Load calculation and strength analysis of floating garbage cleaning equipment

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Abstract. In order to alleviate the problem that there is increasingly floating garbage pollution on the sea, this paper proposes a new design of floating garbage cleaning equipment. This equipment is a slender structure, and whether its structural strength can meet the design requirements requires special attention. In order to ensure the rationality and safety of the design, load calculation and strength analysis are carried out based on the design wave method. The calculation results show that the longitudinal torque load of this equipment is the largest, which is 2.5 times of the second largest vertical bending moment. At the same time, there are three large stress areas in the floating structure, which are the connection between the pontoon and the connecting buntons, the connecting buntons intersecting with the Y axis and the pontoons on both sides. For the above-mentioned high-stress areas, a structural strengthening plan is proposed. After the improvement, the stress in the high-stress areas of the structure is significantly reduced, with a maximum reduction of 52%. The strength of the improved structure meets the design requirements. The research results of this paper can provide relevant references for the development of floating garbage cleaning equipment in the future.

1 Introduction

In recent years, floating garbage on the sea, one of the main pollutants that threats both human living environment and marine environment, has become more and more serious ^[1]. It is inefficient and costly to use ships to salvage floating garbage pollution on the sea. As a result, it is urgent to develop garbage cleaning equipment. This paper introduces a new type of offshore floating garbage cleaning equipment.

According to the different salvage methods, the existing floating garbage cleaning equipment can be categorized as 4 types: conveyor belt, bucket, rotary and grab type. Niramon Ruangpayoongsak designed a type of garbage cleaning equipment for the catamaran, he added a conveyor belt to the catamaran and garbage collection nets on both sides of the catamaran^[2]. The garbage is collected to the catamaran by mechanical arms. Zhongli Wang designed a garbage cleaning equipment based on a quadrimaran, and its recycle device is composed of conveyor belt^[3]. Through numerical analysis, the calculation of hydrodynamic performance and the analysis of the control system have been completed, which provides a basis for the trial. Zhang H T designed a new structure of garbage cleaning equipment based on catamaran and conducted strength analysis^[4]. In addition to the equipment mentioned above, the "Ocean Cleanup 001" manufactured by The Ocean Cleanup Company is an arc-shaped floating tubular structure of approximately 600 meters in length, composed of multiple 1.2meter diameter pipes. The system was analyzed for hydrodynamics and structural strength by the Ocean Cleanup, and its capture

efficiency was analyzed in offshore tests^{[5].}

Based on a new type of floating garbage cleaning equipment proposed by Chunyan JI and Renchuan YE^[6], wave load calculation and structural strength analysis are performed on it through numerical simulation in this paper. The results of the study can provide a basis for the future design of floating garbage cleaning equipment.

2 Theoretical foundation

2.1. Wave load calculation method

Morison's formula^[7], which is usually used to calculate wave loads on slender structures, it is a semi-theoretical and semi-empirical formula based on the theory of flow. The theory of flow assumes that the floating body structure has no significant effect on the waves, and that additional mass effects and viscous effects are the main effects of wave loads on the floating body. Therefore, the Morrison equation is used to calculate the structural wave forces without considering the diffraction forces due to wave loads, and the inertial and drag forces are only considered.

A cylindrical object, located at the bottom of the sea at a water depth of d. When the incident wave transmits in the x-positive direction and the wave height is H, the horizontal wave force acting on the unit column height at any height of the cylindrical object is:

$$f_H = f_D + f_L = \frac{1}{2} C_D \rho A u_x \left| u_x \right| + \rho V_0 \frac{\mathrm{d}u_x}{\mathrm{d}t} + C_m \rho V_0 \frac{\mathrm{d}u_x}{\mathrm{d}t}$$

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2.2. Structural strength analysis method

The wave load on floating garbage cleaning equipment is closely related to wave height, period, phase, and wave direction, there are many different combinations of these factors during the use of floating garbage cleaning equipment. Therefore, when conducting the overall strength analysis of floating garbage cleaning equipment, multiple force states of the equipment need to be analyzed^[8]. The maximum regular wave within fifty years was used as the design wave height, and Sesam/Wadam was used to calculatewave loads on the floating garbage cleaning equipment under each typical operating condition. The calculated wave loads are transferred to the floating garbage cleaning equipment through Sesam/sestra to obtain the overall stress distribution of the structure^[9]. The strength analysis process of the floating garbage cleaning equipment is shown in Fig.1.



