Nonlinear soil models for site response; European experience

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Introduction

Site response analysis can be considered as composed of four components. The first component is the input ground motion, taking into account source and path characteristics. The second component is the site characterization based on geomorphologic and geotechnical conditions taking into account topographical features, soil stratification, nonlinear and inelastic characteristics of the soils encountered in the site profile. The third component is the soil model and the fourth component is the method of site response analysis. A brief review will be presented concerning the approaches adopted in evaluating the second, third and fourth components within the framework of the studies conducted in Europe. There are large numbers of journal and conference papers on these three components. An effort is made to minimize the number of references by citing only few papers on each topic that have emerged from main research groups in Europe. Even though the first component is very crucial in achieving a realistic solution in site response analysis, no comments will be presented concerning the estimation of the input ground motion within the framework of European research.

Site Characterization

Significant number of detailed geological and geotechnical investigations were conducted to determine the soil stratification and properties of soil layers. (Calosi et al., 2001; Pitilakis et al., 1999, Marcellini et al., 1995). In most cases these investigations are composed of in-situ and laboratory testing programs. In-situ tests can be considered as composed of three categories. The first category is SPT and CPT penetration tests. These tests are utilized to identify the properties of soil layers as well as to estimate shear wave velocity profiles (Iyisan, 1996; Baldi et al. 1989 Jamiolkowski et al., 1988) The second category of tests is expansion tests used to estimate medium strain range soil properties (i.e. pressuremeter, Ghionna et al., 1994).

The third category of tests are seismic wave velocity measurements based on down-hole, cross-hole, and PS logging, SASW methodology that have been widely used (Lai et al., 2002; Bessason el al.,1998; Mancuso, 1994; Raptakis et al., 1994). More recently ambient noise array measurements were also utilized to estimate the variation of shear wave velocity profiles extending down to greater depths (Louie, 2001; Kind et al., 2000; Milana et al., 1996).

The behavior of soils subjected to cyclic loading has been studied utilizing laboratory tests such as cyclic triaxial, cyclic shear, cyclic torsional triaxial, resonant column and bender elements by large number of European researchers (i.e. Ansal, et al., 2001; Vrettos & Savidis, 1999; d'Onofrio et al., 1999; Puci & Lo Presti, 1998; Viggiani & Atkinson, 1995; Lo Presti et al., 1993; Talesnick & Frydman, 1992; Georgiannou et al., 1991; Hight et al., 1983; Andersen et al., 1980). Various experimentally determined formulas, relationships and proposed design curves are available to obtain reasonable estimates for empirical modeling of soil behavior (Okur & Ansal, 2001; Vrettos and Savidis, 1999; Kallioglou et al., 1999; Sagaseta, et al., 1991).

Relatively good agreement in the reported empirical relationships such as normalized shear modulus versus shear strain justifies the use of simple models in analyzing soil behavior. However, inherent soil characteristics such as grain size distribution, fabric and soil structure for each soil lead to deviations from generalized and normalized relationships. The importance of nonlinearity of soil behavior under small and medium strain levels observed in laboratory and in-situ investigations demonstrate the necessity to carry out more comprehensive testing programs both in the laboratory and in-situ.

Soil Models

The mechanical response of geomaterials to earthquake loading can be modelled using variety of constitutive models. The complexity varies within a large range (i.e Papadimitriou & Bouckovalas, 2002; Pavlenko, 2001; Wood, 2001; Jardine, 1995). As summarized by Woodword (2004) "*Although research into the development of advanced constitutive soil models has progressed at a healthy rate over the last few decades, the implementation of these models into reliable finite element programs for the solution of real boundary value problems has not.*" Thus in most cases for one dimensional analysis Shake program was used utilizing locally obtained modulus and damping degradation curves.

