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Modeling of energy dissipation in structural devices and foundation soil during seismic loading

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ABSTRACT

Though rocking shallow foundations could be designed to possess many desirable characteristics such as energy dissipation, isolation, and self-centering, current seismic design codes often avoid nonlinear behavior of soil and energy dissipation beneath foundations. This paper compares the effectiveness of energy dissipation in foundation soil (during rocking) with the effectiveness of structural energy dissipation devices during seismic loading. Numerical simulations were carried out to systematically study the seismic energy dissipation in structural elements and passive controlled energy dissipation devices inserted into the structure. The numerical model was validated using shaking table experimental results on model frame structures with and without energy dissipation devices. The energy dissipation in the structure, drift ratio, and the force and displacement demands on the structure are compared with energy dissipation characteristics of rocking shallow foundations as observed in centrifuge experiments, where shallow foundations were allowed to rock on dry sandy soil stratum during dynamic loading. For the structures with energy dissipating devices, about 70–90% of the seismic input energy is dissipated by energy dissipating devices, while foundation rocking dissipates about 30–90% of the total seismic input energy in foundation soil (depending on the static factor of safety). Results indicate that, if properly designed (with reliable capacity and tolerable settlements), adverse effects of foundation rocking can be minimized, while taking advantage of the favorable features of foundation rocking and hence they can be used as efficient and economical seismic energy dissipation mechanisms in buildings and bridges.

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1. Background

Seismic energy dissipation in building and bridge structures has been studied extensively by many researchers in the past [1–16]. One of the conventional seismic design practice of moment frame structures allows inelastic deformation in specially designed locations such as beams or adjacent to beam-column joints [1,17]. The inelastic deformation aids to dissipate seismic energy through hysteretic behavior of those specially designed locations (sometimes referred to as structural fuse mechanisms), so that collapse of the structure is prevented. However, excessive inelastic deformation might cause considerable damage to structural members and non-structural elements, and repeated cyclic inelastic behavior might cause degradation in hysteretic behavior of specially designed locations [1,17].

Alternative seismic design strategies, commonly referred to as passive control techniques, have been developed in the last 20 years [15,18,19]. They are aimed at eliminating or reducing the damage in the structure under strong earthquakes by dissipating the seismic energy through the cyclic load–displacement behavior of special devices inserted into the structural system [20]. The use of passive control techniques in structures reduces the need for stiffening and strengthening measures that would otherwise be required. Current passive control applications mainly utilize the following two strategies: (1) passive energy dissipation devices and (2) seismic base-isolation techniques [18].

The passive control techniques are not commonly used in current civil engineering practice due to many reasons [15,18]. Some of the difficulties include ageing and durability of the devices, installation complexity, replacement and geometry restoration after strong earthquakes, maintenance, and dependence of mechanical performances on temperature [20]. The most important and difficult aspects of the passive energy dissipation systems include the complicated nature of the design and strategic placement of the devices and the accurate prediction of their behavior during seismic loading.

Another mechanism to dissipate seismic energy is foundation rocking, though it is not included in current civil engineering

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