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Towing characteristics of large-scale composite bucket foundation for offshore wind turbines

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Abstract: In order to study the towing dynamic properties of the large-scale composite bucket foundation, the hydrodynamic software MOSES is used to simulate the dynamic motion of the foundation towed to the construction site. The MOSES model with the prototype size is established as the water draft of 5 and 6 m under the environmental conditions on site. The related factors such as towing force, displacement, towing accelerations in six degrees of freedom of the bucket foundation and air pressures inside the bucket are analyzed in detail. In addition, the towing point and wave conditions are set as the critical factors to simulate the limit conditions of the stable dynamic characteristics. The results show that the large-scale composite bucket foundation with reasonable subdivisions inside the bucket has the satisfying floating stability. During the towing process, the air pressures inside the bucket obviously change little and it is found that the towing point at the waterline is the most optimal choice. The characteristics of the foundation with the self-floating towing technique are competitive for saving lots of cost with few of the expensive types of equipment required during the towing transportation.

Key words: large-scale composite bucket foundation; towing; MOSES; offshore wind turbines

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On October 1st, 2010, the first offshore wind turbine with a large-scale composite bucket foundation was installed in the sea area of Qidong city in Jiangsu Province [1-2]. It is the first time that the concrete bucket foundation has been used for a 2. 5 MW offshore wind turbine in China. It leads to the implementation phase of a one-step-installation technique of an offshore wind turbine. The new type of bucket foundation is a bucket-top bearing model, which differs from the bucket-side-resistance-bearing model of the traditional bucket foundation[3]. The composite bucket foundation has a greater bearing capacity and reliability, which is widely applied in offshore structures. After the accomplishment of the installation, a series of full-scale tests on the bucket foundation are conducted. The measuring methods, the instrumentation system and main results of the tests were introduced in the related papers [4-7]. These data can be used to develop the theory and method of calculation for the new bucket foundation structure.

The critical part of the one-step-installation technique is the onshore prefabrication and the self-floating towing technique of the composite bucket foundation. The bucket foundation has the floating stability during the towing processing based on the optimized subdivision scheme inside the foundation. The numerical models by the hydrodynamic software MOSES[8] are established to simulate the towing dynamic properties in the environmental conditions of the construction site. Some important factors [9-11], such as displacements, accelerations in six degrees of freedom, and air pressure inside the bucket are analyzed in this paper.

1 Simulation for Towing Processing on Site

1.1 Composite bucket foundation

Fig. 1 shows the geometric parameters and the subdivision of the composite bucket foundation. There are seven rooms inside the bucket foundation, which is like a honeycomb structure. The towing procedure in-site includes the following steps: watering in the dockyard, self-floating of the foundation, opening the dock doors, towing to the located site. The pictures of the towing process are shown in Fig. 2. The environmental conditions on site are 15 m/s (31 knots) for the speed of wind, 2 m/s for the current flow rate and 1 m (period is 7 s) for the wave height.

1.2 Numerical model

The MOSES model is established as the prototype of the foundation, as shown in Fig. 3. The total weight of the composite bucket foundation is 2 480 t and the water

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levels inside the bucket are set to be 1.4 and 2.4 m with

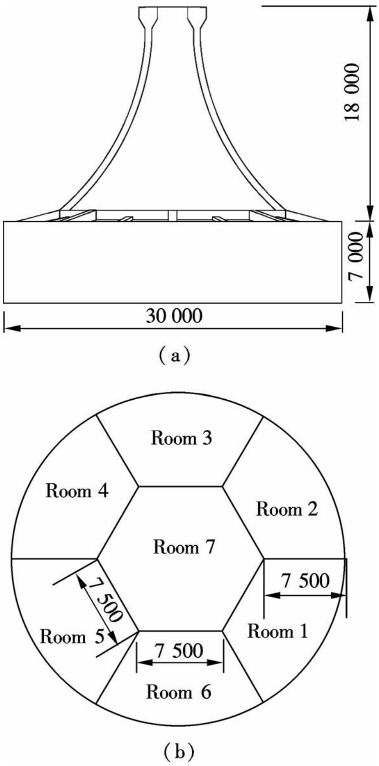

Fig. 1 Geometric parameters and subdivisions of composite bucket foundation. (a) Side view; (b) Subdivisions (unit: mm)

