Research on Anti-ship Collision Measures for Offshore Wind Farm in Operation Period-Case Study of Zone 2 Project of Guodian Zhoushan Putuo No.6 Offshore Wind Farm

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Abstract. Since 2007, China's offshore wind farm construction has developed rapidly, with more than 50 projects under construction and under construction. The operation period of offshore wind farms has a far-reaching impact on the ship traffic pattern in coastal traffic-intensive waters, and the poor compatibility of sea resources has a fragmented and three-dimensional exclusive impact on the use of sea areas, which makes the navigation conditions in nearby waters more complex. At present, there is no universally binding international convention or technical standard for ship navigation safety in offshore wind farm waters at home and abroad, which leads to the lack of unification of several important aspects of standards for offshore wind farm design and construction. For example, the requirements for channel distance, anti-collision requirements, setting standards for navigation marks and warning signs, pollution prevention management, emergency disposal and subsequent abandonment are not uniform. This paper focuses on the analysis of anti-collision measures between ship and wind turbine foundation from the perspective of navigation safety during the operation of offshore wind farm, and takes the No.6 offshore wind farm project in Zhoushan Putuo as an example to discuss.

1. Analysis of the Influence of Offshore Wind Farm on Navigation Safety

1.1. Exclusive occupation of navigable waters by offshore wind farm
Some offshore wind farms are built in intertidal zones or tidal flats with relatively shallow water depth, and the water depth conditions prevent large ships from entering by mistake, so there is basically no impact on navigation safety of these offshore wind farms. But at present, the water depth of offshore wind farm is generally 5 m ~ 50 m, mostly 5 m ~ 30 m. And the distance from the shore is generally about 10 kilometers. The water depth and distance from the shore are also the waters with high density of coastal vessels. Some wind farms are located near the ship's customary route, and this exclusive occupation of waters will cause long-term impact on the navigation environment, change the pattern of nearby marine traffic flow, change the visual perception of nearby waters, affect the normal

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observation of sailing ships, and increase the risk of collision between nearby sailing ships and wind
turbines[1].

1.2. Influence of offshore wind farm on navigation facilities

1.2.1. Impact on the efficacy of existing visual AIDS to navigation. The offshore wind farm site is too close to the navigation route, or may be located between the navigation aid mark and the ship navigation route, which affects the normal use of the visual navigation mark during the ship navigation.

1.2.2. New navigation aid mark. The top or foundation of offshore wind turbines are often equipped with luminous warning devices, which increases the complexity of navigation AIDS in wind farm waters, and may also affect the identification of ship drivers to the original navigation AIDS nearby.

1.2.3. Influence of Offshore Wind Farm on Ship-borne Radar. Offshore wind turbines form a radar shadow area, the larger the size of the wind turbine and the closer to the ship radar antenna, the larger the shadow sector area. The fan is a strong reflector. When electromagnetic wave encounters the fan, it may form multiple reflected echoes and clutter interference.

1.3. Risk of Ship Collision in Offshore Wind Farm Area.

Experience at home and abroad, offshore wind farm waters are generally not closed, in addition to operation and maintenance ships, fishing boats are allowed to operate in wind farm waters under certain conditions, which also greatly increases the risk of collision between ships and wind turbines. But generally, on that basis the wind turbine foundation is provided with the Berthe component, the anti-collision component is additionally arranged, and the main function of the anti-collision component is to absorb energy through formation damage when a small ship accidentally collides with the pile foundation of the wind turbine bearing platform, so as to reduce the risk that the overall stability of the wind turbine foundation is affect. In general, it will not cause fatal damage to the wind turbine foundation.

Large ships in the yaw, out of control, misjudgment of the case, there is a certain probability will break into the wind farm waters. The distance between the two wind turbines in the offshore wind farm is relatively large, generally ranging from several hundred meters. In general, the space between the two wind turbine foundations is enough for the ship to pass through safely when a large ship fails. Although the probability of large ships colliding with wind turbine foundation is relatively low, once the collision accident occurs, especially the ship with steering gear failure, the damage consequences are often more serious[2].

