VC4OWT: MATLAB Interface for Vibration Control of Offshore Wind Turbine

Thanh-Tuan Tran[1,2](✉), Anh-Tuan Cao[1], and Dookie Kim[1]

[1] Department of Civil Engineering,
Kunsan National University, Gunsan, South Korea
tranthanhtuan@hotmail.com.vn,
anhtuan.hcmut@gmail.com, kim2kie@kunsan.ac.kr
[2] Faculty of Technology and Technique,
Quy-Nhon University, Quy Nhon, Vietnam

Abstract. In this study, a new graphical user interface (GUI), VC4OWT, is developed to evaluate the structural response of National Renewable Energy Laboratory (NREL) 5-MW offshore wind turbine (OWT) subjected to seismic excitations. Finite element model of OWT has been modelled and analyzed using the Opensees simulation platform. Performances of structure with and without friction damper considering soil-structure interaction (SSI) have been studied to reduce the effects of seismic load. The diagonal-bracing friction damper system is added at platform for the vibration purpose. The obtained outputs demonstrate that VC4OWT is a functional and efficient software to simulate and study the vibration control of OWT.

Keywords: Vibration control · Friction damper · Wind turbine
Soil structure interaction

1 Introduction

Recently, lots of researchers have found vibration control method for OWT under seismic loading condition [1]. The main object of this work provides a software in order to control the dynamic structural response of NREL 5-MW offshore wind turbine due to earthquake load. Friction damper [2, 3] is applied for the model to control the vibration of the structure. Nonlinear time history dynamic analysis is used for evaluating the performances of the wind turbine.

The Open System for Earthquake Engineering Simulation [4] is one of the most powerful tools for modelling and analyzing the structure under earthquake excitations. This tool includes a wide range of materials, elements, and solution algorithms. The program has been developed as an open-source simulation platform based on C++ and Tcl/Tk languages.

Based on the utilities of OpenSees and Tcl/Tk, the MATLAB [5] interface code for vibration control of offshore wind turbine, namely VC4OWT, is developed. This software is able to simulate responses of OWT subjected to seismic load.

M. F. Randolph et al. (Eds.): VSOE 2018, LNCE 18, pp. 1–7, 2019.
https://doi.org/10.1007/978-981-13-2306-5_75

2 Finite Element Model of the Offshore Wind Turbine

2.1 OTW Structure

The structure used in this study is a typical 5-MW wind turbine jacket foundation model (NREL 5 MW-OC4-Jacket) developed by NREL under flexible, steady wind and regular waves with zero phase. Originally Vemula et al. [6] designed this support structure and Song et al. [7] used this design for the offshore code collaboration continuation (OC4) project at 50 m of water depth and water's density is $1025\,\mathrm{kg/m^3}$.

The interface nodes of the jacket rigidly connected to the transition piece (TP). TP is represented as a density filling a rectangular body. The mass density, Young's and shear modulus and Poisson's ratio of the TP are $1807\,\mathrm{kg/m^3}$, $2.1 \times 10^{11}\,\mathrm{kg/m^2}$, $8.08 \times 10^{10}\,\mathrm{kg/m^2}$ and 0.18 respectively. The rotor nacelle assembly (RNA) along the hub is considered as rigid bodies. The mass of RNA is considered as lumped mass at the top of the tower following to the baseline model. The full model consists of RNA, tower, TP, jacket structure and a circular foundation (monopile below the mudline). The other geometric properties of the structure are listed in Table 1. Figure 1 shows the typical model of the OWT. The damper elements are in form of Truss Element. Four friction dampers, as shown in Fig. 1, are installed.