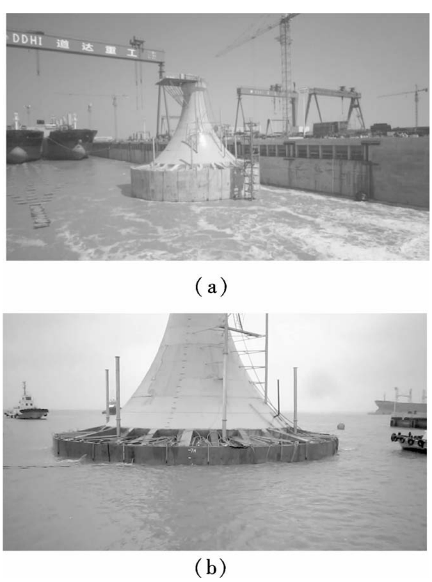

Fig. 2 Pictures of foundation during towing processing. (a) Watering in the dock; (b) Self-floating of the foundation

the draft of 5 and 6 m, respectively. The dynamic motion periods are 12, 9 and 9 s in heave, roll and pitch, respectively.

1.3 Towing force and displacement

Towing resistance mainly includes the hydrostatic resistance and the wave resistance. The results of the MOSES model show that the maximum of towing forces are

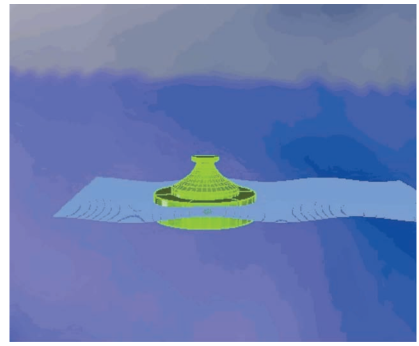

Fig. 3 MOSES model for towing of bucket foundation

550 and 650 kN, and the amplitudes are 270 and 290 kN for the drafts of 5 and 6 m, respectively. Accompanying the abrupt changing of the towing force at the beginning of the towing process, the maximum displacement is about 0.3 m due to heaving of the foundation.

1.4 Air pressure inside the bucket

There are seven rooms of subdivision inside the bucket foundation, as shown in Fig. 1. The air pressures in Room 1 and Room 4 are given in Fig. 4, in terms of water head. The values show the differences under two draft conditions, but the characteristics of the fluctuations are quite familiar. Except for the larger changing values at the beginning, the air pressures in the rooms change like a stable wave with the period of an environmental wave.

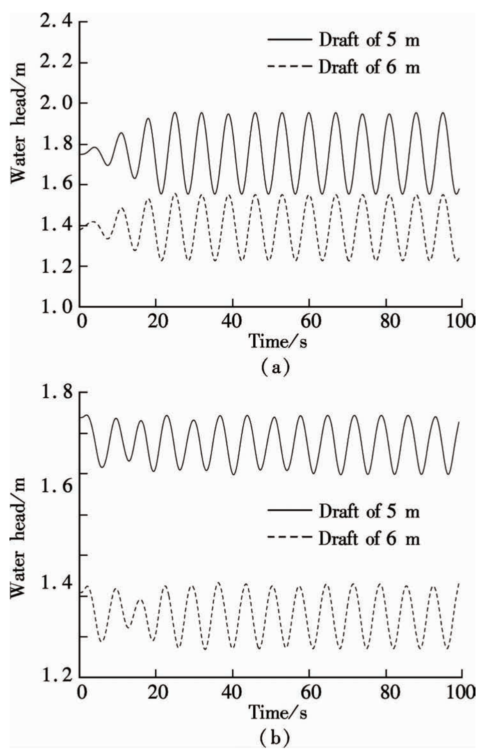

Fig. 4 Air pressures in typical rooms with different drafts. (a) Room 1; (b) Room 4

