Investigation of Floating Transportation Equipment for the Offshore Wind Power

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Abstract: This paper presents a floating transportation equipment (FTE) for the negative pressure suction bucket foundation (NPSBF) of offshore wind turbines, and the basic design and main transportation means are introduced. The hydrodynamic characteristics of integrated FTE-NPSBF structure are comprehensively studied. The ability of FTE as a transportation aid to provide stability for the NPSBF is verified, and the vibration reduction measures under the condition of wave resonance during the floating transportation process are given.
***Keywords*:** offshore wind power, floating transportation equipment, stability

1. Introduction

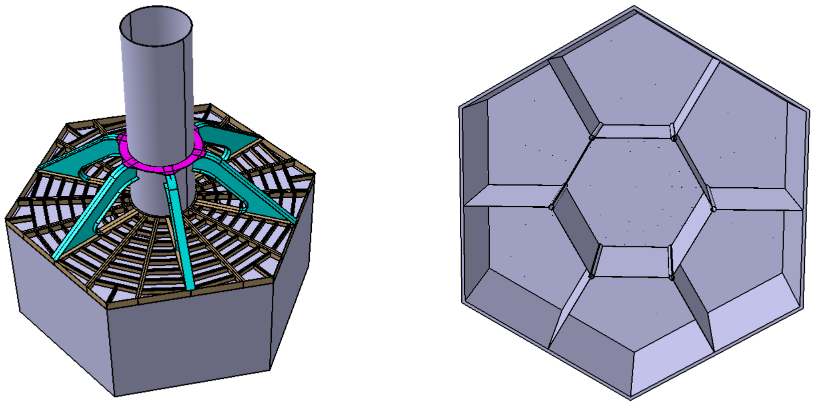
As the clean and renewable type, wind energy has become one of the fastest developing renewable energy in recent years. The offshore wind energy is far stronger than that inland. It is far away from the residence community and has no additional land costs, which has huge development potential. Offshore wind energy is fully capable of playing the dominant role of renewable power and has significant commercial value. Offshore wind power is developing rapidly all over the world in recent years. The pile, gravity and suction bucket foundations are the most common types in offshore wind farm construction. Because of its advantages of high stiffness, strong anti-overturning ability and low cost, the suction bucket foundation type is widely used in offshore wind farms that are affected by typhoon and shallow rock stratum [1-2]. However, suction bucket foundations are usually large in size and weight, and the sidewalls as well as the internal compartment plates are thin-walled structures, which can not directly bear the large weight of the foundation. Therefore, the suction bucket foundation can not be directly placed onto a barge for transportation, but can only be transported in a floating way. The bottom of the suction bucket foundation is large opening, thus its stability and anti-overturning ability are much weaker than those of closed structures such as ships or offshore platform [3-5], so large auxiliary equipment is needed for the transportation of suction bucket foundation. As the suction bucket foundation is a new type of offshore wind infrastructure, there is no mature floating device by now. Therefore, a customized device and its corresponding method for floating transportation, which can provide sufficient stability and guarantee safety, is urgently necessary.

The purpose of this paper is to propose a customized floating transportation device for the suction bucket foundation of offshore wind turbines. By comprehensively studying the amplitude response operator (RAO), the transportation stability is verified. Some practical recommendations are also given with respect to vibration reduction measures under the condition of wave resonance during the floating transportation process. This paper provides a significant reference for the device design and safety evaluation of the suction bucket foundation floating transportation in the future.

2. Suction Bucket Foundation and Floating Transportation Device

The negative pressure suction bucket foundation of offshore wind turbines is shown in Figure 1. The suction bucket foundation has an opening type bottom. The foundation has a 14m height and a 32m skirt to skirt distance.

