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Numerical modeling and analysis of the dynamic motion response of an offshore wind turbine blade during installation by a jack-up crane vessel

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ABSTRACT

Jack-up crane vessels are commonly used to install offshore wind turbine blades and other components. A jack-up crane vessel is subjected to wind and wave loads, which cause motion at crane tip. Excessive motion at crane tip can lead to failure of lifting operations. Therefore, the crane tip motion should be properly assessed for jack-up crane vessels. In this study, a fully coupled model is developed for a typical elevated jack-up crane vessel, considering the hydrodynamic and aerodynamic loads on the vessel, the soil-structure interaction, and the structural flexibility of the jack-up legs and crane. The vessel model developed is further coupled with the SIMO-Aero code to achieve a fully coupled aero-hydro-soil-elastic-mechanical code SIMO-RIFLEX-Aero for numerical modeling and dynamic analysis of offshore single blade installation using jack-up crane vessels. The SIMO-RIFLEX-Aero code is then applied to study the dynamic response of the DTU 10 MW wind turbine blade installed by a typical jack-up crane vessel under various wind and wave conditions. The results show that significant motion is induced at crane tip, mainly due to wave loads. It is important to consider the structural flexibility of the jack-up legs and crane when modeling the installation of offshore wind turbine blades.

1. Introduction

Offshore wind turbines can be installed by either floating or jack-up crane vessels, as shown in Fig. 1. Compared to jack-up vessels, floating vessels provide more flexibility for offshore operations and accessibility in deep water. They have been used to install fully assembled wind turbine towers with rotors and nacelle for floating and jacket-supported offshore wind turbines, as presented in Fig. 1(a) and (b). However, such operations are very challenging and rarely used due to the wave-induced motion of the floating crane vessels.

Jack-up crane vessels are commonly used to install offshore wind turbines in shallow water, because they can provide a stable working platform. They are able to install the components of offshore wind turbines (such as foundation, tower, nacelle and blades) separately and in sequence, as shown in Fig. 1(c) (Ahn et al., 2017). Due to the growing market for offshore wind energy, the demand for use of jack-up crane vessels keeps increasing (Global Data, 2014).

Compared to traditional jack-up platforms used in the offshore oil and gas industry, the jack-up crane vessels for offshore wind turbine installation usually have shallower leg penetration into the seabed because of the frequent repositioning. As a result, the vessels are more sensitive to wind and wave loads. The tip of the crane on the vessel is observed to have notable motion during offshore operations. Large crane tip motion can lead to damaged guide pins at blade root during the blade installation. To ensure safe and cost efficient operations, it is of great importance to study the dynamic response of the jack-up crane vessel, especially of the crane tip and the installed components.

To date, limited work has been carried out on jack-up crane vessels used in offshore wind turbine installation. Duan and Olsson (2014) and Ringsberg et al. (2017) studied the soil impact loads on the spudcans of a jack-up crane vessel during the lowering and retrieval phases of jack-up legs. Weather window assessments were also conducted based on the spudcan impact force criteria. It was found that the leg lowering and retrieval operations are possible under larger wave heights in long waves. Van Dalfsen (2016) studied the effects of soil load modeling on the dynamic structural response of the jack-up crane vessel under

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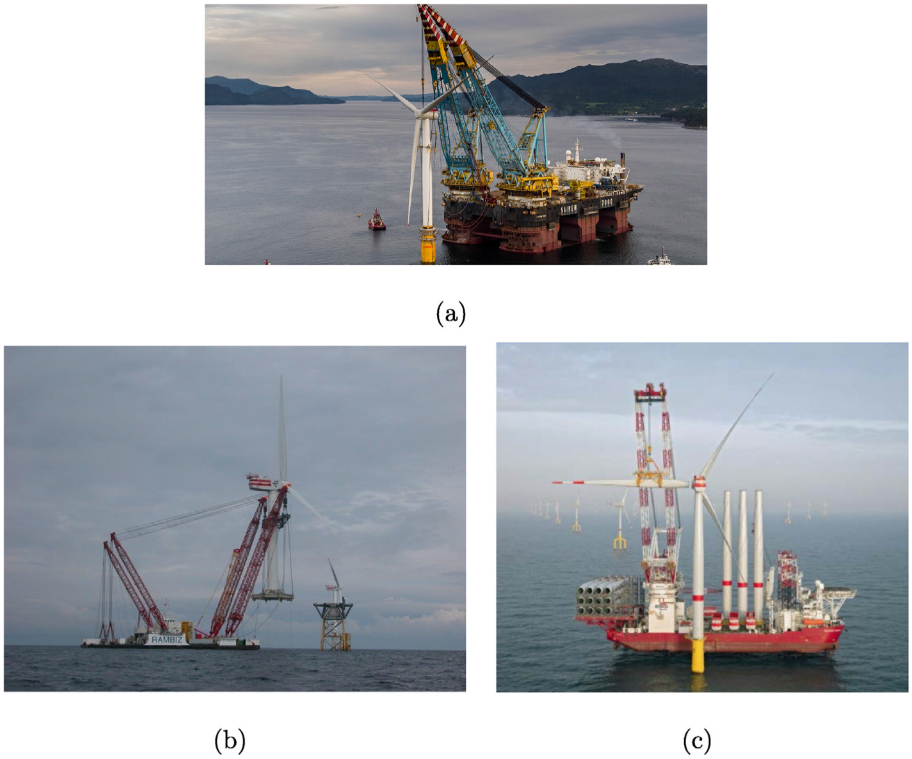