1.5 Acceleration

Fig. 5 illustrates the towing accelerations of the bucket

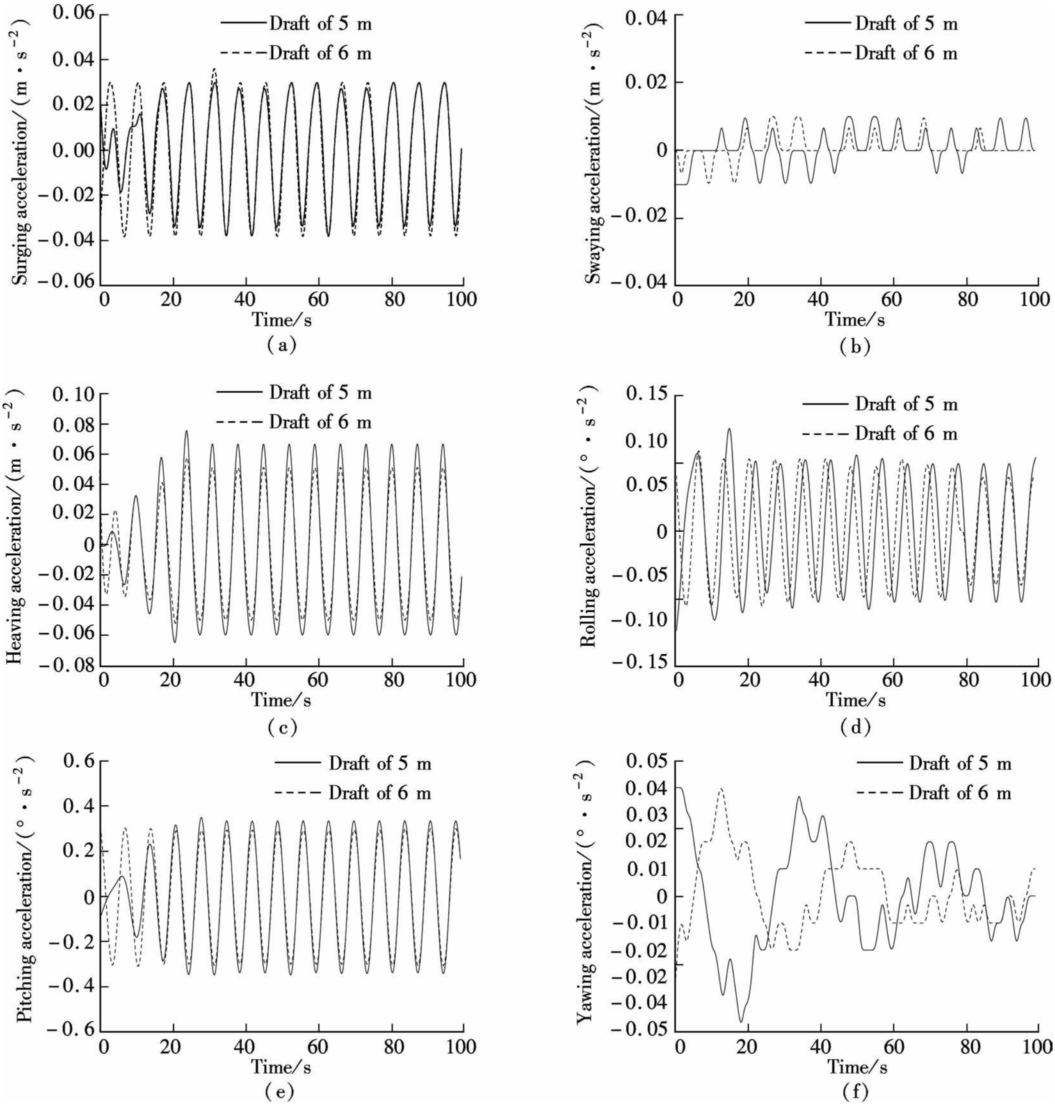

Fig. 5 Accelerations in six degrees of freedom of the bucket foundation with different drafts. (a) Surging acceleration; (b) Swaying acceleration; (c) Heaving acceleration; (d) Rolling acceleration; (e) Pitching acceleration; (f) Yawing acceleration

foundation in six degrees of freedom. Except for the yawing acceleration, the differences in the accelerations under the two draft conditions mainly appear at the beginning of towing, and the dynamic properties change in the same way after 20 s. It is the most possible reason that the towing resistances are different under the two draft conditions. In addition, the changes in the two yawing accelerations are opposite. After the large vibration at the early towing, the vibration of the foundation becomes relatively stable with the rhythm of the wave conditions. Compared with other accelerations, the change in the swaying acceleration is quite small, which may be relatively much larger on site due to the turbulent flow.

