SEISMIC BEHAVIOR OF A HETEROGENEOUS SOIL WITH UNCERTAIN HEIGHT

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ABSTRACT :

This paper deals with the seismic behavior of a heterogeneous multilayered soil profile extending horizontally to infinity, and having random properties. Stochastic soil seismic analysis is carried out via Monte Carlo simulations combined with the Thin Layer Method (TLM). Property of interest is the bedrock depth modeled herein as a random field, by choosing the uniform distribution. The purpose is the investigation of the impact of this uncertainty on the probabilistic seismic response of the soil profile in time and frequency domains. Obtained results indicate that the variability of soil thickness significantly influences the seismic behavior in time and frequency domains, causing a substantial extension to the frequency content. The analysis carried out in this study indicates that uncertainty in bedrock depth is among parameters that should be incorporated in any stochastic soil dynamics investigation.

KEYWORDS: Depth to bedrock, Uncertainty, Monte Carlo simulation, Thin Layer Method

1. INTRODUCTION

The analysis of seismic wave amplification of sites, involves accounting for several uncertainties in the computation of earthquake responses. In geotechnical earthquake engineering, these uncertainties are mainly related to earthquake input, soil properties and also to bedrock depth. Deterministic approaches in this field seem to be not realistic, because soil is heterogeneous in nature, even in small areas where one observes homogeneous zones (Manolis, 2002). Consequently, the reliable behavior of a heterogeneous soil profile under seismic environment cannot proceed from a deterministic approach. The resort to probabilistic techniques enables modeling uncertainties by analyzing their dispersion effects.

It is well known that geological site conditions can cause local anomalies of strong motion. Generally, for layered soils without lateral irregularities, it suffices to use one-dimensional models to account for site effects. Hence, the Thin Layer Method (TLM) (Kausel and Roësset, 1981; Kausel and Peek, 1982) is among the most suitable in this context.

This paper deals with the seismic behavior of a heterogeneous soil profile, composed by a set of superposed layers extending horizontally to infinity, and having random properties. Both depth to bedrock and shear wave velocity are considered as uncertain and modeled using the Uniform and the Lognormal distributions respectively. Stochastic seismic analysis is carried out via Monte Carlo simulations combined with the TLM, which is integrated into a global stochastic formulation in order to investigate effects of the uncertainty regarding the adopted depth to bedrock on the probabilistic seismic response of a soil profile (Badaoui et al., 2008).

2. RANDOM FIELD MODELING FOR SOIL PROFILE PROPERTIES

To account for the variability of the bedrock depth, a uniform distribution is used to sample the soil layer thickness (Rieck and Houston, 2003). For a uniform distribution with boundaries a and b, these parameters are given by the expressions

$$\begin{cases} a = \mu_H + \sqrt{3}\,\sigma_H \\ b = \mu_H - \sqrt{3}\,\sigma_H \end{cases} \tag{2.1}$$

Where μ_H and σ_H^2 stand for soil profile height mean and variance. Shear wave velocity is assumed to be log-normally distributed, because this distribution is suitable for strictly non-negative random variables. The mean shear wave velocity is assumed to be linearly varying with depth. The spatial variability in vertical direction of the shear wave velocity is defined by a Gaussian correlation function (Fenton, 1999), expressed as

$$\rho(\xi) = \exp\left[-\pi\left(\frac{\xi}{a}\right)^2\right] \tag{2.2}$$

To be able to cover all the cases of excitations, 3 artificial time histories corresponding to the rock input motions are used. These input ground accelerations cases are: slight ($M \le 4.9$), moderate ($M = 5 - 6.9$) and great ($M = 7 - 7.9$) earthquakes, M being the earthquake magnitude. These accelerations are modeled using an empirical method of nonstationary artificial earthquakes generation (Sabetta and Pugliese, 1996).

3. APPLICATION

The adopted analysis uses the above procedure for investigating the seismic behavior of a heterogeneous soil profile resting on a rigid base, see Figure 1. The one-dimensional approach of the problem is adopted. Hence, the following data are used: unit weight ρ = 2000 kg/m^3, mean soil shear wave velocity is varied from μ_G = 100 to 1000 m/s, fraction of critical damping: $\beta_0 = 5\%$, mean soil profile height μ_H = 30 m, shear wave velocity coefficient of variation: 0.5.

