Capacity, Settlement, and Energy Dissipation of Shallow Footings Subjected to Rocking

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Abstract: The effectiveness of structural fuse mechanisms used to improve the performance of buildings during seismic loading depends on their capacity, ductility, energy dissipation, isolation, and self-centering characteristics. Although rocking shallow footings could also be designed to possess many of these desirable characteristics, current civil engineering practice often avoids nonlinear behavior of soil in design, due to the lack of confidence and knowledge about cyclic rocking. Several centrifuge experiments were conducted to study the rocking behavior of shallow footings, supported by sand and clay soil stratums, during slow lateral cyclic loading and dynamic shaking. The ratio of the footing area to the footing contact area required to support the applied vertical loads (A/A_c), related to the factor of safety with respect to vertical loading, is correlated with moment capacity, energy dissipation, and permanent settlement measured in centrifuge and 1 g model tests. Results show that a footing with large A/A_c ratio (about 10) possesses a moment capacity that is insensitive to soil properties, does not suffer large permanent settlements, has a self-centering characteristic associated with uplift and gap closure, and dissipates seismic energy that corresponds to about 20% damping ratio. Thus, there is promise to use rocking footings in place of, or in combination with, structural base isolation and energy dissipation devices to improve the performance of the structure during seismic loading.

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Background

Structural fuse mechanisms have been accepted tools for improving performance of buildings during seismic loading (Pall and Marsh 1982; Tsai et al. 1993; Xia and Hanson 1992). The effectiveness of these fuse mechanisms depends on their capacity, ductility, energy dissipation, isolation, and self-centering characteristics. Geotechnical components (e.g., piles or shallow footings) of a structural system can be designed to possess many of these desirable characteristics. The shearing of soil beneath the footing will dissipate energy through friction; and, due to uplift associated with rocking, shallow footings possess significant self-centering characteristics. Performance-based earthquake engineering design methods emphasize the importance of incorporating the nonlinear behavior of structural and geotechnical components and the interaction between them in order to better evaluate the performance of structures, yet current civil engineering practice does not take complete advantage of soil–structure interaction.

Early studies on rocking structures indicated that structures allowed to rock survived in several earthquakes while more modern structures were severely damaged (Housner 1963). One of the major changes in the traditional seismic design procedures adopted in the Federal Emergency Management Agency's (FEMA 1997) National Earthquake Hazard Reduction Program guidelines was in the recognition that mobilization of the ultimate capacity and rocking behavior of shallow footings could reduce the ductility demands on structures, particularly shear walls. The FEMA's "Prestandard and Commentary for the Seismic Rehabilitation of Buildings" document (FEMA 2000), prepared by ASCE, also describes that building footings may rock on their supporting soil in an acceptable manner provided the structural components can accommodate the resulting displacements and deformations. A lack of confidence in our ability to accurately design foundations with the desired capacity and energy dissipation characteristics as well as concern about permanent deformations and the perceived lack of certainty in material properties have hindered the adoption of footing rocking as a primary energy dissipation mechanism.

Fig. 1 shows a schematic of a frame–shear wall structure supported by shallow foundations, where the lateral loads during seismic loading are transferred from beams to shear wall to shallow foundation. Prediction of displacements of shallow foundations when subjected to combined vertical, shear and moment loading is a fundamental, yet inadequately understood problem in geotechnical engineering. Dynamic soil–structure interaction, material (yielding of soil) and geometrical nonlinearities (uplift of footing) and nonlinear-coupled cyclic load–displacement behavior of a footing–soil system cause analytical challenges to footing–soil interface constitutive modeling during earthquake loading. Practical and reliable techniques for modeling foundation behavior under multidirectional loading (vertical, moment, and shear) and data to verify these models is a prerequisite to enable the civil engineering profession to take advantage of (as opposed to avoid) soil nonlinearity to reduce demands on structures.

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