2 Factors Analysis

2.1 Towing point

Fig. 6 shows different towing points with the draft of 5 m. And other enviornmental parameters are the same as the above mentioned. Fig. 7 gives the results of the towing forces with three towing points. When the towing point is above the water level (Point *C*), the towing force shows a trend of stably increasing. Howerver, when the towing point is in the water (Point *B*), the towing force is greater at the beginning, which is up to 130 t. In Fig. 7, it is found that the optimal towing point is Point *A* at the waterline.

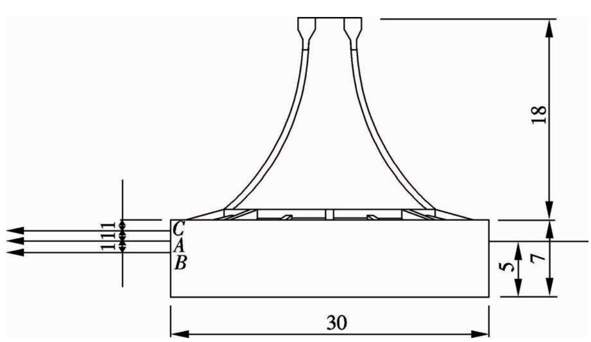

Fig. 6 Towing points (unit: m)

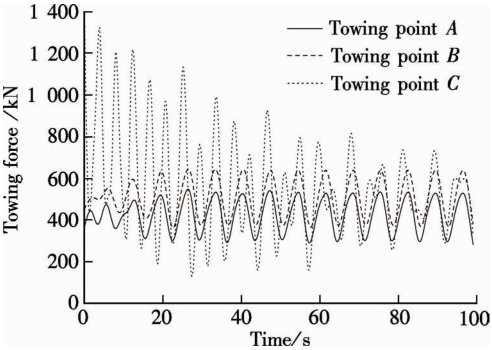

Fig. 7 Towing forces with three towing points

2.2 Wave condition

In order to study the limit state of towing, the MOSES model is established as the water draft is at 4 m. The height of the water seal inside the bucket is only 0.4 m with an aircushion of 6.6 m. The environmental conditions include two situations: one is the same as the condition mentioned above (wave is 1 m/7 s), and the other is the same as the first except that the wave is 1.5 m/7 s.

When the wave height increases from 1 to 1.5 m, the accelerations in all the directions increase, especially surging acceleration, as shown in Fig. 8. In fact, the air pressure in Room 1 is sharply increased with a pitching angle of 1.44°, as shown in Fig. 9. With the increase in the wave height, the air pressure in other rooms shows the obvious change. When the wave height is up to 5 m, the bucket foundation loses limit stability and may overturn in the water.

