8th International Conference on Seismology & Earthquake Engineering
11-13 Nov. 2019, Tehran, Iran

SEISMIC RESPONSE ASSESSMENT OF OFFSHORE WIND TURBINES USING ENDURANCE TIME METHOD

Neda BOZORGI
Ph.D. Candidate, School of Civil Engineering, University of Tehran, Tehran, Iran
nb.bozorgi@ut.ac.ir

Mohammadreza BAHAARI
Professor, School of Civil Engineering, University of Tehran, Tehran, Iran
mbahari@ut.ac.ir

Keywords: Offshore wind turbine, Seismic performance, Endurance time method, Dynamic time history analysis, Incremental dynamic analysis

This study examines the applicability of Endurance Time (ET) method in the seismic response assessment of offshore wind turbines. The ET method is a time history dynamic analysis in which structures are subjected to predesigned intensifying acceleration time histories. The ET method produces incremental dynamic analysis curves by a single time history analysis, and hence considerably reduces the required computational time. Although many research performed to assess offshore wind turbines structures under wind and wave loads, few attentions devoted to their performance under seismic actions. The performance of an offshore wind turbine designed by existing codes is evaluated by the ET method. Results will be presented at different hazard levels. The transformation of ET curves by these endurance time excitations to incremental dynamic analysis curves is briefly explained.

The concept of endurance time method could be explained by a hypothetical test. In this example, the objective is to determine the performance of three structures in an earthquake. These structures are located in a shaking table as shown in Figure 1. These structures are subjected to random excitation, the amplitude of which increases with time. With the intensification of the amplitude of excitation, the vibration amplitude of the structures increases as well as the structures demand. As time passes in this test, structures gradually move from elastic region to nonlinear and they finally collapse. Damage indicators of these structures are monitored during the test. For example, maximum inter-story drift ratio is plotted against time.

The trend of increasing load functions introduces a new definition of time in this analysis type. Time in the endurance time analysis is related to intensity in other dynamic analysis. Endurance time analysis results are presented by increasing curves in which horizontal axis is time as an indicator of intensity and the vertical axis is a response parameter of the structure, that is the maximum response of the structure up to time “t”. The vertical axis is formulated as follows:

$$\Omega\big(f(t)\big) = Max\big(\left|f(\tau)\right|\big) \quad 0 \le \tau \le t \tag{1}$$

where Ω is the maximum response in the time [0,t] and f is the response history as a function of time. Maximum drift, base shear, plastic rotation can be considered as a response. Due to equation 1, if maximum inter-story drift is taken as a response parameter, Ω is the maximum drift ratio that the structure experiences up to time t.

In this paper, a 5 MW Turbine supported by a jacket steel structure in depth of 50 m is selected according to Upwind reference jacket in phase 1 of OC4 project (Fisher et al., 2010). Jacket structure is modeled in SAP 2000 software with fixed support consideration. Supporting structure is composed of four legs and a concrete transition piece to provide support for the tower of wind turbine. All legs and braces are modeled with frame elements while, shell elements are used to model the tower of the wind turbine. Finally, the effect of the gearbox and motor of the wind turbine is considered by aims of concentrated mass definition (see Figure 2).

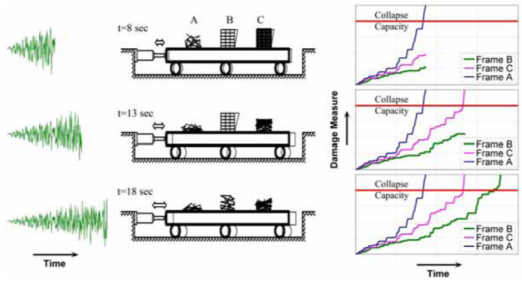

Figure 1. The concept of the endurance time method for determining the seismic demand prediction of three structures (Estekanchi et al., 2008).

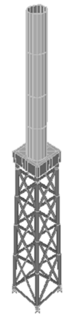

Figure 2. Perspective of 3D SAP model of wind turbine with jacket substructure.

The Wind turbine is analyzed under three endurance time history records that named ETA20kd01 to ETA20kd03 which are plotted in Figure 3. As shown in this figure, the duration of each record is 20 second and the maximum acceleration of records is 0.78 g. Nonlinear time history analysis is done for each record with considering a 5 percent damping ratio for structure. For each ET record, tower top displacement is plotted versus time.

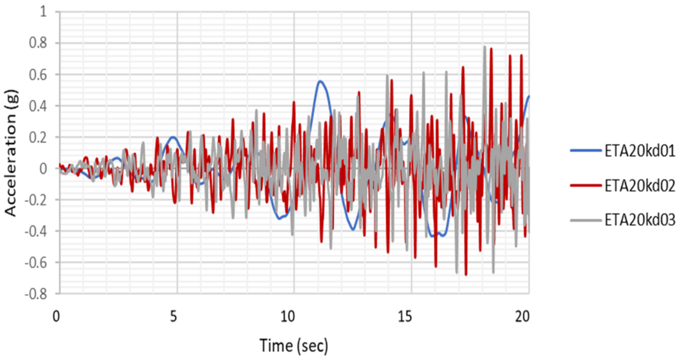

Figure 3. ETA20kd01 to ETA20kd03 acceleration functions.

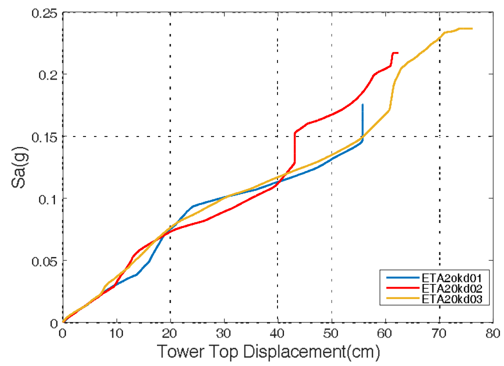

Figure 4. Tower top displacement under ETA20kd01 to ETA20kd03 accelerogram.

As shown in Figure 4, ET curves are presented based on tower top displacement and spectral response acceleration. It could be seen that the maximum displacement of tower is occurred due to ETA20kd03 with the measure of 76 cm. This value could represent the damage measure for seismic assessment of wind turbine or compare with any applicable standard codes in the design process. It may be concluded that not only ET method is applicable in offshore structures, but also could predict the response of structure with more precision. Through this method, the performance of structure could be obtained by only one analysis for each record. Despite IDA method which needs more than ten steps for scaling ground motion records and analysis process, ET curves are produced only by one step analysis; hence, the total time of analysis will be decreased considerably.

REFERENCES

Basim, M.C. and Estekanchi, H.E. (2015). Application of endurance time method in performance-based optimum design of structures. Structural Safety, 56, 52-67, https://doi.org/10.1016/j.strusafe.2015.05.005.

Fischer, T., De Vries, W., and Schmidt, B. (2010). UpWind Design Basis. Technical report, Endowed Chair of Wind Energy (SWE) at the Institute of Aircraft Design, University of Stuttgart, Stuttgart.

Mashayekhi, M., Estekanchi, H.E., Vafai, H., and Mirfarhadi, S.A. (2018). Development of hysteretic energy compatible endurance time excitations and its application. *Engineering Structures*, *177*, 753-769.

Mashayekhi, M., Estekanchi, H.E., Vafai, H., and Mirfarhadi, S.A. (2018). Simulation of cumulative absolute velocity consistentendurance time excitations. *Journal of Earthquake Engineering*, 1-26.