Table 1. Overview of the OWT

Parameter	Value
Tower base OD [m]	5.6
Tower base thickness [m]	0.032
Tower top OD [m]	4
Tower top thickness [m]	0.03
Tower Length [m]	68
TP dimension, [m3]	9.6 × 9.6 × 4
RNA mass [kg]	350 × 103
Tower mass [kg]	230 × 103
TP mass [kg]	666 × 103
Jacket mass [kg]	655.83 × 103
Total OWT mass [kg]	1.9018 × 106

Note: OD = Outer diameter.
TP = Transition piece.
RNA = Rotor nacelle assembly.

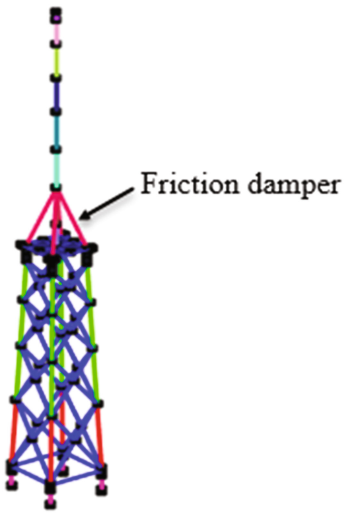


Fig. 1. Model of jacket supported OWT

2.2 Soil-Structure Interaction

In this study, the OWT structure are assumed to be located on a square rigid mat. The underlaying soil is considered as a homogeneous half-space, linear elastic and material damping are neglected, based on the concept of Voigt viscolatics Cone model (Fig. 2). The stress-strain relationship is specified by two independent elastic constants, i.e., the

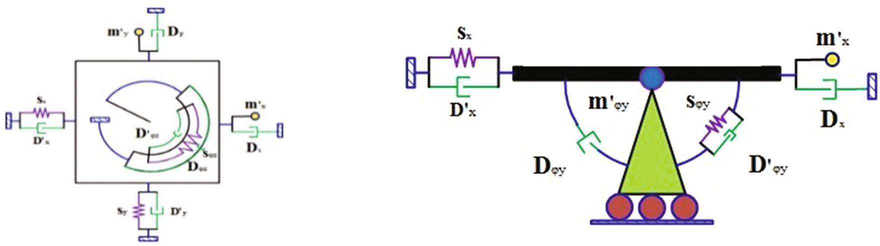


Fig. 2. Soil model

shear modulus G, and the Poisson ratio ν. The Cone model is used for modeling the under-laying soil with sufficient accuracy [8].

Expressions for the soil foundation model properties such as spring stiffness, viscous damping coefficient and added masses are presented as follows:

$$K = \frac{\rho V^2 A_0}{z_0}, C = \rho V A_0, C' = 2\frac{\zeta_0}{\omega_0} S, m' = \frac{\zeta_0}{\omega_0} C$$
$$K_\varphi = \frac{3\rho V^2 I_0}{z_0}, \quad C = \rho V I_0, \quad C'_\varphi = 2\frac{\zeta_0}{\omega_0} S_\varphi, \quad m'_\varphi = \frac{\zeta_0}{\omega_0} C$$

Where V is the shear wave velocity for sway and torsional motions and the dilatational wave velocity for rocking motions; ρ is the specific mass of soil and z_0 is a parameter that depends on soil's property [8]. A_0 is the area, I_0 is the area moment of inertia, ζ_0 is the damping ratio and ω_0 is the fundamental frequency of the soil-structure system.

3 Description of VC4OWT

The software consists of four main groups. In order to conduct the control vibration for an OWT structure, the number of parameters in these groups should be defined. Figure 3 illustrates the main groups of the software. Each group will be introduced with its capabilities as follows:

Group 1 "Input": The initial parameters for the OWT model, including the geometries of model and the ground motions. The button "Model" is used for importing the model from an existing excel file. The drop-down button in earthquake data panel allows user to define the directions of excitation seismic, including x-, y- or bi-directions.

Group 2 "Analysis Cases": This group includes a set of three options and one checkbox.

- "w/o damper": This option is used for setting up the model without friction damper.
- "brace": This option is used for setting up the model with braces.
- "damper": This option is used for setting up the model with friction damper.
- "SSI": This checkbox is used for considering the Soil-structure interaction.