Fig. 1. Installation of offshore wind turbines: (a) and (b) Installation of fully assembled tower by floating crane vessels (Carbon Brief Ltd, 2017; Scaldis Salvage & Marine Contractors NV, 2018); (c) Single blade installation for using a vessel (Fred. Olsen Windcarrier AS, 2017).

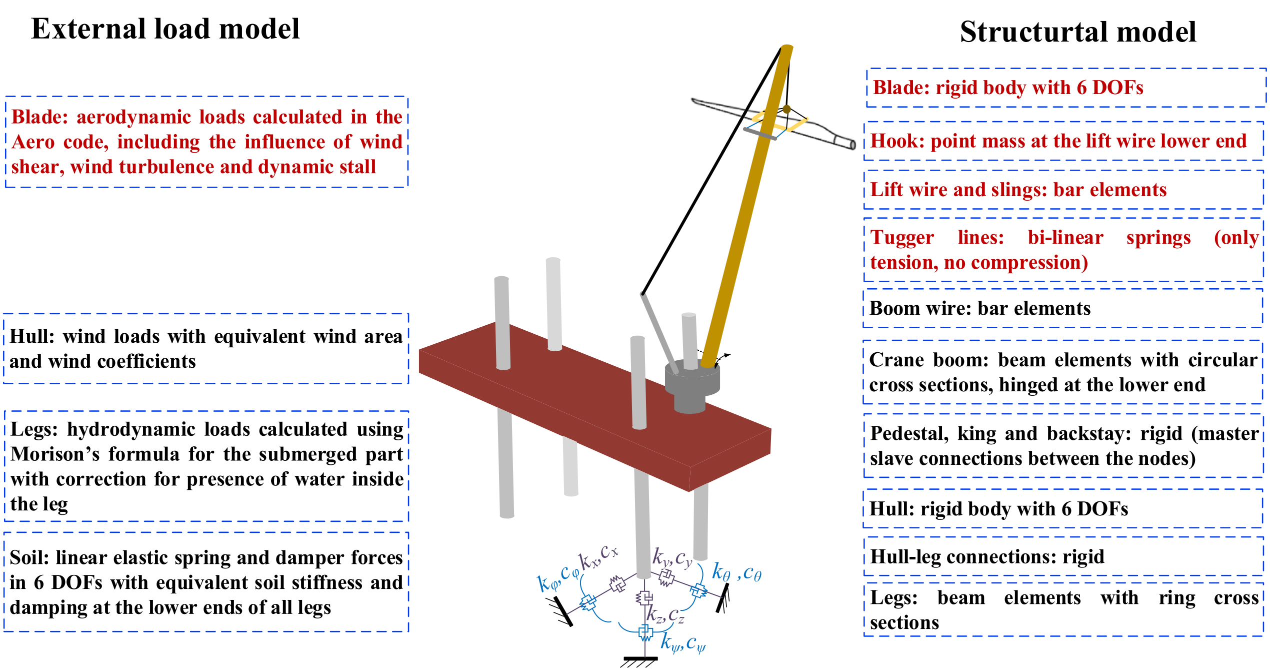

Fig. 2. The structural and external force models of a typical elevated jack-up crane vessel. The blade and the lifting gear are also illustrated here to give an overview of the fully coupled aero-hydro-soil-elastic-mechanical code, i.e., SIMO-RIFELX-Aero, for simulating installation of offshore wind turbine blades by jack-up crane vessels. The integration of the codes and the modeling of the blade and the lifting gear are discussed in details in Section 5.

survival conditions. The results indicated that advanced soil models are essential in the design check of jack-up crane vessels in extreme sea states. However, the dynamic motion response of the vessels during crane operations are not considered in these studies.

Zhao et al. (2018) developed an integrated dynamic analysis method for simulating installation of a single blade for wind turbines. The coupled aero-hydro-mechanical code SIMO-Aero was developed and verified, which is capable of accounting for blade aerodynamics, vessel hydrodynamics and system mechanical couplings. The SIMO-Aero code was used to study the dynamic response of a single blade installed by a jack-up crane vessel; however, the motions of the vessel and the crane were not considered by Zhao et al. (2018).

In the present study, a fully coupled model is developed for a typical jack-up crane vessel by using the SIMO (SINTEF Ocean, 2017b) and