Ali Vatanshenas
Structure and Environment 2025, vol. 17, (1), pp. 18-27, Article number: el 003
https://doi.org/10.30540/sae-2025-003

Structure and Environment
ISSN 2081-1500
e-ISSN 2657-6902
https://content.sciendo.com/sae
https://sae.tu.kielce.pl

sciendo

Kielce University of Technology

DOI: 10.30540/sae-2025-003

INVESTIGATING EFFECTIVENESS OF TUNED MASS DAMPER (TMD) ON CONTROL VIBRATION OF WIND TURBINE-SOIL INTERACTION

BADANIE EFEKTYWNOŚCI DYNAMICZNEGO TŁUMIKA DRGAŃ (TMD) POD KĄTEM KONTROLI WIBRACJI W INTERAKCJI TURBINY WIATROWEJ Z PODŁOŻEM GRUNTOWYM

Ali Vatanshenas*
Tampere University, Finland

Abstract

Soil-structure interaction (SSI) effects were investigated on structural responses of wind turbine. Force versus deformation (i.e., p-y curves) was simulated by multilinear elastic springs. The whole system, including the structure, control vibration system and soil nonlinear effects are simulated within a single three-dimensional finite element model. Modeling accuracy was verified using available results related to a 65 kW wind turbine discussed in the literature. Pushover analysis results indicated a fixed-base assumption ends up with overestimation of stiffness compared to the case where SSI effects are considered. Moreover, it is observed that the performance of tuned mass damper (TMD) is highly dependent on its tuned frequency domain, and its efficiency decreases significantly after SSI effects are considered. Lateral deformations of a wind turbine are much higher compared to the fixed-base condition. Therefore, SSI effects play a crucial part in designing wind turbines and should not be neglected in practice.

Keywords: dynamic analysis, pushover analysis, p-y curves, soil-structure interaction, tuned mass damper, wind turbine

Streszczenie

Zbadano wpływ interakcji konstrukcji z podłożem gruntowym (SSI) na zachowanie konstrukcji turbiny wiatrowej. Zależność siły od odkształcenia (tj. krzywe p-y) zasymulowano za pomocą wieloliniowych sprężyn elastycznych. Cały system, w tym konstrukcja, system kontroli wibracji i nieliniowe efekty podłoża, jest symulowany w ramach jednego trójwymiarowego modelu elementów skończonych. Dokładność modelowania została zweryfikowana przy użyciu dostępnych wyników dla turbiny wiatrowej o mocy 65 kW, omówionych w literaturze. Wyniki analizy statycznej (pushover) wykazały, że przy założeniu o nieruchomej podstawie dochodzi do przeszacowania sztywności w porównaniu z przypadkiem, w którym uwzględniono efekty SSI. Ponadto zaobserwowano, że wydajność tłumika TMD jest silnie zależna od jego dostrojonej domeny częstotliwości, a jego efektywność znacznie spada po uwzględnieniu efektów SSI. Odkształcenia poziome turbiny wiatrowej są znacznie większe w porównaniu z warunkami nieruchomej podstawy. Dlatego efekty SSI odgrywają kluczową rolę w projektowaniu turbin wiatrowych i nie powinny być pomijane w praktyce.

Słowa kluczowe: analiza dynamiczna, krzywe p-y, analiza statyczna (pushover), interakcja konstrukcji z podłożem, dynamiczny tłumik drgań, turbina wiatrowa

REFERENCES

[1] Arakawa C., Ueda Y. (2012): *Development of wind power in Japan after disaster of earthquake and Fukushima accident*. [in] Proceedings of the European Wind Energy Association Annual Event, Copenhagen, Denmark, 2012.