2. Design of Wind Turbine Foundation Berthing Member

Taking the No.6 offshore wind farm project in Zhoushan Putuo of Guodian as an example, two groups of berthing members are arranged for each wind turbine foundation cap according to the flow direction characteristics, and each group of berthing members consists of two steel pipes, and the berthing members are placed on the steel pipe piles and fixed after pile sinking in the form of a sleeve cage. The main function of the anti-collision component is to absorb energy through deformation damage and reduce the risk of affecting the overall stability of the wind turbine foundation when a small ship accidentally collides with the pile foundation of the wind turbine platform.

2.1. Calculation of impact capacity of berthing member.

The impact force is designed to be all 500kN acting on a berthing steel pipe according to the most unfavorable condition. In the actual construction, the finite element analysis software ANSYS is used to calculate and analyze the berthing structure. The impact force of routine maintenance ships and small fishing boats in this project is calculated as 500kN. As the ship type, tonnage and speed of the ship out of control in channel yawing for which the anti-collision component is aimed are uncertain,
the design impact force of the anti-collision component in this project is taken as 1000kN in consideration of engineering economy and feasibility.

**Figure 1.** Load acting at design high tide position

**Figure 2.** Load acting at 1m above design high tide level
The anti-collision structure is calculated and analyzed by ANSYS. The ANSYS calculation model is shown in Figure 3, and the steel pipe pile and stay pipe are simulated by PIPE16 element. When the impact force is 1000 kN, the maximum stress of the anti-collision component body has reached 1040 MPa. The anti-collision component absorbs energy through self-destruction under the large impact action of the steel pipe pile, and has obvious protection effect on the steel pipe pile body.

2.2. Case Analysis of Wind Turbine Foundation Stress Caused by Ship Impact

Taking the No.6 offshore wind farm project in Zhoushan Putuo of Guodian as an example, the impact capacity of the berthing member is 500kN (about 50t), and the anti-collision member 1000kN (about 100t) of the wind turbine foundation on the north side close to the channel will be damaged and the installed foundation will be protected from major damage.

The speed of the wind turbine foundation impacted by the ship is about 2kn according to the measured flow velocity in the water area of this project, and is calculated as 3kn about 1.5m/s in the extreme.

According to the "General Code for Design of Highway Bridges and Culverts" (JTGD60), the standard value of impact force of drift objects in transverse bridge direction is calculated by the formula:

\[ F = \frac{WV}{gT} \]  \hspace{1cm} (1)

In the formula, \( W \) is the gravity of the drift (kN); \( V \) is the flow velocity (m/s), \( T \) is the impact time (s), and 1s can be used when there is no actual data.

\[ F = \frac{WV}{gT} = \frac{9.8 \times 1000 \times 1.5}{9.8 \times 1} = 1500kN \]  \hspace{1cm} (2)
(1) That is to say, the impact force of 1000t ship at 3 knots is 1500kN (about 150t), which is greater than the design impact force of 1000kN (about 100t) of the anti-collision component of this project.

(2) Similar calculation can easily conclude that under the condition of flow velocity near this project, the impact of about 700t ships can reach the design impact force limit of 1000kN (about 100t impact force) of the anti-collision components of this project.

(3) The maximum ship passing through the vicinity of the project is about 50,000t, and it is still calculated by 3kn flow of about 1.5m/s. Similar calculation can easily obtain that the impact force of 75000kN (about 7500t) is about 75 times of the design impact force of 1000kN (about 100t) for the anti-collision components of the project.

3. Scheme of Ship Collision Prevention Measures System for Offshore Wind Farm in Operation Period

The work of ship collision prevention in offshore wind farms is complex, and there is no mature experience for reference at present. The anti-collision measures for offshore wind farms during operation period include both management work and engineering work, which not only need to compile and issue special navigation safety management regulations, but also need to add facilities and equipment such as early warning, response and interception on the basis of the existing anti-collision design and navigation safety facilities. Various means of ship collision prevention for offshore wind farms are independent of each other and have strong unity, which is a complete system. According to the idea of gradual enhancement of prevention and control measures, the ship collision prevention system can be divided into six aspects: navigation management, operation and maintenance ship selection, navigation aid and warning, early warning measures, and emergency disposal[4-5].