Six hexagonal inner hatch plates are designed inside the inner space of the foundation wall, and six subdivision plates are designed between the hexagonal inner hatch plate and the foundation wall to strengthen the support and improve the stiffness of the whole structure. The inner space of skirt is therefore divided into seven separate part. During foundation installation process, a certain amount of subsidence will be generated by the self-weight of the foundation. At the same time, the gas inside the skirt is closed inside the wall by the seabed. After the self-sinking, the gas inside the skirt is pumped away for forming a negative pressure environment, and the foundation continues to sink under the action of negative pressure until the whole skirt is embedded into the mud surface.



a) b)

Figure 1. a) Sketch of foundation; b) Bottom view of foundation

The floating transportation of suction bucket foundation is realized by the floating transportation platform that is shown in Figure 2. The floating transportation platform has a length of 88.2m, a width of 65m, a height of 6m and a designed draft of 3.5m. The floating transportation platform completely wraps and clamps the suction bucket foundation, so that these two forms one combination for moving. The movement of the foundation, especially the pitch and roll which play a key role in overturning, will be transmitted to the floating transportation platform and these two parts move together. The large waterline surface of the floating transportation platform is used to provide sufficient stability for the suction bucket foundation during transportation process.

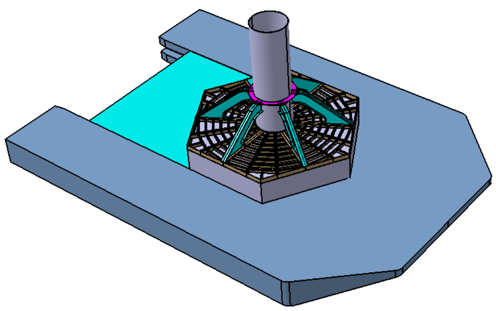


Figure 2. Suction bucket foundation completely wrapped and clamped by the floating transportation platform

The floating transportation platform is assembled by two modules, one active embedded module (light blue) and the other passive embedded module (dark blue) shown in Figure 3 and Figure 4. The floating platform is an assembled non self-propelled device, which is of steel structure. It is manufactured in the shipyard in advance and transported to the wind turbine foundation manufacturing site. When assembling the floating transportation platform, two winches are used to pull the active embedded module into the passive one, so that the front end of the active module is in close contact with the suction bucket foundation. After assembly in place, the suction bucket foundation is completely wrapped and matched, and the two modules are tensioned and fixed. These two modules and the suction bucket foundation consequently form a stable combined system that can move together. After the bucket foundation is clamped by the floating transportation platform, it is towed by the tugboat to the installation position in the wind farm site, as shown in Figure 5.

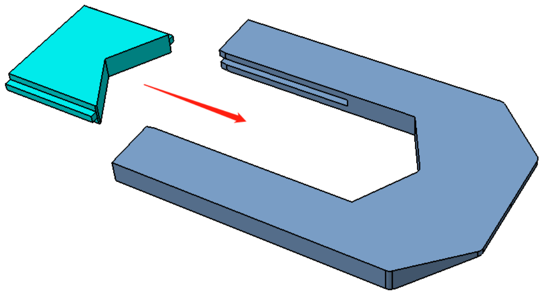


Figure 3. Splicing of active embedded module (light blue) and passive embedded module (dark blue)