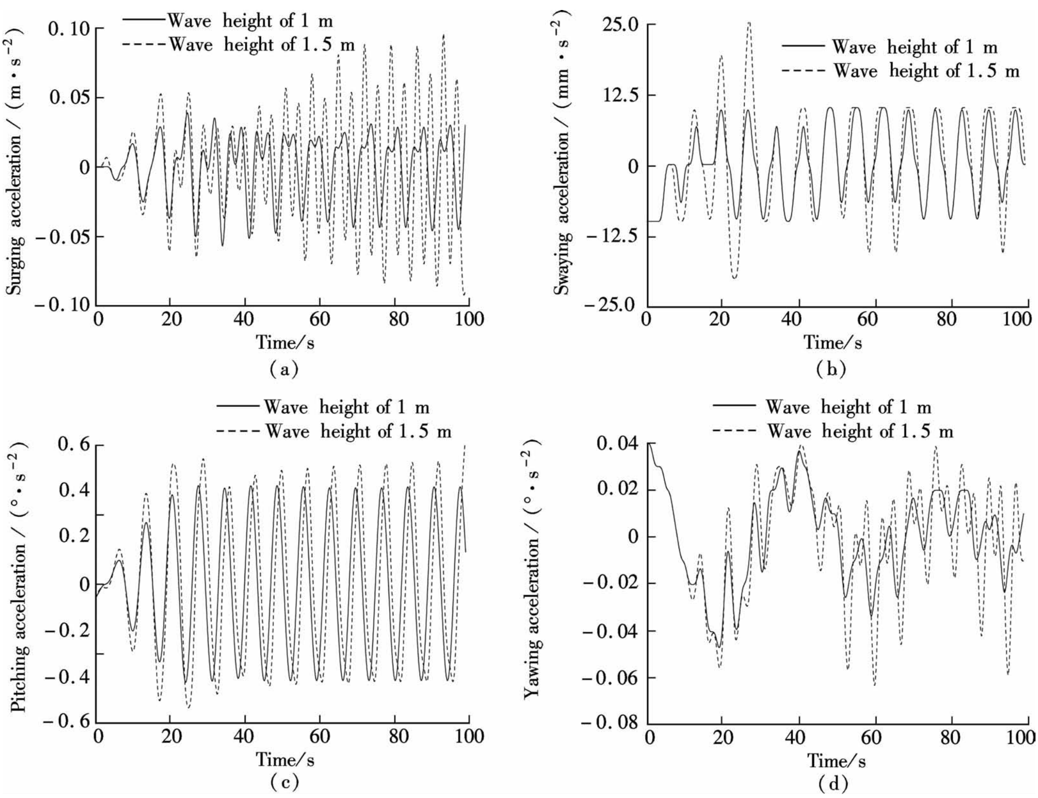

Fig. 8 Accelerations in six degrees of freedom of the bucket foundation with different wave heights. (a) Surging acceleration; (b) Swaying acceleration; (c) Pitching acceleration; (d) Yawing acceleration

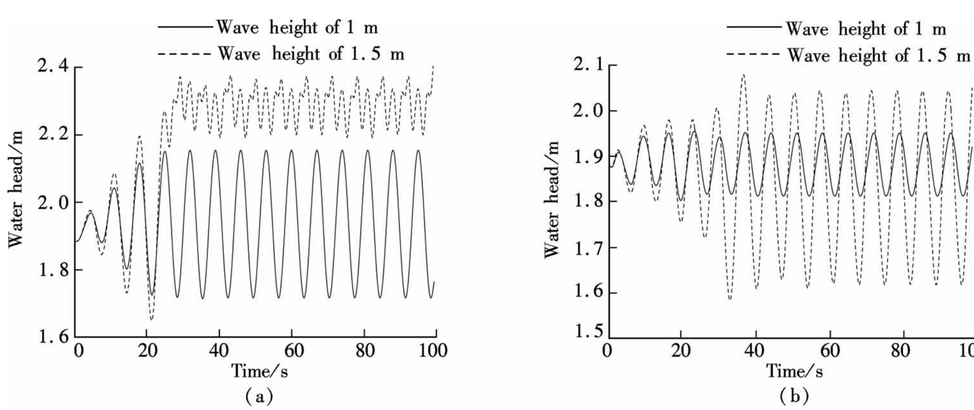

Fig. 9 Air pressures in typical rooms with different wave heights. (a) Room 1; (b) Room 4

3 Conclusion

From the above MOSES model analysis, it is shown that the composite bucket foundation has reasonable motion characteristics and towing reliability. With the special characteristics of self-floating towing, the foundation is economical for there being no heavy equipment required and fast installation. And the MOSES model simulates well the towing of the foundation under various environmental conditions. It is an effective method to establish and simulate the towing scheme of the prototype structure on site.

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海上风电大尺度复合筒型基础拖航特性分析

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摘要:为了研究海上大尺度复合筒型基础的拖航动力特性,采用水动力学软件 MOSES 模拟海上风电复合筒型基础结构现场气浮拖航的运动情况. 模型采用基础原型尺寸,通过模拟现场海域 5 和 6 m 吃水条件下的基础拖航情况,详细分析了复合筒型基础拖缆力、位移、加速度、筒内气压力等相关动力特性因素. 同时,通过变换关键变量,分析了不同的拖缆点和波浪条件对基础极限动力特性的影响. 结果表明:具有合理分舱的复合筒型基础具有稳定的自浮拖航浮运特性,拖航过程中筒内气体压力变化较小,拖缆点在水线附近拖航阻力最小. 复合筒型基础可自浮拖航的特性使其运输施工过程不需要使用大型设备,可大大节约成本,具有很强的竞争性.

关键词:大尺度复合筒型基础;拖航;MOSES; 海上风电
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