DYNAMIC SOIL-STRUCTURE INTERACTION OF MODERN WIND TURBINES

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This paper provides new insights into the way soil-structure interaction phenomena affect the seismic response of modern wind turbines. To this end, a novel element for three-dimensional finite element analysis of rigid rectangular foundations is proposed and its efficiency and robustness are demonstrated (Esmaeili, 2014). The new model, which has only six degrees of freedom at the center, is implemented using the computational platform OpenSees. Each of the bottom face and four side faces of the foundation is assumed to be in contact with three sets of distributed translational springs in three mutually perpendicular directions so as to take account of soil properties in the stiffness matrix (Figure 1). It is worthy of note that the proposed model is capable of capturing the effect of soil nonlinearity using the Beam-on-Nonlinear-Winkler-Foundation concept (Raychowdhury, 2008).

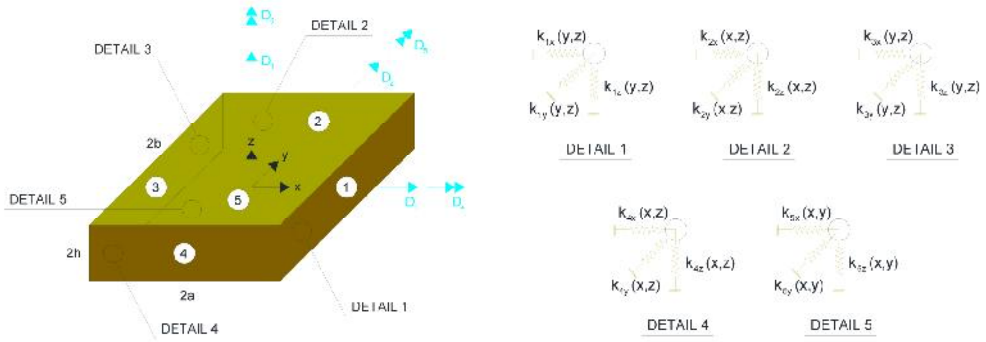

Figure 1. The proposed element for three-dimensional finite element analysis of rigid rectangular foundations

Afterward, using the NREL 1.5-MW baseline turbine, four different models are introduced. The base of the first model is encastre, whereas the rest are supported on pad foundation systems with three types of cohesionless soils, including soft, medium and stiff soils (Table 1).

Table 1. Interaction models and soil properties

Model No.	1	2	3	4
Support	Encastre	Soft Soil	Medium Soil	Stiff Soil
$\gamma\left(kN/m^3\right)$	-	17	19	21
ϕ°	-	30	35	40

With respect to the designed foundations, the assumptions of modeling are also tested. Modal analyses show a decrease in natural frequencies when SSI is considered; and higher modes especially undergo bigger changes (Table 2).

Table 2. Changes in natural frequencies

Model No.	Change	
	1st Bending Mode	2nd Bending Mode
1 (Encastre)	0 %	0 %
2 (Soft)	-1.5 %	-3.2 %
3 (Medium)	-0.7 %	-1.4 %
4 (Stiff)	-0.2 %	-0.7 %

The effect of viscous damping on the predicted turbine response is assessed as well. This investigation suggests that damping is of relatively little influence on the peak acceleration at the top of the tower. Figure 2 shows a comparison of the acceleration time histories at the top of the tower for the 1 % and 5 % damped scenarios using the ground motion of the 2003 Bam earthquake.

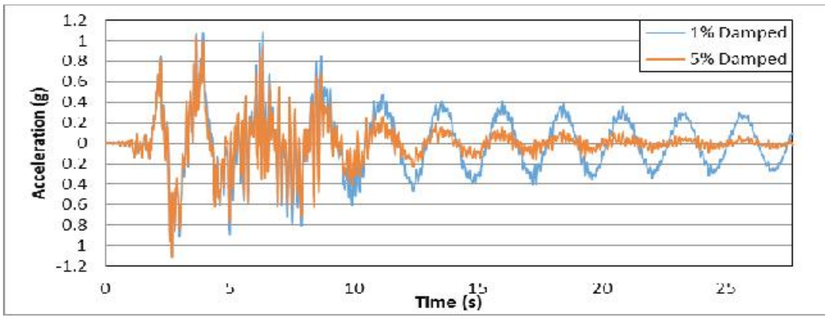

Figure 2. The acceleration at the top of the tower for the 2003 Bam earthquake

Finally, several nonlinear dynamic time-history analyses are conducted using the horizontal components of three earthquakes with different peak ground accelerations in order to assess the effect of SSI on the maximum internal forces of the tower. Results reveal that SSI influence on the value and distribution of the maximum moment and shear demand will be significant (Table 3). On occasion, the maximum internal forces of the tower as a member of a soil-foundation-structure system change by up to 31 %. However, the alterations in the horizontal displacement at the top of the tower are subtle and not likely to require redesign of the turbine to account for SSI.

Table 3. Changes in average response of the tower as a member of a soil-foundation-structure system

Response	Base Shear			Base Moment		
Model No.	Change					
	0.2 g	0.4 g	0.6 g	0.2 g	0.4 g	0.6 g
1 (Encastre)	0 %	0 %	0 %	0 %	0 %	0 %
2 (Soft)	27 %	31 %	18 %	7 %	5 %	-12 %
3 (Medium)	8 %	8 %	4 %	2 %	2 %	-4 %
4 (Stiff)	3 %	3 %	1 %	1 %	1 %	-1 %

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