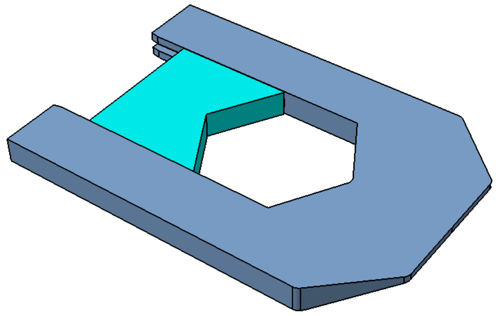


Figure 4. Assembly completion sketch of the floating transportation platform

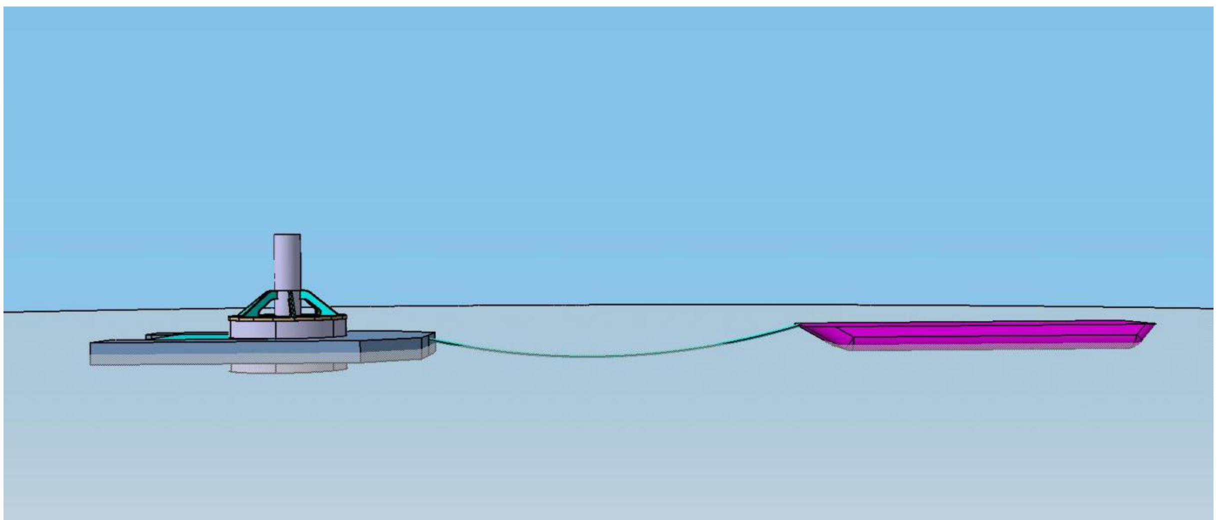


Figure 5. Towing of floating transportation platform and the suction bucket foundation

3. Main parameters and Coordinate system definition

As a combined system consisted of the floating transportation and suction bucket foundation, the main parameters are presented in Table 1. The origin of the coordinate system is established at the bottom of the suction bucket foundation, the X axis points to the forward direction, and the Z axis is vertical upward, as shown in Figure 6.

Table 1. Main parameters of the combined transportation system

Mass	Center of mass			Moment of inertia(with respect to COG)		
	X	Y	Z	Ixx	Iyy	Izz
t	m	m	m	$kg.m^2$	$kg.m^2$	$kg.m^2$
14189	-3.19	0.00	8.23	7.30E+09	7.22E+09	10.1E+09

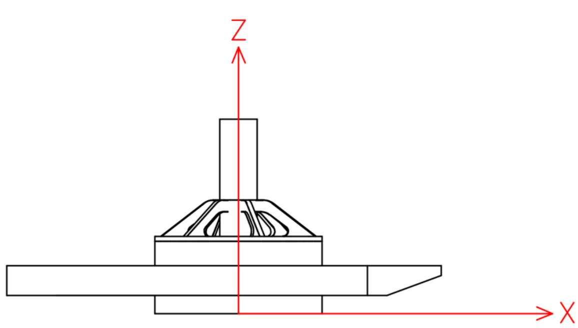


Figure 6. Illustration of coordinate system

4. Analysis of Rao and motion characteristics

Take Guishan sea area of as an example, as shown in Table 2. It can be seen that the wave period with the highest probability of occurrence in Guishan sea area throughout the year is 2s ~ 4s, and the cumulative frequency of waves with a period less than 2s is only 1%.

Table 2. Joint probability distribution of significant wave height and spectral peak period (Hs-Tp) in Guishan sea area for one year in %

Hs \ Tp	0 ~ 2	2 ~ 3	3 ~ 4	4 ~ 5	5 ~ 6	6 ~ 7	7 ~ 8	8 ~ 9	9 ~ 10	10 ~ 11	11 ~ 12	12~ 13	13~ 14	14~ 15	≥15	SUM
0.0 ~ 0.1			0.01		0.05											0.06
0.1~ 0.2	0.13	0.68	0.34	0.69	0.58	0.42	0.80	0.30	0.25	0.37	0.15	0.03	0.03	0.03		4.8
0.2 ~ 0.3	0.58	3.04	1.70	1.86	2.44	2.51	5.07	2.15	1.19	0.81	0.50	0.06	0.05	0.02		21.98
0.3 ~ 0.4	0.26	5.67	2.73	1.39	2.35	3.07	5.26	3.31	2.33	1.33	0.37	0.11	0.13	0.05	0.01	28.37
0.4 ~ 0.5		4.86	3.79	1.35	0.93	1.07	1.94	1.97	2.07	1.44	0.50	0.01	0.05	0.02	0.02	20.02
0.5 ~ 1.0	0.07	2.64	9.23	2.58	0.54	0.85	1.49	1.11	1.74	2.26	0.68	0.21	0.08	0.22	0.06	23.76
1.0 ~ 1.5			0.06	0.26	0.07	0.03	0.03	0.06	0.06	0.16	0.07	0.05				0.85
1.5 ~ 2.0				0.05	0.02					0.03	0.02	0.01				0.13
2.0 ~ 2.5										0.01						0.01
2.5 ~ 3.0																
≥3.0																
SUM	1.04	17.91	18.74	7.42	6.51	7.31	13.81	8.69	8.11	6.82	2.35	0.46	0.36	0.36	0.09	100