*Tampere University, Finland, e-mail: a.vatanshenas@gmail.com

[2] Arany L., Bhattacharya S., Macdonald J.H., et al. (2016): *Closed form solution of Eigen frequency of monopile supported offshore wind turbines in deeper waters incorporating stiffness of substructure and SSI*. Soil Dynamics and Earthquake Engineering. 1(83): 18-32.
[3] Babakhani B., Saffar Yosefi Fard H. (2019): *Advanced structural modeling techniques with SAP2000*. Pardis-Elm Publications.
[4] Bak C., Zahle F., Bitsche R., et al. (2013): *The DTU 10-MW reference wind turbine*. In Danish Wind Power Research.
[5] Bakre S.V., Jangid R.S. (2007): *Optimum parameters of tuned mass damper for damped main system. Structural Control and Health Monitoring.* The Official Journal of the International Association for Structural Control and Monitoring and of the European Association for the Control of Structures 14(3): 448-470.
[6] Butt U.A., Ishihara T. (2012): *Seismic load evaluation of wind turbine support structures considering low structural damping and soil structure interaction.* European wind energy association annual event. April 2012, pp. 16-19.
[7] Bazeos N., Hatzigeorgiou G.D., Hondros I.D., et al. (2002): *Static, seismic and stability analyses of a prototype wind turbine steel tower.* Engineering structures 24 (8): 1015-1025.
[8] Carlton B.D., Pestana J.M. (2012): *Small strain shear modulus of high and low plasticity clays and silts*. [in.] 15th World Conference on Earthquake Engineering, Lisbon, Portugal.
[9] Clark A.J. (1988): *Multiple passive tuned mass dampers for reducing earthquake induced building motion*. [in] Proceedings of the 9th world conference on earthquake engineering, Tokyo-Kyoto, Japan 2 Aug 1988 (Vol. 779, p. 784).
[10] Connor J.J. (2003): *Structural Motion Control*, Pearson Education, Inc.
[11] CSI. SAP2000 v14 (2008) Calculation of wave load values, Technical note. California: CSI (Computers and Structures Inc.) Berkley.
[12] Damgaard M., Zania V., Andersen L.V., et al. (2014): *Effects of soil–structure interaction on real time dynamic response of offshore wind turbines on monopiles*. Engineering Structures. 15(75): 388-401.
[13] Darendeli M.B. (2001): *Development of a new family of normalized modulus reduction and material damping curves.*
[14] GB 50135:2006 (2006) Code for design of High-rise Structures. Beijing, China.
[15] Hau E. (2006): *Wind Turbines: Fundamentals. Technologies*, Application, Economics–2nd edition–Springer-Verlag Berlin Heidelberg.
[16] He G., Li J. (2008): *Seismic analysis of wind turbine system including soil-structure interaction*. [in] Proceedings of the 14th World Conference on Earthquake Engineering Jan 2008.
[17] Hokmabadi A.S., Fatahi B., Samali B. (2014): *Assessment of soil–pile–structure interaction influencing seismic response of mid-rise buildings sitting on floating pile foundations.* Computers and Geotechnics. 55: 172-186.
[18] Kareem A., Kijewski T., Tamura Y. (1999): *Mitigation of motions of tall buildings with specific examples of recent applications*. Wind and structures 2(3): 201-251.
[19] Katsanos E.I., Sextos A.G., Elnashai A.S. (2014): *Prediction of inelastic response periods of buildings based on intensity measures and analytical model parameters*. Engineering structures. 15(71): 161-177.
[20] Katsanos E.I., Thöns S., Georgakis C.T. (2016): *Wind turbines and seismic hazard: a state-of-the-art review*. Wind Energy 19(11): 2113-2133.
[21] Kaynia A.M. (2019): *Seismic considerations in design of offshore wind turbines*. Soil Dynamics and Earthquake Engineering. 1(124): 399-407.
[22] Khodair Y., Abdel-Mohti A. (2014): *Numerical analysis of pile–soil interaction under axial and lateral loads.* International Journal of Concrete Structures and Materials 8(3): 239-249.
[23] Kjørlaug R.A., Kaynia A.M., Elgamal A. (2014): *Seismic response of wind turbines due to earthquake and wind loading*. [in] Proceedings of the EURODYN 9th International Conference on Structural Dynamics, Porto, Portugal.
[24] Kondner R.L. (1963): *Hyperbolic stress-strain response: cohesive soils*. Journal of the Soil Mechanics and Foundations Division. 89(1): 115-143.
[25] Lin C.C., Ueng J.M., Huang T.C. (2000): *Seismic response reduction of irregular buildings using passive tuned mass dampers*. Engineering Structures 22(5): 513-524.
[26] Liu L., Gou W., Xie Q., et al. (2012): *Analysis of Elasto-plastic Soil-Structure Interaction System Using Pushover Method*. [in] 15th World Conference on Earthquake Engineering.
[27] Malcolm D.J., Laird D.L. (2003): *Modeling of blades as equivalent beams for aeroelastic analysis*. [in] ASME 2003 Wind Energy Symposium 1 Jan 2003 pp. 293-303. American Society of Mechanical Engineers Digital Collection.
[28] McClelland B., Focht J.A. (1956): *Soil modulus for laterally loaded piles*. Journal of the Soil Mechanics and Foundations division. [in] Proceedings of the American society of civil engineers Vol. 1, p. 22.
[29] Molinari M., Pozzi M., Zonta D., et al. (2011): *In-field testing of a steel wind turbine tower*. [in] Structural Dynamics and Renewable Energy Volume 1 (pp. 103-112). Springer, New York, NY.
[30] Nagarajaiah S., Varadarajan N. (2005): *Short time Fourier transform algorithm for wind response control of buildings with variable stiffness TMD.* Engineering Structures 27(3): 431-441.

