Using MATLAB, the result is shown in Fig. 9.

$$u = \frac{gkA}{\omega} \frac{\cosh\left(ks \frac{d}{d+\eta}\right)}{\sinh kd} \cos(\alpha) \tag{18}$$

$$a = \frac{2\pi^2 H}{T^2} \frac{\cosh\left(ks \frac{d}{d+\eta}\right)}{\sinh kd} \sin(\alpha) \tag{19}$$

$$f = f_I + f_D = C_M A_I a + C_D A_D u|u| \tag{20}$$

$$F = \int_{20}^{\eta} (f_I + f_D)\, dS \tag{21}$$

$$\eta = 4\cos(\alpha)$$

Table 9. Different coefficients corresponding to different diameters

A_{I1}/ kg/m^2	A_{I2}	A_{D1}/ kg/m^2	A_{D2}
724,529.8057	181,132.4514	15,375	7,687.5

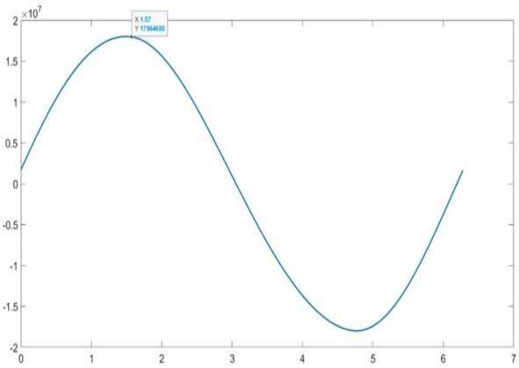

Fig. 9 Calculation results of Morrison force. The horizontal axis is the phase angle/rad and the vertical axis is the Morrison force magnitude/N.

4. Cost budget

4.1. Structure form and design

The form of this structure adopts a three-column structure plus a middle column and adds a tower and a fan above the middle column, and a positive triangle of 140 m is connected by a truss above the three columns, and the photovoltaic panels are laid in this area, and the angle and horizontal surface of each photovoltaic panel are 30°, which greatly improves the photovoltaic area. Underneath the photovoltaic panels, the structure is connected by trusses, supporting the entire structure.

4.2. Materials and Costs

The structural materials of this time mainly consider concrete, DIN EN 1.4401 austenitic stainless steel, and then use the extreme 670 W TSM-DEG21C.20 photovoltaic panels and MHIVestas V164-10.0 MW wind turbines in the device selection. By selecting the model, the photovoltaic panels provide 2 MW while the wind turbine provides 10 MW.

In terms of cost, the following aspects were considered this time: tower processing, equipment procurement, survey and design, inspection and operation and maintenance, engineering construction, wind power supervision, wind power technical transformation, wind power environmental protection, wind power services, and spare parts. First of all, according to the various materials, we roughly derive the following budget results as shown in Table 10. In addition, the labor cost is calculated according to be 3,500 RMB/KW, and the final total estimate is 58,573.78009 RMB/KW.

Table 10. Cost estimate

Material	Model	Unit cost	Quantity	Total cost
Photovoltaic panels	Supreme 670 W TSM-DEG21C.20	2,000 RMB/m^2	9,800 m^2	19,600,000 RMB
Wind turbines	MHIVestas V164-10.0 MW	10,000 RMB/KW	1	
Concrete	Concrete	550 RMB/m^3	6,864.8401m^3	3,775,662.055 RMB
Steal	DIN EN 1.4401 Austenitic stainless steel	17,000 RMB/t	30,441.747 t	517,509,699 RMB
Cost per kW	55,073.78009 RMB/KW			

5. Conclusion

In marine engineering, the semi-shallow platform on the wave movement response is very small, to combine green clean solar energy and wind energy, this paper sets up a three-column structure and adds a middle column in the middle, connected by trusses, forming 4 positive triangle platforms for placing photovoltaic panels, and tilting the photovoltaic panels 30° to increase the photovoltaic area, while adding a tower above the middle column and installing a fan to form a floating offshore structure of wind and solar power generation. During the design phase, the exterior design of the structure, including materials, dimensions, the spatial layout of fans, and photovoltaic panels, was carried out, and the entire structure was 3D modeled and rendered by CAD. Secondly, based on the various conditions of the sea wind and waves, the calculation of wind load and wave load was carried out, and then the stability of the structure was also analyzed and verified according to various modeling data, and finally, the wind load and wave load were estimated to be 3.5 million N and 50 million N, respectively, and the center of gravity height was less than the floating center height in the initial stability test, which met the platform stability conditions. In the end, through the search for relevant information, the material price, labor price, etc., the cost budget was carried out, and the final rough estimate per KW was 58,500RMB, which was in line with the economy, safety, and feasibility of the structure. There are also some shortcomings in this design, such as the calculation of the wave load is only an approximate result, and the cost is only a rough estimate. In the future, it is possible to make more accurate improvements in the calculation of loads, and the control of prices can be more accurately estimated through more on-site.

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