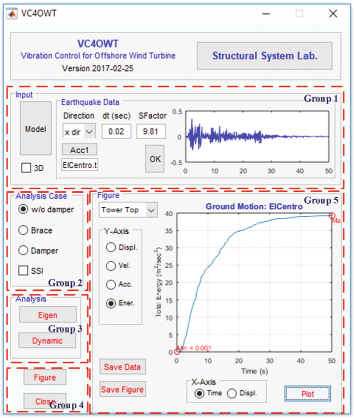


Fig. 3. Main groups of VC4OWT software

Group 3 "Analysis": This group contains two buttons. They are summarized as follows:

– "Eigen": The Eigen analysis is performed.
– "Dynamic": The user can conduct the dynamic analysis.

Group 4: The group shows the results and shut down the software.

– "Figure": This button is used for plotting.
– "Close": This button is used for shutting down the software.

Group 5: shows panel in order to plot the results.

– "Plot": This button shows the results of OWT.
– "Save Data": The output data can be saved by using this button.
– "Save Figure": This button is used for saving figures.

4 A Case Study

To assess the efficiency of VC4OWT, natural frequency of model are compared with the results using SAP2000. The results is good enough to verify the software (The natural frequency of mode 1 from model using SAP2000 and VC4OWT are 0.3274 and 0.32648, respectively).

In this study, the Imperial Valley is applied to evaluate the effect of friction damper on vibration control. Figure 4 represents time histories of ground motions applied on OWT structure.

The displacement at tower top and base node of OWT without damper (red line), brace (black line) and friction damper (blue line) are shown in Fig. 5. As seen that the decreasing amounts of maximum tower top and base displacements are 56% and 53% under earthquake load for friction damper. In case using the brace, the decreasing amounts at top node are 38% under seismic load.

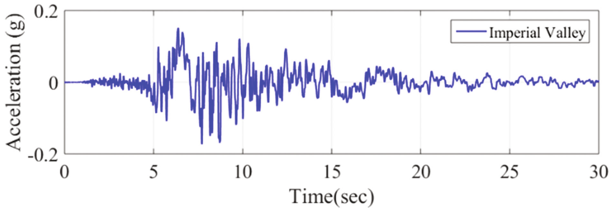


Fig. 4. Ground motions

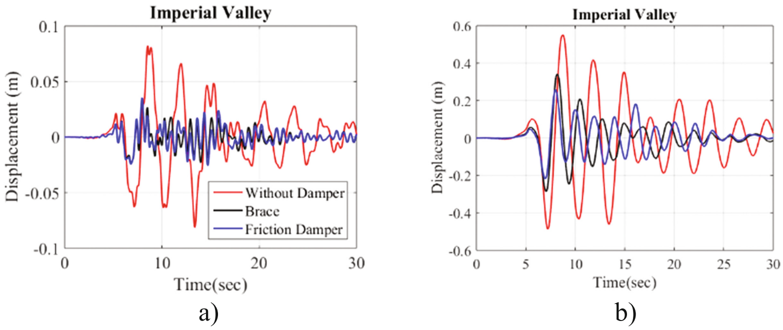
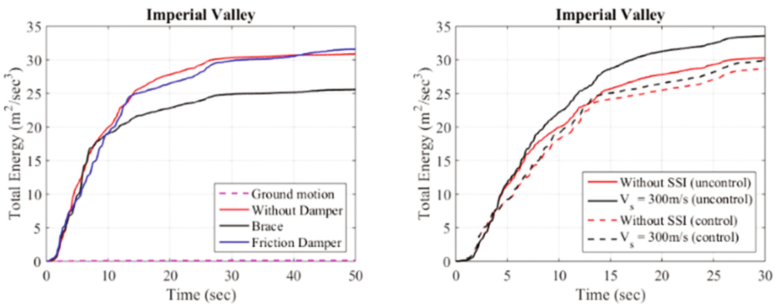


Fig. 5. Maximum displacement at base (a) and top (b) of tower with different controls

In this software, the wavelet analysis is applied to evaluate the release of energy. Many researchers have used wavelet analysis in damage detection of the wind turbine [9, 10]. Total energy of a certain earthquake is almost unchanged, but the energy of dynamic response of the structure will be different. The 10th order Daubechies mother wavelet [11] is used as a basis wavelet function.

