# Effects of nonlinear soil–structure interaction on distribution of seismic vulnerability in torsionally coupled steel structures

Masoud Shirzadi Dehkohne, Farhad Behnamfar, Payam Asadi, January 2019

Nonlinear analysis is used to investigate the seismic vulnerability of structures under earthquake ground motion. Seismic vulnerability analysis for structures that do not have severe irregularities can also be done with static or dynamic linear analysis or static nonlinear analysis with the nonlinear dynamic analysis being preferable for more precision and reliability. In conventional studies of seismic performance evaluation, it is assumed that the structures rest on rigid foundations. This hypothesis is realistic if only the structure bears on a relatively rigid rock or a very hard soil. Although several studies have shown the effects of the elastic dynamic soil-structure interaction (SSI) on the response of elastic and inelastic structures, few studies have considered the effects of SSI and site effects on a structure resting on a soil medium having nonlinear behavior. Considering the SSI in structural analysis causes a change in the predicted behavior of structure and therefore in its performance during seismic excitation. There are several methods for modeling the effects of soil-structure interaction. These methods include analysis using the direct and substructure methods. In the direct method, structure and a significant volume of the underlying soil are analyzed in a general model. In the substructure method, the effect of soil behavior is modeled using springs and dampers. In this study, the effect of SSI on the response of steel structures with torsional irregularities in plan was investigated. In order to determine the seismic vulnerability of the structures, the soil-foundation system of the structures was modeled using the Beam on Nonlinear Winkler Foundation (BNWF) approach. In this approach, a series of nonlinear springs are used to model the soil behavior under dynamic excitation. Simplicity and efficiency of this modeling approach have made it popular in the SSI problems. The studied buildings are 4, 8 and 12 stories in height resting on the soil type D according to ASCE07-16. The supposed structural system for buildings is a special moment resisting frame and the floor diaphragms have been considered to be rigid. The three-dimensional model of the nonlinear structural system was developed in the OpenSees software. Concentrated plastic hinges at the end of frame elements were used to model the nonlinear behavior of these elements. The nonlinear time history analysis of structures under 11 properly scaled earthquake ground motions, once was implemented for the fix-base and once for the flexible-base buildings with a mass eccentricity variable from zero to 30% of the plan dimension. Also the analysis were performed under the design basis earthquakes (DBE) and the maximum considered earthquakes (MCE) hazard levels. Results of the nonlinear time history analysis and comparison of the performance level of structural components show that taking SSI into account changes the performance level and increases the seismic damage in some of the structural components. Soil-structure interaction increases the relative displacement in the first floor of 4, 8 and 12 story buildings up to 14, 16 and 28% showing larger significance of SSI in taller buildings. Also, the effect of SSI on the ductility demands of stories, rotation of plastic hinges at the DBE and MCE hazard levels has been investigated.

Keywords: Seismic vulnerability, soil structure interaction, Beam on Nonlinear Winkler Foundation, torsional irregularity.