Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 137 (2017) 346–357

Energy Procedia

www.elsevier.com/locate/procedia

14th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2017, 18-20 January 2017, Trondheim, Norway

A review of slamming load application to offshore wind turbines from an integrated perspective

Ying Tu[a,*], Zhengshun Cheng[b], Michael Muskulus[a]

[a] *Department of Civil and Environmental Engineering, Norwegian University of Science and Technology. Høgskoleringen 7A, 7491 Trondheim, Norway*

[b] *Department of Marine Technology, Centre for Autonomous Marine Operations and Systems (AMOS), Norwegian University of Science and Technology. Otto Nielsens veg 10, 7491 Trondheim, Norway*

Abstract

In harsh sea conditions, it is possible for offshore wind turbines (OWTs) to be exposed to slamming loads due to breaking waves, especially plunging breaking waves. These slamming loads lead to significant structural responses and can affect the ultimate limit state (ULS) design and the fatigue limit state (FLS) design of OWTs. However, detailed consideration of slamming loads is not a common practice in the design of primary structures in offshore wind industry. Studies on integrated dynamic analysis of OWTs with consideration of slamming loads are very limited. When applying slamming loads on OWTs, several aspects should be considered, such as the detection of breaking waves, the calculation of slamming loads, and the approaches to integrate the slamming loads in fully coupled analysis, etc. This paper provides an extensive review of key issues concerning these aspects, which can benefit the application of slamming loads on OWTs.

Keywords: Breaking waves; slamming loads; integrated dynamic analysis; offshore wind turbine

1. Introduction

Slamming loads resulting from plunging breaking waves are dangerous for offshore wind turbines (OWTs) exposed to certain wave conditions. Although many studies have been carried out in the past decades about slamming loads and their application to OWT designs, detailed consideration of slamming loads is still not a common practice in the design of primary structures in offshore wind industry. The slamming load application involves many research topics in oceanography and ocean engineering, which have been elaborated separately in their respective fields. However, a state-of-the-art method that takes different aspects of the application problem into account is still in absence; accord-

* Corresponding author. Tel.: +47 735 94557 ; fax: +47 735 97021.
E-mail address: ying.tu@ntnu.no

1876-6102
10.1016/j.egypro.2017.10.359

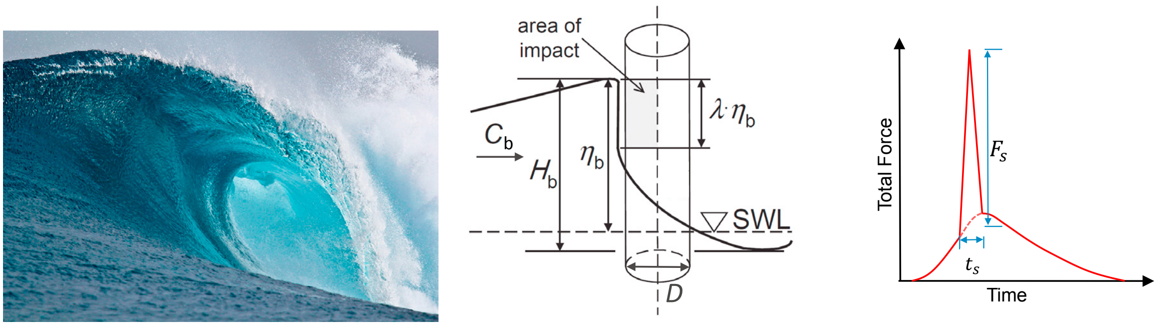
ingly, the numerical tools used in offshore wind industry usually do not have a function to include slamming loads in the simulations. These limitations restrain the application of slamming loads in the design practice of OWTs.

This study starts from an general introduction of breaking waves and slamming loads. Then, how to include the slamming load in the integrated dynamic analysis of OWTs is thoroughly reviewed and discussed, including the detection of slamming events, the calculation of slamming loads and the integration of slamming loads in fully coupled analyses. The status and issues of slamming load applications are discussed and some improvement possibilities are proposed.

2. General slamming force characteristics

2.1. Breaking waves

A breaking wave is a wave whose amplitude reaches a critical level at which it becomes unstable and dissipates large amounts of wave energy into turbulent kinetic energy. It may occur at certain sites, depending on the local water depth, the breaker height, the local wave length, the wave steepness, the sea bed slope and probably some other parameters. Among different types of breaking waves, the plunging breaking wave is most relevant to slamming loads on the offshore wind turbine supporting structures. It features a relatively small dissipating area, a very high local pressure and a high impulsive load. In this paper, wave slamming loads due to plunging breaking waves are mainly reviewed and discussed.



(a) Plunging breaking wave (b) Sketch of a breaking wave [28] (c) Typical wave slamming force

Fig. 1. Breaking wave and wave slamming force on a circular cylinder

2.2. Slamming load

The quasi-static wave force on a slender cylindrical structure is normally calculated by the Morison's equation as

$$F_{qs} = F_D + F_M \tag{1}$$

where F_D and F_M are the drag and inertia forces, respectively, and they are expressed as

$$F_M = \int_{-h_b}^{\eta_b} \rho \pi C_m \left(\frac{D}{2}\right)^2 a_x dz \tag{2}$$

$$F_D = 0.5 \int_{-h_b}^{\eta_b} \rho C_D D u \left|u\right| dz \tag{3}$$

in which ρ is the water density, η_b is the wave elevation at the breaking point, D is the diameter of the cylindrical structure, u and a_x are the velocity and acceleration of water particle. C_D and C_m are the drag and inertia coefficients, respectively, and they are dependent on Keulegan-Carpenter number, Reynolds number, roughness parameters and interaction parameters.