Fatigue strength analysis of desilting platform structure

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Abstract—In order to ensure the fatigue reliability of the dredging platform and key equipment structure, the fatigue of the platform is analyzed by using the analysis method based on S-N curve and fatigue cumulative damage criterion. Firstly, according to the wave characteristics of the Pearl River Basin, the periodic load of the dredger is calculated by using hydrodynamic analysis tools. Then, the fatigue life of dangerous parts is analyzed by using cumulative damage theory and S-N characteristic curve. The results show that the joint of desilting equipment and conveying device is easy to suffer fatigue damage, and the fatigue life limit is 2328h, and the other equipment and structure meet the fatigue requirements.

1. Introduction
With the increase of the number of marine engineering facilities, the special installation and dredging operation equipment for underwater structures has become a research hotspot in the world. Desilting platform is a new type of high efficiency and large displacement operation platform. Due to the complex water flow in the Pearl River Basin, the structural fatigue reliability of desilting equipment is challenged. At the same time, due to the rapid development of dredging operation platform in recent years, there is a lack of in-depth research on dredging operation platform and relevant experience in China. Therefore, it is of great theoretical value and practical significance to study the structural fatigue of dredging platform to ensure the safety of dredging platform.

2. Fatigue analysis method of dredging platform

2.1. Basic principle
When the dredging platform works in the Pearl River Basin, it is in the state of single point mooring. In the hydrodynamic analysis of the platform, the selection of environment and wave load has a great influence on the hydrodynamic analysis results. Environmental and wave loads mainly include wind load, wave load and current load. Due to the large energy magnitude of wave load, the wave frequency motion under wave frequency load is mainly considered in the hydrodynamic analysis of the platform [1]. In this paper, the fatigue analysis of the platform is carried out based on the spectral analysis method. Firstly, according to the wave load, the load response of the dredging platform under the working state is calculated by using the hydro-dynamic analysis tool. Then, the finite element analysis software is used to refine the platform locally, and the wave load under different wave directions is applied on the finite element model to obtain the stress response. Finally, the fatigue analysis results of the platform are obtained according to the S-N characteristic curve of the material.
2.2. Wave loads

2.2.1. Wave spectrum selection

Waves are random in time and space. In order to describe them conveniently, wave spectrum is usually used. JONSWAP [2] wave spectrum is obtained from a large number of measured statistical data in the United Kingdom, the United States and other countries, and is often used in the hydrodynamic analysis of structures

\[
S_h(\omega) = \frac{0.78}{\omega^2} \exp \left( -\frac{3.11}{H^2 \omega^4} \right) \exp \left[ \frac{(\omega - \omega_{\max})^2}{2\sigma \omega_{\max}^2} \right]
\]

(1)

where, \( \gamma \) — the factor of peak elevation can be taken as 3.3; \( \omega_{\max} \) — peak frequency; \( \sigma \) — the peak coefficient can be determined by the following formula:

\[
\sigma = 0.09 \quad \omega > \omega_{\max}
\]

\[
\sigma = 0.07 \quad \omega \leq \omega_{\max}
\]

2.2.2. Calculation of wave force spectrum

At present, Morrison formula is usually used to calculate the wave load acting on the platform. Morrison formula is a semi theoretical and semi empirical formula based on the theory of flow around. When the ratio of platform width \( D \) to wavelength \( L \) is small and satisfies \( D/L \leq 0.15 \), it can be considered that the wave field will not be affected by the platform. Morrison formula divides the wave force \( F \) of the platform into two parts: inertial force \( F_D \) and velocity force \( F_I \) [3].

Inertial force \( F_D \) is an inertial force generated by the water flow which is blocked by the platform, and the space occupied by the platform changes from motion to stillness. The value of inertia force is equal to the mass of this part of water multiplied by its acceleration. The mass is achieved by multiplying the mass acting on the platform by an inertia force coefficient \( C_m \), and the calculation of the inertia force is as follows:

\[
F_D = C_m \rho D^2 \frac{\partial u}{\partial t} \Delta Z
\]

(2)

Where: \( C_m \) is the inertia force coefficient, \( \frac{\partial u}{\partial t} \) is the horizontal acceleration, and \( \rho \) is the density of the fluid.