Fig. 1. Overall strength analysis process of floating garbage cleaning equipment

3 Scheme and parameters of floating garbage cleaning equipment

As shown in Fig.2, floating garbage cleaning equipment is a semi-circular structure composed of pontoons and connecting buntons. Each two adjacent pontoons are connected by several groups of connecting buntons, and each group of connecting bunton consists of four independent bunton. The net is arranged behind the connecting buntons in order to collect the garbage. The garbage removal equipment is fixed at a certain place by mooring, and when the wave direction changes, the floating garbage cleaning equipment can rotate with it.



Fig. 2. Floating garbage cleaning equipment

Table 1. Parameters of floating garbage cleaning equipment

Parameter	Size	Unit
Radius	200	М
Diameter of pontoon	2	М
Diameter of independent bunton	0.2	М
draft	1	М
Number of pontoons	14	-

4 Load calculation of floating garbage cleaning equipment

4.1. Geometric model

According to the main parameters mentioned above, the geometric model is established through Sesam/GeniE as shown in Fig. 3, with a partial enlargement of the model in the box in the figure.



Fig. 3. Geometric model

4.2. Coordinate system

The coordinate system of the floating garbage cleaning equipment is shown in Fig. 4. When the wave spreads along the positive X-axis, the wave direction is 0° . When the wave spreads along the positive Y-axis, the wave direction is 90° .



Fig. 4. Wave direction definition

4.3. Hydrodynamic model

The finite element model of the floating garbage cleaning equipment consists of pontoons and connecting buntons, where each pontoon adopts a 2m mesh as shown in Fig. 5(a) and the connecting bunton adopts a 0.5m mesh as shown in Fig. 5(b).



Fig. 5. Hydrodynamic finite element model

4.4. Motion response

In order to study the effect of different wave directions and different periods of waves on the motion response of floating garbage cleaning equipment. Referring to the DNV specification^[10] and considering the symmetry of the structure about the Y-axis, the wave direction range from -90° to 90° with a step of 30°, and the wave period range from 1s to 25s with a step of 1s to calculate the motion response of the floating garbage cleaning equipment through Sesam software.

As shown in Fig.6, the motion response is more sensitive in the range of wave period 2 to 15 s. After 15 s, the motion response amplitude becomes larger with the increase of wave period, and the change rate tends to be flat. Surge RAO (Fig.6(a)), Heave RAO (Fig.6(c)), and Roll RAO (Fig.6(d)) all reach the maximum value at the wave period of 20 s. Heave RAO (Fig.6(c)) and Pitch RAO (Fig.6(e)) are more sensitive to the change of wave direction.





Fig. 6. RAO of floating garbage cleaning equipment

4.5. Calculation of section load

In order to more accurately predict load values to which the floating garbage cleaning equipment is subjected, nine computational sections along the x-axis of the equipment are selected as shown in Fig.7. The longitudinal force, transverse force, vertical force, longitudinal torque, vertical wave moment and horizontal bending moment of the calculated1~9 are used as the basis for calculating design wave parameters^[11]. The calculated results of longitudinal force, transverse force, vertical force, longitudinal torque, vertical wave moment and horizontal moment for the nine sections are shown in Fig.8. The maximum longitudinal force, maximum lateral force, maximum vertical force, maximum longitudinal torque, maximum vertical wave moment and maximum horizontal wave moment are taken as the main control parameters for profile loads, long-term forecast and design waves.



