COMPARISON THE EFFECTS OF ELASTIC AND INELASTIC DAMPING RATIO OF EQUIVALENT REPLACEMENT OSCILLATORS TO ANALYZE SOIL-STRUCTURE SYSTEMS

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A common analysis method of soil-structure systems in seismic design procedures, that is the subject of recent researches such as Ganjavi et al. (2018), is to replace the entire soil-structure system by a fixed-base oscillator with an equivalent fundamental period and damping ratio to consider inertial effect of soil-structure interaction (SSI). Current SSI-related regulations in seismic codes, such as NEHRP (2003) are based only on the knowledge of the SSI effect on elastic response of structures. However, recent studies indicate that the effects of SSI should be reconsidered when a structure undergoes a nonlinear displacement demand. In recent documents on nonlinear static procedures, FEMA-440, a modified damping ratio of the replacement oscillator was proposed by introducing the ductility of the soil-structure system obtained from pushover analysis.

In this paper, a comparison is performed between FEMA-440 (2005) inelastic equivalent damping ratio and common elastic damping ratio definitions to investigate the accuracy of seismic ductility demands resulted from these equivalent replacement oscillators against exact ductility demand of structures with surface and embedded foundation located on soft soils. For this purpose, natural damping ratio of equivalent replacement oscillators is defined in two ways: first by FEMA-440 (2005) damping definition, where considers inelastic behavior of structures, and second by Aviles and Perez-Rocha (2005) equations, where the structure is assumed to be elastic.

The soil-structure system considered as exact model in this study is shown in Figure 1-a. The super-structure is modeled as an equivalent elasto-plastic SDOF system with height h, mass m and mass moment of inertia I, which may be considered to be the effective values for the first mode of vibration of a real multi degree of freedom structures. The foundation is considered to be a rigid disk with embedment depth e and mass and mass moment of inertia m_f and I_f, respectively. The soil beneath the structure is considered as a homogeneous half-space and replaced by a discrete model based on the concept of cone model for embedded foundations (Wolf, 1994). In this model, two sway and rocking degrees of freedom are introduced for the foundation. An additional internal degree of freedom is introduced for the soil model to consider frequency dependency of soil's dynamic stiffness. Representative springs of soil behave elastically, and effect of soil nonlinearity is approximately introduced using a degraded shear wave velocity, consistent with the estimated strain level in soil (Kramer, 1996), for the soil medium. Consequently, a 4-degree of freedom model is formed for the whole soil-structure system as shown in Figure 1-b.

A total of 20 earthquake ground motions recorded on site condition E (as defined in NEHRP (2003) and classified in FEMA-440 (2005), Appendix C), which the more SSI effects are probable, are used in this study. Results of this study are the average error values of ductility demand of two kinds of fixed-base oscillators against exact results of soil-structure system, $E(\tilde{\mu})$ for 20 ground motions.

As an example, Figure 2 presents a comparison between $E(\tilde{\mu})$ caused by elastic and inelastic damping definitions of equivalent replacement oscillator in elasto-plastic structures with post yielding stiffness ratio, ductility demands of 4 with medium-embedded foundation. As a general conclusion, the inelastic damping definition proposed by FEMA-440 (2005) results in larger errors than elastic damping definition that may cause very conservative results. However, because of its negative errors, using elastic damping definition may cause unacceptable results in engineering concepts, especially in low-rise buildings. The results also demonstrate that with an increase in the embedment ratio and slenderness ratio and a decrease in ductility demand, the errors caused by FEMA-440 (2005) damping definition decrease, and therefore, this definition becomes more acceptable. This phenomenon can be explained in the way that lower ductility ratios represent a system where the structure does not undergo remarkable nonlinear displacement. Therefore, it is reasonable to assume that the structure behaves elastic in the foundation damping calculation and errors caused by this simplification decrease. In addition, slender structures gain less radiation damping from the soil, and therefore their corresponding response is not as sensitive as for structures with low slenderness ratios to the type of damping definition.

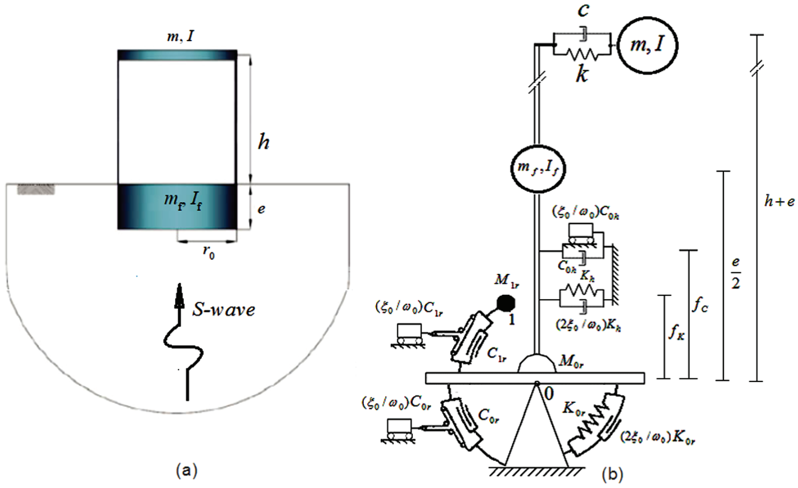

Figure 1. The soil-structure system.

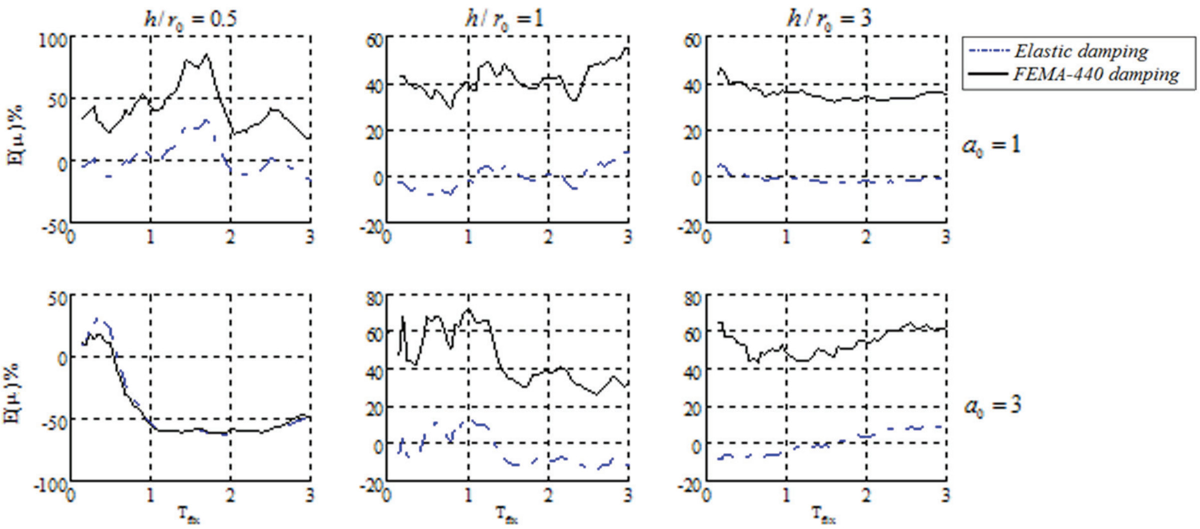

Figure 2. Error of ductility demand of soil-structure system, for structural ductility of 4 and embedment ratio of 1.

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