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A practical method for utilization of commercial cyclic testing apparatuses for computation of site response in central Adapazari

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ABSTRACT

We suggest a practical method for estimating strain–modulus–damping relationships for utilization in equivalent-linear site response analyses, so that the necessity for more sophisticated sampling and testing procedures can be justified. The method employs the commercial cyclic testing apparatuses, which have limitations in low-strain ranges, and the in-situ seismic tests. The shear modulus at about 1% cyclic shear strain amplitude and the shear-wave velocity measured in-situ is used for building a hyperbolic relationship between shear stress and shear strain. An extension of Masing's rule and the constraint on hysteretic damping at 1% cyclic shear strain amplitude leads to a strain–damping relationship. By putting a particular emphasis on the soils of Adapazarı, a city famous for the concentrated damage on alluvium basin during the 1999 Kocaeli (Mw7.4) earthquake, we demonstrated the usefulness of the method, and concluded that the shear-modulus reduction and damping characteristics of Adapazarı soils can yield to site amplification factors greater than those predicted by strain–modulus–damping relationships presented in literature, and can more efficiently explain the concentration of damage on the alluvium basin. Through the comparisons of spectral amplification factors computed by equivalent-linear site response analyses, we justified the necessity to run a more sophisticated testing program on determination of cyclic stress–strain behavior of Adapazarı soils, and consequently to consider transient nonlinear site-response analyses in order to reduce the possible bias in calculation of spectral amplification factors.

1. Introduction

The site-response analyses are widely used for estimating the site amplification factors and for justification of design spectra proposed for structures on soil sites, despite their limitations involving the severe uncertainty in the characterization of ground motions on the basin boundaries (Heidebrecht et al. [30]; Kwok and Stewart [42]). As long as the plausible ground-motion amplitudes, that have the largest damage potential to structures, are considered the implementation of material nonlinearity in analyses becomes necessary (Beresnev and Wen [10]; Dobry et al. [19]). The hysteretic response of soils to stress reversals can be characterized through cyclic shearing tests in labs through sophisticated sampling and testing procedures (Richart et al. [54]; Shirley and Hampton [60]; Doroudian and Vucetic [20]), or by employing a number of empirical relationships that are derived from tests on similar materials (e.g., Vucetic and Dobry [65]and Darendeli [17]). However due to budget and time limitations, the latter option is usually chosen by engineers, supposing that the depositional process, the loading history and the mineral structure do not have a major effect on the hysteretic soil behavior.

The level of nonlinearity in soil response to shearing leads to the strain-dependent reduction in secant shear modulus, G. G is generally normalized by $G_{\max}$, the shear modulus in the elastic range of strains, typically as low as 10^{-4}%. Several relationships between $G/G_{\max}$ and shear strain, γ, have been proposed in literature. A comprehensive study, employing the data provided by several other studies on cyclic shearing, is that of Darendeli [17]. Darendeli's study supports the conclusions of Vucetic and Dobry [65] and Ishibashi and Zhang [34] that the normalized modulus reduction is strongly dependent on the plasticity index (PI), effective mean normal stress, and over-consolidation ratio (OCR). These three factors are frequently used for defining the relationship between $G/G_{\max}$ and γ to be employed in site-response analyses. However, the cyclic shearing tests of Yamada et al. [66] on different soil types showed that the values of G at ranges of γ exceeding 0.5% converge to each other, though $G_{\max}$ was observed to be strongly dependent on initial soil structure.

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