Fig. 7. Cross-section position



(b) Lateral force



Fig. 8. Different section forces/section bending moments

From Fig.8, it can be seen that: the longitudinal force and the transverse force reach their maximum values in section 9 and section 7, respectively. The vertical force, longitudinal torque, and vertical bending moment reach their maximum values in section 5, and the horizontal bending moment reaches their maximum values in section 8.

The maximum longitudinal force, maximum lateral force, maximum vertical force, maximum longitudinal torque, maximum vertical wave moment and maximum horizontal bending moment are shown in Table 2.

Section load	Periodicity	Wave direction	Maximum value
Longitudi nal force	3 s	60 °	2.12×10 ⁵ N/m
Lateral force	2 s	-90 °	2.2×10 ⁵ N/m
Vertical force	15 s	0 °	5.32×10 ⁵ N/m
Longitudi nal torque	16 s	0 °	1.49×10 ⁸ N·m/m
Vertical bending moment	12 s	90°	3.57×10 ⁷ N·m/m
Horizontal bending moment	3 s	90°	$2.37 \times 10^7 \mathrm{N \cdot m/m}$

Table 2. Maximum value of load in different sections

4.6. Long-term forecast

The significant wave height in the working area of the floating garbage cleaning equipment is 9 m, and the wave period is 12 s. In the long-term forecast, the Jonswap spectrum is used to fit the long-term sea state, and the wave elevation factor is taken as 2.

Table 3 shows the long-term forecast values for each section load selected according to DNV specifications.

Table 3. Long-term forecast values for different section loads

Response Period /a	50
Longitudinal force	6.33×10 ⁵ N
Lateral force	5.3×10 ⁵ N
Vertical force	3.93×10 ⁶ N
Longitudinal torque	6.93×10 ⁸ N⋅m
Vertical bending moment	2.72×10 ⁸ N⋅m
Horizontal bending	5.77×10 ⁷ N·m
moment	

4.7. parameters of design wave

The design wave amplitude is the long-term forecast value divided by the maximum value of the corresponding section load response, and the wave direction, period, and phase are the same as the maximum value of the corresponding section load. The design wave parameters for each typical operating condition are shown in Table 4.

Fable 4. Typ	oical working	condition	design	waves
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Typical working conditions	Period	Wave amplitude	Wave directions	Phases
Longitudinal force	3s	2.99m	60 °	41.6°
Lateral force	2s	2.41m	-90 °	-102.6 °
Vertical force	15s	7.39m	0 °	94.4°
Longitudinal torque	16s	4.65m	0 °	-20.2 °
Vertical bending moment	12s	7.62m	90°	92.3 °

Horizontal bending	3s	2.43m	90°	-20.2 °
moment				

5 Calculation and result analysis of overall strength

5.1. Calculation and analysis of overall strength of equipment before improvement

The combined wave conditions are shown in Table 5.

Table 5.	Wave	combination	working	conditions

Combined working conditions	Description of working conditions
Lc101	Hydrostatic working condition + Longitudinal force working condition
Lc102	Hydrostatic working condition + Transverse force working condition
Lc103	Hydrostatic working condition + Vertical force working condition
Lc104	Hydrostatic working condition + Longitudinal torque conditions
Lc105	Hydrostatic working condition + Vertical bending moment condition
Lc106	Hydrostatic working condition + Horizontal bending moment condition

According to the above wave combination conditions, the parameters were input into Sesam/sestra to obtain the maximum stress values and stress distribution for each operating condition of the floating garbage cleaning equipment. Table 6 shows the maximum von mises stress values at critical locations of the equipment. Fig.9 shows the stress contour of the equipment under the most dangerous working conditions, and Fig.10 shows the enlarged view of the high stress area. Table 7 shows the location of the high stress area and the maximum stress value.