![Figure 4. Schematic diagram of ship collision prevention system for offshore wind farm](image-url)
3.1. Navigation Management Measures
The core purpose of navigation management measures is to maintain good navigation order in wind farm waters, requiring ships to navigate normally according to regulations. To achieve this management goal, the first is to formulate and issue regulations on navigation management in relevant waters (including wind farms and adjacent major waterways); Second, we should establish and improve the organizational structure and implement the navigation management measures; Third, we should strengthen propaganda and propaganda work; Fourth, establish the navigation management and control center of the project (hereinafter referred to as the "Management and Control Center") to implement the comprehensive management and control of navigation. The Management and Control Center can be set up in Liuheng Marine Department. Fifthly, the owner unit of this project shall strengthen the on-site monitoring of the wind farm during the operation period, including the wind farm and adjacent waters, and report the situation to the competent authority when necessary and take emergency action measures.

3.2. Type selection of operation and maintenance ship
Normally, it is the operation and maintenance ship that allows the wind turbine foundation to dock with the ship, so the selection of the operation and maintenance ship and the corresponding technical indicators have a direct impact on the wind turbine ship collision.

3.3. Navigation aid and warning measures
The perfect navigation aid and warning facilities are the necessary guarantee to clearly display the channel position and the offshore wind farm position, guide the passing ships to navigate according to the normal channel and avoid entering the wind farm waters by mistake.

3.4. Early warning measures
When the navigation aid and warning measures fail to guide the normal navigation of the passing ships, the effective early warning and response measures can timely detect and correct the abnormal navigation behavior of the ships, and reduce the risk of ship collision with the offshore wind farm. In addition, for the operation and maintenance ships and fishing ships allowed to enter the wind farm for navigation, when the weather and sea conditions are not suitable for operation and need to be evacuated, early warning and response measures can be taken in time to reduce the risk of ship collision with the wind farm.

3.5. Anti-ship collision protection works (interception measures) (if necessary)
When a series of measures such as management, warning and early warning fail to correct the abnormal navigation behavior of ships, compulsory corrective measures will be taken to forcibly block the abnormal navigation ships and force them to stop sailing, so as to eliminate the risk of ship collision with the wind farm.

3.6. Emergency treatment
Including the emergency treatment of collision risk before the ship collides with the wind farm; Emergency treatment in case of ship collision with wind turbine foundation.

4. Conclusion
In general, on the basis of strengthening navigation management, operation and maintenance ship selection, navigation aid and warning, early warning measures, anti-ship collision protection engineering technical measures (if necessary) and emergency disposal, the risk of wind turbine foundation being collided by ships in this project is generally controllable.
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References
[1] Mehdi,ens-UweSchröder-Hinrichs,eroenOverloop,enrik Nilsson,onasPålsson. Improving the coexistence of offshore wind farms and shipping: an international comparison of navigational risk assessment processes[D]. WMU Journal of Maritime Affairs, 2018(17) p:397~434.
[2] Song LI, Yuanqiang ZHANG. Study on the Soft Power Construction of National Marine Oil Spill Emergency Equipment Library in Zhejiang Province. Journal Of ZHEJIANG International Maritime Colleges, 2015, 11, 22–25.
[3] Robert W. Thresher, Darrell M. Dodge. Trend in the evolution of wind turbine generator configurations and systems[J]. Energy Policy, 2015(10):70-86.
[4] Yan Y, Xia CL. Assessing the growth and future prospect of wind power in China[C]. IEEE Electrical and Control Engineering International Conference. 2010,(16):45-58.
[5] Information on http://www.chinaports.com
[6] Information on http://www.msa.gov.cn