[31] Prowell I., Veletzos M., Elgamal A., et al. (2008): *Shake table test of a 65 kW wind turbine and computational simulation*. [in] 14th World Conference on Earthquake Engineering, Beijing, China 12 Oct (pp. 12-17).
[32] Prowell I., Veletzos M., Elgamal A., et al. (2009): *Experimental and numerical seismic response of a 65 kW wind turbine.* Journal of Earthquake Engineering 13(8): 1172-1190.
[33] Prowell I., Uang C.M., Elgamal A., et al. (2012): *Shake table testing of a utility-scale wind turbine.* Journal of engineering mechanics. 138(7): 900-909.
[34] Prowell I., Elgamal A., Uang C.M., et al. (2014): *Shake table testing and numerical simulation of an utility-scale wind turbine including operational effects*. Wind Energy. 17(7): 997-1016.
[35] Ritschel U., Warnke I., Kirchner J., et al. (2003): *Wind turbines and earthquakes*. [in] 2nd World Wind Energy Conference, Cape Town, South Africa Nov 2003, pp. 1-8. Cape Town: World Wind Energy Association.
[36] RP2A-WSD AP (2000): Recommended practice for planning, designing and constructing fixed offshore platforms–working stress design. American Petroleum Institute, Washington Dc.
[37] Schreck S.J., Robinson M.C., Hand M.M., et al. (2001): *Blade dynamic stall vortex kinematics for a horizontal axis wind turbine in yawed conditions*. J. Sol. Energy Eng. 123(4): 272-281.
[38] Sextos A.G., Pitilakis K.D., Kappos A.J. (2003): *Inelastic dynamic analysis of RC bridges accounting for spatial variability of ground motion, site effects and soil–structure interaction phenomena. Part 1: Methodology and analytical tools*. Earthquake engineering & structural dynamics. 32(4): 607-627.
[39] Skau K.S., Page A.M., Kaynia A.M., et al. (2018): *REDWIN–REDucing cost in offshore WINd by integrated structural and geotechnical design.* [in] IOP Conference Series-Journal of Physics, EERA DeepWind.
[40] Smith A., Stehly T., Musial W. (2015): *2014-2015 offshore wind technologies market report*. National Renewable Energy Lab.(NREL), Golden, CO United States, Sep 1.
[41] Song B., Yi Y., Wu J.C. (2013): *Study on seismic dynamic response of offshore wind turbine tower with monopile foundation based on M method.* In Advanced Materials Research Vol. 663, pp. 686-691. Trans Tech Publications Ltd.
[42] Swan S., Hadjian A.H. (1988): *The 1986 North Palm Springs earthquake: effects on power facilities* (No. EPRI-NP-5607) EQE, Inc., San Francisco, CA (USA) Bechtel Power Corp, Norwalk, CA (USA).
[43] Vatanshenas A. (2024): *Nonlinear Soil-structure Interaction of Bridges: Practical Approach Considering Small Strain Behaviour.* Doctoral Thesis, Tampere University. ISBN: 978-952-03-3234-1.