Study on the determination method of the ship construction window period

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Abstract: With the development of major engineering such as offshore deep-water ports, marine energy exploitation and open sea reefs, ocean engineering has gradually distracted its attention from coastal areas to offshore areas of open seas. Offshore construction faces unfavourable challenges including severe weather conditions, great difficulty in construction and high cost in project scheduling. It is important to organize the process in an efficient way during the operation window for ships. In this study, physical model tests are conducted to investigate the motion characteristics of large-scale construction ships. Based on the field data of certain sea area, statistical analysis are performed to find the suitable operational conditions for the ships. The results show that auxiliary measures of seakeeping improvement can be taken to short the non-operational time of the ship and extend the operation window of ships.

1. Introduction

In recent years, with the construction of numerous mega projects, China has made significant progress in long-span bridges, large-scale tunnels and offshore construction and gained considerable construction experience. With the construction of the project in the open sea, the environment becomes more and more complex and changeable. Various kinds of high-tech and specialized construction ships and equipment have been developed and widely applied to meet the construction requirements in offshore environment. Reasonable and efficient use of the construction window would not only ensure the construction safety, but also reduce the scheduling costs and improve the operation efficiency of the equipment. To date, the majority of researches on the operation window of ships are focused on ship loading and unloading operations\cite{1}\cite{2}. The limit values of wind, wave, current and other impact factors have been stipulated in the relevant standards for the loading and unloading operations of different loads and ship types\cite{3}. The adaptability of construction ships are also studied by many domestic and foreign scholars, but few researches has been done on the operation window of offshore ships.
2. Ship construction window

Construction window is closely related to the number of operating days of the wharf[4]. In the early construction stage of the port, it is necessary to make a reliable demonstration of the operating days for ship loading and unloading. Based on the requirements for ship loading and unloading, the unfavourable factors such as wind, rain, fog, thunderstorms, tidal currents and waves are respectively counted according to the historical data of local meteorological stations and marine hydrological stations. The calculation of the non-operational days is given as below:

\[ N = \sum_{i=1}^{n} P_i \xi d \]

Where: 
- \( N \) -- the number of non-operational days in a year;
- \( n \) -- Number of affect factors for ship operation;
- \( P_i \) -- the probability of the number \( i \) factor appears throughout the year;
- \( \xi \) -- Adjustment factor;
- \( d \) -- Days of the year, taken as 365.

The operating days of the wharf is evaluated based on the occurrence probability of unfavourable factors and statistically analysed in the unit of day. For offshore construction, the sea states are relatively complicated. If the project location is far from the coast, the round-trip time of the ship is longer and its operating time will be greatly shortened with counting number of days. For the project with limited construction period, the use of construction window period should be more efficient, and thus the statistical analysis based on days is imprecise.

The determination of the construction window period requires comprehensive consideration of various factors, such as organization plan, construction content, operation efficiency, and environmental conditions, which change with the project content. For ship-led construction content, the length of the window period is mainly affected by its operational wave conditions, which actually depends on the type of ship.

3. Ship type selection and operating standards determination

There are many types of large-scale offshore construction ships, including floating crane, pile driving barge, dredger, icebreaker, survey ship, pipe-laying ship, barge, floating concrete mixer, and auxiliary ships. Zhang[5][6] studied the motions of several ships by physical model tests and proposed relevant operating standards. In this study, Pile driver 20# is used to determine the window period of construction ship. The main parameters and analysed results are shown in Table 1.

| Ship type      | Pile driver 20# |
|----------------|------------------|
| Simulation methods | Physical model tests; Mathematical model simulation |
| Main conditions  | Model scale: 1:50; Test water depth: 15m; Wave type: Irregular wave |
| Operating wave conditions | ship motion≤0.5m |
| Results         | 0°wave, 0°wind and 0°flow, Hs≤1.2m, Tp≤6s; Hs≤1.0m, Tp≤10s; 90° wave, 90° wind and 90° flow, Hs < 1.0m, Tp < 6s. |

In the construction process, the orientation of the ship can manually adjust to better adaption with the wave conditions on site. Thus, in this study, the wave direction of 0° is considered.

According to the simulation results, standard of operating wave conditions of Pile driver 20# is mainly affected by wind, wave and current, and wave is the key factor for normal operation. To illustrate the method, a measured waves for 10 consecutive months in 2016 in South China Sea is adopted in the statistical analysis.

4. Analysis of construction window period of Pile driver 20#

4.1. Analysis of non-operational time

Taking the measured wave parameters exceeding the permitted operating conditions of pile driver 20# as standard, non-operational time was counted in days and hours respectively (if the wave parameters exceed the limited value during the day, it is determined that the whole day is non-operation day), the
results are shown in Table 2. Compared with the statistical method counted by days, the non-operational rate has dropped a lot when counted by hours. It is obvious that different statistical methods cause significant differences in results.