The motion response characteristics of floating system can be characterized by the amplitude response operator (RAO), and RAOs under wave incidence angles of 0 °, 45 °, 90 °, 135 ° and 180 ° have been calculated. Take two typical displacement types closely related to overturning, namely pitch and roll, as examples. The RAO results of roll and pitch response are shown in Figure 7 and Figure 8. According to the wave parameters listed in Table 2, the wave period with the highest probability of occurrence in Guishan sea area throughout the year is 2s~4s, while the RAOs results of roll and pitch show that the natural period of the floating system is concentrated in 10s~13s, thus the natural period is far away from the wave period.

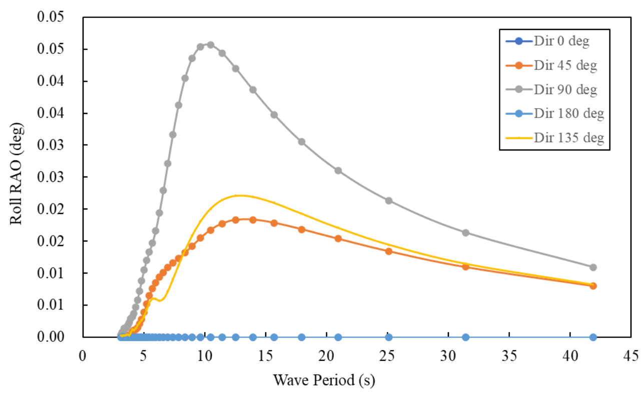


Figure 7. RAO responses of roll under different wave direction angles

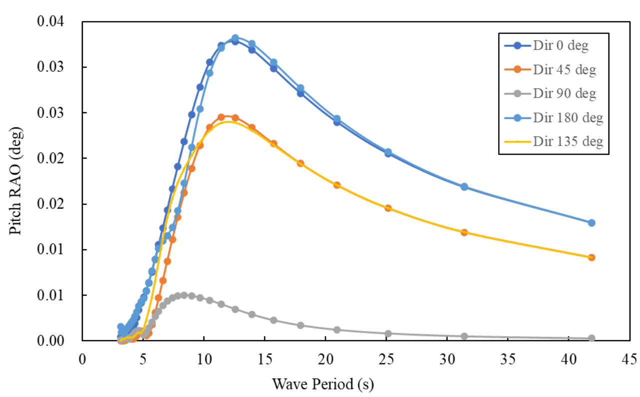


Figure 8. RAO responses of pitch under different wave direction angles

It can be seen from Figure 7 and Figure 8 that the roll RAO response is the largest at wave direction angle of 90deg, and the pitch RAO response is the largest at that of 0deg or 180deg. However, it should be noted that a reasonable change in the wave angle of attack (for example, when the wave angle of attack is adjusted to 45 degree) can effectively reduce the response of the floating system under wave induced resonance.

During the transportation of the floating system, when the wave period is about 10s, the roll and pitch responses reach the maximum near the 10s wave period, and the floating system will resonate under the wave excitation. However, since the resonance takes a certain time to accumulate the excitation, the transportation will be stopped in advance when it is predicted that there is a resonance risk, and safety measures such as adjusting the angle of attack and adjusting the suction bucket foundation air pressure will be taken to avoid excessive oscillation and ensure safety. In addition, the sea conditions will be predicted 2-3 days in advance before transportation, and the floating transportation will not start until the wave height is small enough in the next 2-3 days.

5. Conclusion

A customized floating transportation device for the suction bucket foundation of offshore wind turbines has been proposed. It has been found that the reasonably changing the wave angle of the floating system can effectively reduce the response under wave induced resonance. When the transportation encounters wave induced resonance, the wave angle should be reasonably adjusted to ensure the safety of the system. This paper providing a good reference for the further improvement of safety evaluation investigation for the suction bucket foundation floating transportation and engineering design work of transportation device in the future.

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