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Key Issues From Practice Perspective
Opinion Paper by

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In general, dynamic soil response analyses are used in practice primarily for the following classes of problems: 1) to estimate earthquake ground motions within a natural soil deposit or formation, for use in subsequent analyses of a man-made structure, 2) to estimate dynamic stresses and strains, and/or permanent deformations of a soil deposit or man-made earth structure, and 3) to evaluate the ground motions and stresses in a man-made building structure as a result of interaction with its foundation soils. From a practice viewpoint, the main sources of uncertainty in dynamic soil response analyses typically lie in: the ground motions at the reference point or boundary used for analysis, the stratigraphy of natural soil deposits, the behavior of the materials as characterized by their dynamic soil properties, and the accuracy of the numerical models.

Analyses to estimate ground motions for use in the evaluation of building structures are typically performed using equivalent-linear procedures, unless strong non-linear behavior or phase transformation of the soil from liquefaction is expected to occur. Depending on the geometry of the soil deposit, 1-D or 2-D numerical analysis models are typically used with 1-D models being the most common. Two-dimensional models are commonly used for the analysis of man-made earth structures that cannot be approximated by a horizontally layered system. Three-dimensional models are only occasionally used in practice.

The 1-D equivalent-linear approach has been shown to approximate reasonably well the measured horizontal response of soils in the centrifuge where the boundary conditions and material behavior are well known and are closely resembled by the numerical model. Likewise, a number of case history studies after past earthquakes have shown that the approach can approximate the measured horizontal response of natural soil deposits in some cases with sufficient accuracy for practical purposes.

In practice, however, there are often significant uncertainties associated with the use of the equivalent-linear approach. Parametric studies typically show that the analysis results are most sensitive to the stratigraphy of small-strain shear wave velocities in the deposit and the choice of modulus reduction and damping relationships. The choice of input ground motions that are compatible with the assumed half-space boundary is also a key aspect of the analyses, which deserves careful attention. For projects of some importance, the shear wave velocity model for the deposit is typically constrained by field explorations involving drilling and sampling and geophysical measurements. The choice of modulus reduction and damping relationships is often guided by comparisons with similar materials in terms of index

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properties, but seldom (typically only for very large projects) by dynamic testing in the field or laboratory.

It should be noted that 1-D equivalent-linear procedures are also sometimes used to estimate vertical ground motions under the assumption of vertically propagating compression waves. Needless to say, such use of the procedures is subject to considerable uncertainty as well.

Additional case histories on comparisons between calculated and recorded motions are needed to better identify and quantify the sources of uncertainty in the practical application of equivalent-linear procedures under conditions that reflect the extent to which the stratigraphy and material properties are known in typical projects. Ideally, by quantifying how well the procedures do under various conditions, the amount of uncertainty introduced by various factors, including the assumption of vertical propagation of waves, could be quantified.

Where strong non-linear soil behavior occurs, for example in the case of soft clays under strong earthquake shaking or of soil liquefaction, the equivalent-linear approach is typically not sufficiently adequate, and non-linear procedures are used for dynamic response analysis. Such procedures are now commonly used in practice to estimate the dynamic response and permanent deformations of important earth structures under strong earthquake shaking.

In addition to the uncertainties described above, the choice of constitutive non-linear model represents another source of uncertainty in non-linear dynamic soil response analyses. Models that allow close approximation to the backbone curve observed in dynamic testing of soils, such as multiple-nested yield surface models, are generally favored over elasto-plastic models built into now popular commercially available computer codes. In general, the dynamic response of earth structures calculated using total stress non-linear procedures and the first type of models compares well with that calculated using equivalent-linear procedures, in cases where the latter may be considered applicable. Non-linear effective stress analysis procedures are also gaining increased use in practice, although limited experience is yet available with these types of analyses and the uncertainties associated with them. Clearly, this is an area that deserves further research.