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Seismic Analysis of Wind Turbines Including Soil-Structure Interaction

Mohammad Vatanchiyan[1], Ahmad Shooshtari[2]

1- Ph.D. Student, Department of Civil Engineering, Ferdowsi University, Mashhad, Iran

2- Assistant Professor, Department of Civil Engineering, Ferdowsi University, Mashhad, Iran

ashoosht@um.ac.ir

Abstract

This paper investigates the seismic behavior of wind turbines including soil-structure interaction (SSI). Because of high risk of earthquake in Iran and the effects of soil condition in seismic analysis, one of the most important issues in design of wind turbines is seismic analysis of these structures including SSI. In this study a model for seismic analysis of wind turbines including SSI is introduced. SSI can be considered by rigorous or approximate methods. Rigorous methods require considerable amount of expertise in idealizing the dynamic system and significant data preparation and interpretation of the results and also are not economical. Instead the approximate methods can save time and expenses by representing a more practical model for SSI, although these procedures have approximations that cause deviations smaller than the typical engineering accuracy. For the present study SSI effects is considered using Cone Models that is an approximate procedure. Wind turbine is modeled in FE based program OpenSees with beam-column elements. Results show that SSI can affect the responses and should be considered in seismic analysis of wind turbines to have more trustworthy outputs.

Keywords: wind turbine, soil-structure interaction, seismic analysis, cone models, OpenSees

1. Introduction

Demand for higher rated power from wind turbines causes a great development in size of these structures. The size of wind turbines in last years has beensignificantly increased. Increase in size of these structures and also theneed to have a more economical structure make modern wind turbines more flexible than the older ones. This more flexibility means that dynamic behavior and ability to predict it becomes more important and the wind turbine is sensitive to dynamic excitation in low frequencies. Modern wind turbines are designed with variable speed systems so that rotating speed of rotor varies in range 10-20 rpm. So the first excitation frequency is around 0.17-0.33 Hz that is considered as 1P frequency. Since in modern wind turbines the first resonance is between 1P and 3P, exact evaluation of resonance frequency has a great importance [1].

Generally design loads of a wind turbine are from wind loads but when these structures are installed in regions with high level of earthquake risk, dynamic response of them to loads and seismic excitations must be investigated and considered in design. In seismic analysis soil-structure interaction (SSI) must be considered because dynamic behavior of wind turbine structure during an earthquake is affected by interaction among three substructures: wind turbine structure, foundation and soil around the foundation [2].This issue has been confirmed in many studies that a general review of researches can be found in [3]. In a study by Zhao and Maisser [2], a multi-body model for dynamic analysis of wind turbine towers under wind loads and earthquake excitations including SSI was proposed. It was concluded that considering SSI in analysis can lead to lower natural frequencies. Also they showed that SSI has effects on bending vibrations of tower and in seismic design of wind turbines, especially in areas with soft soil, SSI must be considered. Guangling and Jie [4], in a study on a 1 MW wind turbine, showed that the effect of earthquake in design of wind turbines is not negligible and must be considered in seismically active zones. Adhikari and Bhattacharya [5] deriveda closed-form approximate expression for the first natural frequency of the wind turbine structures taking the soil-structure interaction into account. Harte et al. [1] investigated the along-wind forced vibration response of an onshore wind turbine. The study included the dynamic interaction effects between the foundation and the underlying soil. The soil-structure interaction was shown to affect the response of the wind turbine. This was examined in terms of the turbine structural displacement and also the base shear and bending moment in the tower and the foundation.

Because of seismically active zones in Iran and the effects of soil condition in seismic analysis, this paper attempts to investigate the seismic behavior of wind turbines including SSI. In this study a full FE model of a