The velocity force \( F_I \) is the surface friction produced by the flow of undisturbed wave velocity field on the platform surface. Due to the influence of viscosity, there is a boundary layer near the platform surface, and the flow velocity in the boundary layer becomes smaller due to the influence of the boundary, so the friction force is generated at the platform boundary, which is proportional to the square of the flow, as follows:

\[
F_I = C_d \frac{\rho}{2} D u^2 \Delta Z
\]

(3)

Where: \( C_d \) is the velocity force coefficient and \( u \) is the flow velocity.

Then the total wave force \( F \) acting on the unit height is:

\[
F = F_D + F_I = C_m \rho D^2 \frac{\partial u}{\partial t} + C_d \frac{\rho}{2} D u^2
\]

(4)

According to Airy linear wave theory, the flow velocity and horizontal acceleration are determined, and the wave force on the whole platform can be obtained by calculating along the height direction of the platform.

2.3. Cumulative damage theory

When the dredging platform works in the Pearl River area, it is subjected to random loads such as wind, wave and current. The fatigue damage of the structure under alternating loads is a cumulative process.
The total fatigue damage can be obtained by accumulating the fatigue damage caused by different amplitude stress cycles according to the appropriate principle. When the total fatigue damage degree of the structure reaches a limit, the fatigue damage will occur. The fatigue cumulative damage theory is one of the basis for the fatigue analysis of offshore structures.

Miner's linear cumulative damage theory [4] has been widely used in structural fatigue life analysis because of its simple calculation and its ability to meet most engineering applications. The fatigue damage $D_i$ caused by the stress cycle in a certain stress range is equal to the ratio of the actual number of cycles $n_i$ of the stress range acting on the structure and the number of cycles $N_i$ required for the structure to achieve fatigue failure under constant amplitude alternating action in the stress range. Assuming that the stress range level is $m$-level, then:

$$D = \sum_{i=1}^{m} D_i = \sum_{i=1}^{m} \frac{n_i}{N_i}$$

When the structure is damaged by fatigue, the cumulative fatigue damage degree $D$ should be equal to 1. Because miner's theory does not consider the influence of load sequence and other factors on the fatigue life of the junction, $D$ is not necessarily equal to 1. In general, high low load $D<1$, low high load $D>1$, and random fatigue load $D$ is near 1.

2.4. $S$-$N$ curve
The fatigue analysis is carried out by using the $S$-$N$ curve obtained from the fatigue test. The number of stress cycles $N$ required for the structure to reach the fatigue failure under the cyclic action of the alternating stress range $S$ is the fatigue strength index of the structure. The $S$-$N$ curve used by marine equipment is a double logarithm $S$-$N$ curve:

$$\lg N = \lg A - m \lg S$$

Where, $S$ is the range of alternating stress, $N$ is the fatigue life, and $m$ and $A$ are the parameters of fatigue test.

The $S$-$N$ curve of common carbon steel material used in desilting equipment in double logarithmic coordinate system is shown in Fig 1. It can be seen from the curve that when the number of cycles reaches $10^6$, the fatigue limit will not change and can be regarded as infinite life.

![Fig 1](characteristic_curve_of_common_carbon_steel.png)

3. Fatigue analysis of dredging platform

3.1. Simulation model establishment
The main scale parameters of the dredging platform used in the simulation calculation are shown in Table 1. The dredging platform is mainly composed of four parts: hull, mobile device, conveying device and desilting equipment. The flange plate of desilting equipment is connected with the expansion column of the conveyor by bolts. In order to avoid the convergence of the finite element analysis because of the large grid model, the simulation platform model is simplified and the equivalent model as shown
in Fig 2 is established. The distribution of the volume, center of mass and mass of the model and the real object is the same, which ensures the consistency of the mechanical properties between the equivalent model and the platform structure.