Table 2. Statistics of non-operational time for Pile driver 20#

|               | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | non-operational rate |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----------------------|
| non-operational day (d) | 0   | 0   | 5   | 0   | 0   | 3   | 7   | 4   | 3   | 2   | 8.0%                 |
| non-operational hour (h)  | 0   | 0   | 38  | 0   | 0   | 14  | 87  | 31  | 28  | 7   | 2.8%                 |

The main reason for the difference of the results caused by the above statistical methods is due to occurrence of short period of severe sea conditions, which cause ships unable to operate in short term. Therefore, in order to explore the characteristics of the ship's construction window, it is necessary to study the distribution of non-operational time. Taking July as an example, the distribution of ship non-operational time is shown in Figure1 to Figure 3. The continuous non-operational time in hours can be generally divided into the following four types:

1. Isolated-Type. There is only 1~2 hours of non-operational time and longer adjacent periods are available for operation. The wave parameters are close to the permitted operation condition, corresponding to A-point in Figure 1.

2. Continuous-Type. The wave conditions are relatively poor and exceed the ship's operating conditions in relatively long periods, as showed in Figure 1. B-point.

3. Interval-Type. In this case, non-operational time appears alternately and interval of the non-operational time is short, corresponding to position C Figure1 C-point.

4. Mixed-Type. Unworkable time presents various forms as the continuous type and the interval type appear alternately, resulting in fragmented operational time, while the entire non-operational time is longest, as showed in Figure2 D-point.

Figure 1. Distribution of Non-operational time during 19th July~20th July

Figure 2. Distribution of Non-operational time during 15th Aug.~20th Aug.
4.2. Classification and distribution characteristics of construction window period

The ship operational time is divided into numbers of segments by the above four un-operational types in time axis, and the operational time can be divided into different lengths of time window. The ship construction window can be classified into five levels during the year, i.e. 1–6h, 6–12h, 12–24h, 24–240h, and >240h, etc. The relevant statistical results are shown in Table 3.

It is clearly shown that the number of window period of 1–6 hours is largest, but has a small percentage less than 1%. This can be due to that the operational time is fragmented in the segmentation of the unworkable time of the Isolated-Type and the Interval-Type. The frequency and probability of the construction window period of 7~12h and 12~24h are small. In contrast, the class of >240h accounts for the largest proportion, among which the longest workable time can be continuous for several months. This indicates that the construction window period shows an evident seasonal characteristic.

| item | 1~6h | 7~12h | 12~24h | 24-240h | >240h | Total |
|------|------|-------|--------|---------|-------|-------|
| Pre-Optimization Windows number | 34 | 3 | 3 | 2 | 9 | 51 |
| Probability | 0.9% | 0.4% | 0.8% | 1.2% | 94.0% | 97.2% |
| Post-Optimization Windows number | 1 | 0 | 0 | 2 | 3 | 6 |
| Probability | 0.0% | 0.0% | 0.0% | 1.6% | 98.0% | 99.6% |

4.3. Optimize for construction window

Un-operational time of the Isolation-Type and Interval-Type have great influence on the construction organization. To promote construction efficiency for specific ships, one effective way is to reasonably utilize different periods of window for organization, another way is to enhance the sea-keeping of ships by auxiliary methods.

There are several recognized methods to improve the sea-keeping performance of the ships, i.e. adjusting the anchoring layout of ships, enlarging the pretension of the mooring lines, increasing the draft of the ships, and setting auxiliary wave-dissipation facilities. However, considering the swell waves in the offshore conditions, the influence of the wave-dissipation facilities is generally not satisfactory. Based on the experimental results for Pile driver 20#, it is proved that enlarging the pretension of the mooring lines is effective and the suitable wave conditions for operation is improved to $H_s \leq 1.2m$ and $T_p \leq 9s$. The statistical results of the operation window based on the conditions are listed in Table 3.

From the Table3, it can be seen the construction window of the ships has changed greatly after the implementation of optimization measures. In particular, the number of window periods of 1–6 hours is reduced from 34 to 1, which indicates that most of the isolated and interval types are eliminated. For the window period of more than 240h, the optimized probability is increased from 94% to 98%. It is obvious that the operational time is significantly increased and the length of the construction window is extended with the application of optimization measures.

5. Conclusion

The statistical analysis and research of the construction window based on historical measured data has important guiding significance for the pre-construction organization plan, selection of construction ships and construction techniques. However, as the environmental factors during the construction process changes, the construction window period of ships should be adjusted. Thus, it is necessary to master of the field hydrometeorology conditions and trends, especially for the unfavourable natural factors, for a reliable determination of construction window. With the continuous upgrading in the field measurement technology and forecast accuracy, a dynamic and accurate prediction of the
construction window can be achieved based on the combination of hydrological data, field measurement and hydrological forecast.

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