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A Study on Lateral Deformation of Monopile of Offshore Wind Turbine due to Environmental Loads

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Abstract

An analytical study is performed to evaluate the displacement behavior of monopile of offshore wind turbine founded in sandy soil. The system consists of pile, turbine tower and soil modeled as 3D finite element model in ANSYS. An explicit dynamic analysis is performed in a time domain considering soil as an explicit material and wind and wave loads act on the turbine tower as static loads. Behavior of monopile in soil is analyzed by considering soil pile interaction. The study shows that pile displacement and pile tilt angle depends on soil properties and pile embedded length and pile diameter.

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Keywords: Deformation, Explicit dynamics; Monopile; Offshore wind turbine; Soil-pile-interaction.

1. Introduction

Wind turbines are power tools to tap nonconventional wind energy. Onshore wind turbine needs plenty of land area for power generation. Thus it was a natural step to take Offshore Wind Turbine (OWT). The wind resources are even more abundant and of better quality at sea as compared to onshore.

The major components of the offshore turbine are turbine blades, Rotor- Nacelle Assembly (RNA), tower transition piece and the foundation. It can provide 2 or 3 blades for turbine, but mostly 3 blades are provided.

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Cumulative Capacity for offshore wind turbine is approximately 9 -10 GW in Europe. Mostly 4 to 11 rpm is approximately taken for a wind turbine.

The design and construction of foundations for offshore turbines are challenging because of the harsh environmental conditions. The support structures for OWT are monopile structure, tripod structure, lattice structure, gravity structure, tripile foundation, and floating structure.

The choice of monopiles results when water depth ranges from 10 m to 30 m. OWT supported on monopile foundations are dynamically sensitive because the overall natural frequencies of these structures are close to the different forcing frequencies imposed upon them. Degradation of soil stiffness due to dynamic and cyclic loading may lead to permanent displacement of the turbine which may jeopardise its performance. Wind turbines typically cannot tolerate more than 0.5 degrees tilt [1].

The overturning moment in jacket super structure supported in multi-piles is transferred as axial loads to opposing foundation piles. For monopile the overturning moment is resisted by horizontal soil reaction along embedded length of monopile. As the pile is not fixed at the top, it is free to rotate and translate. The pile must be long enough to mobilise enough soil over its length to transfer all loads and prevent toe kick. Hence soil pile interaction has an important influence to resist lateral loads. Relation between lateral forces (P) applied to monopile and lateral displacement of pile (y) is the P-y curve shows soil pile interaction of the system is the lateral stiffness of soil.

This study deals with pile displacement behavior by considering soil pile interaction for laterally loaded wind turbine tower.

2. Wind Turbine and Soil Characteristics

About 75% of offshore wind turbine is founded on monopiles foundation. A location at Rameswaram, Tamilnadu has been selected based on environmental data obtained from National Institute of Ocean Technology (NIOT), Chennai. Soil profile mainly consists of sand and a few layers of silt and clay [2]. Soil is behaves as an elasto-plastic material, hence it is modelled as Drucker - Prager model. The Drucker–Prager yield criterion is a pressure-dependent model for determining whether a material has failed or undergone plastic yielding. The criterion was introduced to deal with the plastic deformation of soils.

The material of turbine tower and monopile is steel and the strength properties are modulus of elasticity, Poisons ratio, density. Turbine tower with height 80 m and cross section diameter of 4.5 m is selected as per NIOT, Chennai [2]. Diameter (D) of monopile ranges from 4 m - 6 m and corresponding embedded length is ranges from 7D to 8D.

3. Loads on Turbine Tower

The response of the support structure depending on the loading conditions that the structure likely to experience in ocean environment.

3.1. Wave Load

Compared to the wave load the other loads like current loads are negligible and are not taken into consideration. For slender structures, Morison’s equation can be applied to calculate the wave loads [3], [4], [5], [6] and [7].

Wave force = Drag force + Inertia force

$$F = C_D \ \tfrac{1}{2} \rho D |U| U + \rho C_I \ \pi D^2/4 \ a_x \tag{1}$$

C_D - Drag coefficient

ρ - Mass density of sea water = weight density of water / acceleration due to gravity in kg/m^3

D - Projected area normal to cylinder axis / unit length in m

C_I - Inertia coefficient for smooth circular cylinder

U - Component of velocity vector of water due to wave normal to axis of thee member in m/s

The expression for velocity and acceleration are;

$$U = \{h_w \pi \cosh(k (z_2 + d_w)) \ \cos(kx - \omega_w t)\} / \{T_w \ \sinh (kd_w)\} \tag{2}$$