Some finite element packages (i.e. Sigma/w; Z-Soil; Sage-Crisp; Flac, Plaxis, Gefdyn, Dynaflow, Joyner, 1975) that contain various soil models (linear-elastic, anisotropic linear-elastic, nonlinear-elastic 'hyperbolic', elasto-plastic based on Tresca & Mohr-Coulomb failure criterion, strain-softening based on Von Mises failure criterion, Cam-clay, modified Cam-clay 'Critical State'; Schofield model) have been used to analyze some case studies (Beyen & Erdik, 2004; Siyahi et al., 2004; Yang et al., 2002; Mestat & Riou, 2002; Wieland & Malla, 2002; Biarez et al, 1998; Calabresi et al., 1993).

Site Response Analysis

The ground motion records obtained from broad spectrum of earthquakes have been utilized for estimating the site amplification; by determining the generalized inversion GIT (Parolai et al., 2000) and based on SSR, HVSR spectral ratios (Dimitriu, et al., 1999; Raptakis et al., 1998; Theodulidis & Bard, 1995). Ambient noise measurements were also utilized to assess the site conditions (Teves-Costa et al., 1996; Ansal et al., 2001; Bard, 1998).

Geologic structures such as basins and sediment filled valleys, and topographical effects have been investigated by many (i.e. Bakir et al., 2002; Bouckovalas & Kouretzis, 2001; Paolucci et al., 2000; Chávez-García et al., 2000; Riepl et al., 2000; Psarropoulos & Gazetas, 1999; Gomes et al., 1999; Rassem et al., 1997; Neichtschein et al., 1995; Faccioli, 1991; Bard & Bouchon, 1985;). In some cases the approach was based on Rayleigh's method for fast estimating the shear resonance frequencies of 2D geological structures. In some cases records obtained during weak and strong earthquakes were utilized to demonstrate and to model the site response.

Discussion

The need for more realistic soil models arise from the necessity of making better predictions for assessing the ground motion characteristics on the ground surface. However, the problem is very complex since the three components of the site response analysis, input motion, site characterization, soil model and numerical analysis can have significant effect on the calculated final results. Therefore the improvements in the site response analysis is not only limited with the improvements in the soil models.

Site characterization and determination of soil parameters needed for soil models in general requires various levels of assumptions. In problematic areas (i.e. alluvial deposits) where site specific ground motion characteristics are more important, the complexity and diversity of soil stratification and the variation of soil properties for different soil layers can introduce significant limitations for conducting a realistic site response analysis. The procedures adopted to overcome these difficulties are based on simplifying assumptions (i.e. characterizing each soil layers in term of one parameter such as shear wave velocity).

The other issue is related with numerical procedure to estimate the site response. It was observed that one dimensional wave propagation analysis cannot explain the recorded earthquake motions in the existence of complex site conditions. By contrast, two-dimensional analyses are reasonably more successful in predicting the surface ground motion, showing clearly the necessity for site response analyses that can take geomorphologic conditions into account on a case-by-case basis. However two-dimensional effects are much less significant in cases where soil response is strongly non-linear. Then, the developing high material damping reduces the amplitude of the multiply reflected and horizontally propagating waves and leads to a better agreement between one-dimensional and two-dimensional response analysis.

In some cases 2D models produced an additional amplification in response spectra that cannot be accounted for without reference to the lateral heterogeneity of the subsoil structure. Comparison of numerical results with observations in time, frequency and response spectra domain showed that this additional amplification computed from 2D model was real and that it affected the response spectra by a significant factor. Thus, it was suggested that the definition of an aggravation factor due to the complexity of local geology is worthy of consideration in microzonation studies and seismic codes.

Parameters determined from ground motion records are often very dependent on the magnitude and distance of the earthquake thus few sets of records would not yield very reliable estimates especially if strong ground motion records are limited. The weak to strong motion spectral ratios were observed to be variable from site to site most likely due to the differences in the site conditions as well as due to the differences in the frequency contents among the weak and strong ground motion records. However, with the increase in the accumulated data, it is also appears possible to determine soil amplification and site response maps based on ground motion records.

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