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Estimation of Nonlinear Time-dependent Soil Behavior in Strong Ground Motion Based on Vertical Array Data

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Abstract — To improve our understanding of nonlinear elastic properties of soils, a method is proposed of estimation of stress-strain relations of soils *in situ* in strong ground motion based on vertical array data. Strong motion records provided by seismic vertical arrays allow estimation of nonlinear stress-strain relations in soil layers at different depths, from the surface down to the location of the deepest device. As an example, records obtained during the main shock of the 1995 Kobe earthquake at Port-Island, SGK, and TKS sites were used to estimate the stress-strain relations in the soil profiles. For different layers, different types of nonlinear stress-strain relations were selected, according to the profiling data. To account for temporal changes in the soil behavior, consecutive parts of records were examined, and for successive time intervals, the relations were found showing the best-fit approximation to the observed data. At Port Island and SGK sites, where the strongest accelerations were recorded, the obtained stress-strain relations showed systematic changes in the upper layers (0–14 m), such as, a progressive reduction of the slopes of the stress-strain curves due to liquefaction at Port Island and reduction and recovery of the slopes at SGK and TKS sites. At the three sites, the stress-strain relations remained stable in layers below 11–14 m. Thus, the proposed approach gives us a representation of the soil behavior in layers at different depths in strong ground motion; it allows calculation of the propagation of arbitrary seismic signals in the studied profiles and estimation of nonlinear components in the ground response by the nonlinear system identification technique. The method can also be applied to evaluate the ground response at sites where profiling data are available and an imposed motion can be estimated.

Key words: Strong ground motion, nonlinear soil behavior, liquefaction, stress-strain relations, seismic vertical arrays.

Introduction

Recent earthquakes, such as the 1985 Michoacan earthquake, the 1989 Loma Prieta earthquake, the 1994 Northridge earthquake, and the 1995 Kobe earthquake provided new experimental data on the soil behavior in strong ground motion, in particular, on the liquefaction phenomena, and discussions on the nonlinearity of soil behavior were induced (LOMNITZ *et al.*, 1995; AGUIRRE and IRIKURA, 1997; FIELD *et al.*, 1997; O'CONNELL, 1999, etc.). Though nonlinear elastic properties of soils were

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