Total maximum energy at the top node of the structure is shown in the Fig. 6. Figure 6(a) shows the total released energy at tower top node of structure response under excitation. The maximum total energy is 0.094 m^2/s^3 which is increased to 8.25 m^2/s^3 when the friction damper is applied. Additional, the total energy is released in structure with friction damper case increases comparing to the total energy is released in structure without damper. Figure 6(b) describes the maximum total energy of structure with and without friction damper under the seismic load considering SSI effect. Generally, when decreasing the shear wave velocity, the total energy associated with the response of structure increases. It is raised from 8.24 m^2/s^3 to 9.58 m^2/s^3 when shear wave velocity decrease from 1000 m/s to 300 m/s. In case of uncontrol structure, the total energy shows some similar results when considering the effect of SSI.



(a) (b)

Fig. 6. The total released energy of OWT structure with (a) the different control system (b) the different shear wave velocity

5 Summary

This paper introduces a graphical user interface is developed based on the Opensees source for vibration control of the OWT structure. In this software, the structural responses of structure with and without friction damper were observed while SSI was considered as an option. Because of its functionality and sufficiency, VC4OWT software is promising in further studies of vibration control for offshore wind turbine. In the future work, multiple choices of ground motion will be available and nonlinear friction damper will be considered.

References

1. Basu, B., Staino, A., Dinh, N.V.: Vibration of wind turbines under seismic excitations. In: Fifth Asian-Pacific Symposium on Structural Reliability and its Applications (5APSSRA), 23–25 May 2012, Singapore (2012)
2. Pall, A.S., Marsh, C.: Energy dissipation in large panel structures using limited slip bolted joints. In: Proceedings, AICAP/CEB Seismic Conference, Rome, Italy, May, vol. 3, pp. 27–34 (1979)
3. Pall, A.S., Marsh, C.: Friction devices to control seismic response. In: Proceeding, SCE/EMD Specialty Conference on Dynamic Response of Structure, Atlanta, USA, pp. 809–818 (1981)
4. OpenSees – Open System for Earthquake Engineering Simulation: Pacific Earthquake Engineering Research Center. (2017). http://opensees.berkeley.edu
5. MATLAB and Statistics Toolbox Release: The MathWorks Inc. Natick, Massachusetts (2015)
6. Vemula, N.K., DeVries, W., Fischer, T., Cordle, A., Schmidt, B.: Design solution for the upwind reference offshore support structure. Upwind deliverable D4.2.6 (WP4: offshore foundations and support structures), Ramb_ll Wind Energy (2010)
7. Song, H., Damiani, R., Robertson, A., Jonkman, J.: A new structural-dynamics module for offshore multimember substructures within the wind turbine computer-aided engineering tool FAST. In: The Twenty-third International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers (2013)

8. Wolf, J.P.: Foundation vibration analysis using simple physical models. Pearson Education, Upper Saddle River (1994)
9. Dinh, V.-N., Basu, B., Brinkgreve, R.B.J.: Wavelet-based evolutionary response of multispan structures including wave-passage and site-response effects (2014). American Society of Civil Engineers
10. Dinh, V.-N., Basu, B.: Monitoring of flexible support effects using the responses of multi-span bridges via wavelet transform. In: 6th European Workshop on Structural Health Monitoring. Tu.3.D.4
11. Daubechies, I.: Ten lectures on wavelets. Society for Industrial and Applied Mathematics, Philadelphia (1992)