### Table 1  Main dimension parameters of dredging platform

| Parameters       | data     |
|------------------|----------|
| Length           | 60m      |
| Width            | 60m      |
| Depth            | 237.6m   |
| Waterline length | 12m      |
| Design draft     | 7.3m     |
| Displacement     | 26000t   |

![Mobile device]

**Fig 2**  Equivalent 3D model of dredging platform

#### 3.2. Wave load calculation of platform based on hydrodynamic force

In order to simulate the effect of wave load on the platform, a finite element model for hydrodynamic analysis of the platform is established. The waves with incident angles of 0°, 45°, 60°, 90°, 120°, 135°, 180°, and periods of 2s ~ 16s are selected for hydrodynamic analysis and calculation. According to the statistical data of the Pearl River current, the wave parameters are shown in Table 2, where T is the period, $H_s$ is the significant wave height, and $\lambda$ is the wavelength.

### Table 2  Wave parameters[5]

| T/s | $H_s$/m | $\lambda$/m |
|-----|---------|--------------|
| 2   | 0.96    | 6.24         |
| 4   | 1.56    | 21.67        |
| 6   | 2.14    | 56.15        |
| 8   | 3.45    | 98.23        |
| 10  | 5.10    | 160.03       |
| 12  | 7.68    | 226.45       |
| 14  | 10.17   | 310.72       |
| 16  | 14.56   | 400.19       |

By setting wave parameters and incident angle, the wave force on the platform surface can be obtained by simulation, and then the bending moment on the platform can be obtained by integrating the wave force [6-7]. The bending moment load spectrum of rolling and pitching obtained by hydrodynamic simulation is shown in Fig. 3.
3.3. Static analysis of platform
The main material of dredging platform is ordinary carbon steel with yield strength of 345MPa. It can be seen from the load spectrum that the platform bears the maximum load when the wave incidence angle is 120° and the six degrees of freedom load of the dredging platform is obtained by the hydrodynamic simulation of the wave incidence angle.
- Roll: 128926 N•m; Pitch: 102647 N•m; Yaw: 19441 N•m;
- Surge: 8610 N; Sway: 6691 N; Heave: 1548 N;

The above loads are the maximum loads of the platform in the same wave cycle when the incident angle of the wave is 120° and they are applied to the finite element model of the platform for strength check. The stress distribution nephogram of the platform is shown in Fig 4.

From the stress cloud chart, it can be concluded that the stress concentration of the dredging platform under wave load is distributed in the connection part of the flange plate of the dredging equipment and the telescopic column bolt of the conveying device, and the maximum stress value is 146.15mpa, which is the most vulnerable part of the platform structure, so further fatigue analysis is needed for this part.

3.4. Fatigue life analysis of platform structure
In this paper, Fatigue tool fatigue analysis module in Workbench is used. According to the material S-N curve and load spectrum, the nominal stress method is used to perform fatigue analysis on the platform structure [8]. The calculation results of fatigue life and safety factor are shown in Fig 5. The calculated fatigue life of the joints of the dredging equipment under the action of wave loads in different incident directions is shown in Table 3.
Fig 5  Cloud diagram of fatigue life and safety factor of the joint between dredging equipment and conveying device under the action of 120° wave direction.

| Wave direction | 0° | 45° | 60° | 90° | 120° | 135° | 180° |
|---------------|----|-----|-----|-----|------|------|------|
| Cycle         |    |     |     |     |      |      |      |
| Fatigue life/h| 3478 | 4830 | 2573 | 3160 | 2328 | 4720 | 3390 |

It can be seen from Fig. 5 and table 3 that the joint between the flange of dredging equipment and the telescopic column of conveying device is prone to fatigue failure. Under the action of wave load with incident angle of 120°, the shortest life is 2328 h. Therefore, when the total working time of the dredging platform reaches 2000 h, the flange of the dredging equipment should be checked for fatigue damage to ensure the continuous and stable operation of the platform.

4. Conclusion
Through the fatigue analysis of the dredging platform, the following conclusions can be drawn.

1) By setting the wave conditions of different periods and incident angles, the load spectrum of the platform structure is obtained based on the hydrodynamic analysis module of workbench software.

2) Through the stress analysis of the platform structure, it can be seen that the joint between the flange of the dredging equipment and the telescopic column of the conveying device is the most prone to fatigue failure.

3) Through the analysis, the shortest fatigue life of the connection between the platform structure and the dredging equipment flange and the telescopic column of the conveying device is 2328h, which provides an effective reference for the maintenance and improvement of the platform.

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