Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 116 (2015) 32 – 39

Procedia Engineering

www.elsevier.com/locate/procedia

8th International Conference on Asian and Pacific Coasts (APAC 2015)

Dynamic Analysis of an Offshore Wind Turbine Including Soil Effects

K.A. Abhinav, Nilanjan Saha*

[a]*Department of Ocean Engineering, IIT Madras, Chennai 600036, India*

Abstract

Offshore wind turbines (OWTs) offer an attractive, sustainable solution to the impending global energy crisis. A major challenge in fixed-bottom OWT design is accounting for soil-structure interaction (SSI) under the influence of random dynamic loading from wind, waves and currents. Usually, SSI is either ignored in OWT studies or is incorporated by means of simplified foundation concepts like the apparent fixity model. OWTs in shallow water depths (less than 30 m) are mostly supported on monopiles - large diameter steel pipe piles driven into the subsoil. Monopiles transfer the dynamic lateral loads into the soil by bending action. The present work deals with the dynamic analysis of the NREL 5MW OWT on a monopile foundation, in Indian waters. It involves parametric studies on various clayey soil profiles - soft, medium stiff and stiff clay. An operational wind speed of 12 m/s and a sea state of 4 m significant wave height and 10 s spectral peak period are considered. The OWT design should ensure that the natural frequency is away from the forcing frequencies of wind, wave and rotor. A water depth of 20 m is considered. Hub-height aerodynamic loads are obtained using the NREL-FAST code, which is based on the blade-element momentum (BEM) theory. The hydrodynamic time domain analyses are performed in the FEM based coupled hydrodynamic - geotechnical software, DNV-GL - USFOS. USFOS makes use of the JONSWAP spectrum to generate irregular waves. Soil is represented by means of *p-y*, *Q-z* and *t-z* curves. Results indicate the significance of including SSI in OWT studies. Variation in response due to change in pile penetration depth and pile diameter are also highlighted. Stiffness of clay is the design driver for OWTs.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015

* Corresponding author. Tel.:+91-44-22574827; fax:+91-44-22574802.
*E-mail address:*nilanjan@iitm.ac.in

1877-7058 © 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer- Review under responsibility of organizing committee , IIT Madras , and International Steering Committee of APAC 2015
doi:10.1016/j.proeng.2015.08.261

Keywords: offshore wind turbine, soil-structure interaction, monopile

1. Introduction

Offshore wind turbines are gaining popularity as the need to offset the nonrenewable energy crisis is being recognized. OWTs in shallow waters are usually supported on monopile substructures, which are essentially large diameter piles in the range of 3-6 m. Monopiles transfer lateral loads from wind and waves by bending action, into the soil. Unlike oil and gas structures, OWT systems are subjected to heavy lateral loads, often to the tune of 150% of the vertical loading (Lesny, 2010). This calls for a comprehensive dynamic analysis, especially in soft soils, where the natural frequency of the system could undergo significant variations (Bazeos *et al.*, 2002).

Laterally loaded piles are designed using the $p-y$ method specified by the API (2000). However, these soil curves are derived from experiments involving small diameter piles and their validity for monopile design is still being debated (Achmus and Abdel-Rahman, 2012). Lesny and Wiemann (2005), Haiderali *et al.* (2013), Achmus *et al.* (2009) etc. have made use of quasi-static mudline loads to investigate the response of monopiles. Abhinav and Saha (2015) analysed for a jacket subjected to random wave loads considering soil structure interaction while, Gao *et al.* (2010) showed that jacket structure can be analysed as a set of monopiles of varying diameters. ABS (2011) followed a quasi-aerostatic-hydrodynamic approach to study OWT response under different water depths. Bisoi and Haldar (2014) analyzed a 2MW OWT under dynamic loads, including soil-structure interaction (SSI) Here, the aerodynamic load at the hub was modelled as a function of the rotor frequency.

The present work deals with the analysis of a monopile support structure for the NREL 5MW baseline OWT, under aerodynamic and hydrodynamic loads, for varying soil conditions. The FEM-based code USFOS (SINTEF Group, 2001) is used for hydrodynamic analysis. USFOS implements a nonlinear FE formulation based on Green strain E (valid for all magnitudes of rotation and displacement), where a finite element represents an actual element of the structure. This pre-empts the choice of mesh-size and speeds up computation. The HHT-α method is used for dynamic analysis. Aerodynamic loads are derived using an aeroelastic code, FAST (Jonkman and Buhl, 2005). Three different clayey soil profiles - soft, medium stiff and stiff clay - are considered. The effects of soil stiffness variation, pile penetration depth and pile diameter, on the lateral response and natural frequency of the OWT structure are investigated. Soil stiffness is derived using the soil curves specified by API (2000). Results show significant variations in the response and point towards the need for detailed modelling of soil-structure interaction in the analysis of OWT structures.

2. Numerical modeling

2.1. Structural model

The NREL 5MW baseline OWT, conceptualized by Jonkman *et al.* (2009), is considered in the present study. The numerical model of a monopile supporting the NREL 5MW OWT, in a water depth of 20 m is developed in USFOS. The turbine rotor-nacelle-assembly (RNA) is supported by a steel tower, connected to the monopile through a cylindrical transition piece. The diameter and thickness of the tower varies from 6m and 0.027 m respectively, at the base, to 3.87 m and 0.019 m respectively, at the top. The components of the OWT structure and the corresponding design levels are represented in Figure 1. A higher density value is considered for steel (8500 kg/m^3) to account for the absence of bolts, flanges and welds in the model. The monopile has a diameter of 6 m and is founded on uniform stiff clay. Two other soil profiles (medium-stiff clay and soft clay) are also considered for the analysis, to investigate the response of the structure under dynamic loads. The soil profiles are defined in Table 1. Here, γ' is the submerged unit weight, Su is the undrained shear strength and ε_{50} is the strain at 50% of maximum stress in undrained compression test. The depth of embedment is taken as 42m or 7 times the pile diameter. The wall thickness (t) of the monopile is defined by API (2000), on the basis of its diameter (D), as shown in equation 1.

Download English Version:

https://daneshyari.com/en/article/855974

Download Persian Version:

https://daneshyari.com/article/855974

Daneshyari.com