 Table 6. Maximum von mises stress value at critical locations of equipment

Work conditions	High stress area 1/Mpa	High stress area 2/Mpa	High stress area 3/Mpa
Lc101	628	423	659
Lc102	604	347	556
Lc103	356	322	483
Lc104	415	362	642
Lc105	375	428	569
Lc106	511	435	703

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Fig. 9. Overall von mises stress contour



Fig. 10. High stress region von mises stress contour

Table 7. Location a	and maximum	value of h	igh stress areas

Number	Location	Maximum stress value
High stress area 1	pontoon	628 Mpa
High stress area 2	Connecting buntons	435 Mpa
High stress area 3	The connection between pontoon and Connecting buntons	703 Mpa

The study used the Von Mises for the overall strength assessment^[12]. From Table 6 and Table 7, Fig.9 and Fig.10, it can be seen that:

(1) The floating garbage cleaning equipment is subject to uniform stress distribution, but there are high stress areas at certain areas, as shown in Table 7.

(2) Maximum stress value of 628Mpa in high stress region 1, Maximum stress value of 435Mpa in high stress region 2, Maximum stress value of 703 Mpa in high stress region 3.

5.2. Structural improvement and overall strength analysis

5.2.1 Improvement of structure

According to the calculation results of the overall strength of the equipment, the improvement plan is proposed for the high stress area as shown in Table 8, and the specific measures are shown in Figure 11.

	-		
Number	Description of improvement	Structure	
Number	methods	Diagram	
High stress	Pontoon structure with	11(-)	
area 1 additional reinforceme		11(a)	
High stress	h stress Connecting buntons from the 4		
area 2	area 2 buntons to 8 buntons structure		
High stress area 3	The direct connection between		
	the Connecting buntons and the	11(c)	
	pontoon is changed to a flared		
	connection to increase force		
	area.		



11(c)

Fig. 11. Specific improvement measures

5.2.2 Analysis of overall strength

Table 9 shows the maximum stress value of the improved floating garbage cleaning equipment, Fig.12 shows the stress contour diagram of the improved floating garbage cleaning equipment, and Fig.13 shows the local enlarged diagram of the high stress area.

Table 9.	Maximum	von mises	stress in	critical	areas	after
	stru	uctural imp	proveme	nt		

Work conditions	High stress area 1/Mpa	High stress area 2/Mpa	High stress area 3/Mpa
Loc101	322	317	321
Loc102	302	280	329
Loc103	281	297	268
Loc104	306	326	312
Loc105	294	332	318
Loc106	324	325	335



Fig. 12. Improved overall von mises stress contour



Fig. 13. Improved von mises stress contour in high stress region

From Table 9, Fig.12 and Fig.13, it can be seen that:

(1) The overall strength of the improved structure of the floating garbage cleaning equipment meets the design requirements. The comparison with the calculation results before the improvement shows that the stress value in the high stress area is significantly reduced.

(2) The maximum stress value of the pontoon is 306 Mpa, and the stress value of the pontoon is significantly reduced, with a 26% decrease in the maximum stress; this is the structural strength result with reinforcement of the pontoon. The maximum stress values at the connecting bunton and the connections between the pontoon and the connecting bunton are 332Mp and 335Mp respectively. the maximum stress is reduced by 22% and 52%.

6 Summary

This paper introduces a new type of floating garbage cleaning equipment. Wave load forecasting and strength analysis are also carried out. The following conclusions were obtained from numerical calculations and theoretical analysis:

(1) The load calculation results of the floating garbage cleaning equipment show that it is subjected to the largest value of longitudinal torque, followed by the value of vertical bending moment, the longitudinal torque value is 2.5 times the vertical bending moment.

(2) The overall stress distribution of the floating garbage cleaning equipment is basically uniform, but there are some high stress areas, mainly at the connection between the pontoon and the connecting bunton, the connecting bunton intersecting with the y-axis and the pontoon on both sides of it.

(3) The maximum stress value of the pontoon is 306 Mpa, and the stress value of the pontoon is significantly lower than that before the improvement, with a 26% decrease in the maximum stress; this was the structural strength result with reinforcement of the pontoon. The maximum stress values at the connecting bunton and the connections between the pontoon and the connecting bunton are 332Mp and 335Mp respectively. The maximum stress is reduced by 22% and 52%.

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