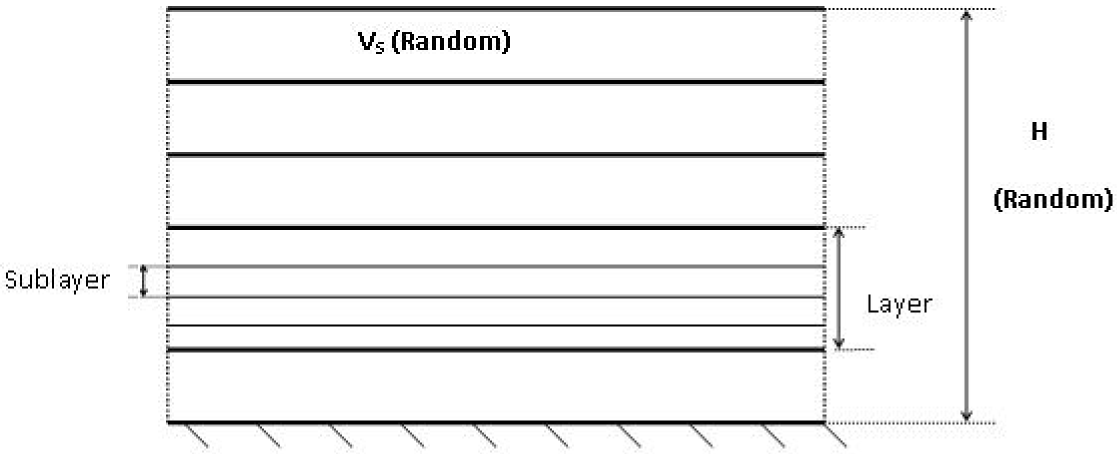

Figure 1 TLM procedure

In this study, we suppose that the soil density is constant because the statistical variation of this factor is relatively small compared to other soil properties (Wang and Hao, 2002). The mean bedrock depth choice results from the fact that site classification is based on properties within the first 30 m from the surface, which corresponds to the maximum depth where standard penetration test (SPT) are typically available (Nikolaou et al., 2001).

Soil thickness variability influence on the seismic soil response is investigated. Three coefficients of variation of bedrock depth CV_H are adopted: 0.0, 0.2 and 0.5 (Rieck and Houston, 2003). We will adopt a log-normal distribution for the output parameters.

The extreme ground surface accelerations resulting from the great acceleration excitation is considered in this section. Figure 2 depicts their variation versus mean shear wave velocity for varying values of the bedrock depth variability. When the coefficient CV_H increases, mean values increase for low shear wave velocity: V_{S0} < 120 m/s. For important velocities, an appreciable decrease in acceleration according to the coefficient CV_H is noted, especially for CV_H = 0.5. The standard deviation increases with CV_H and with V_{S0}. The values becoming constant for high values of the shear wave velocity.

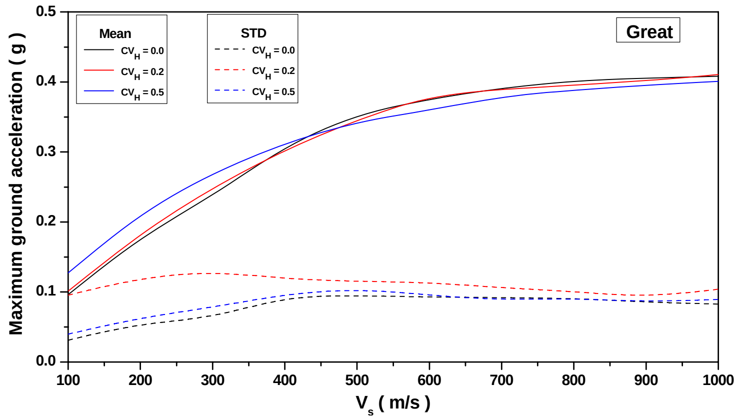

Figure 2 Extreme ground acceleration statistics

The amplification of the system with respect to heterogeneity of the depth to bedrock is analyzed. First, for the full range of frequencies, the transfer function statistics corresponding to V_{S0} = 500 m/s are investigated, see figure 3.

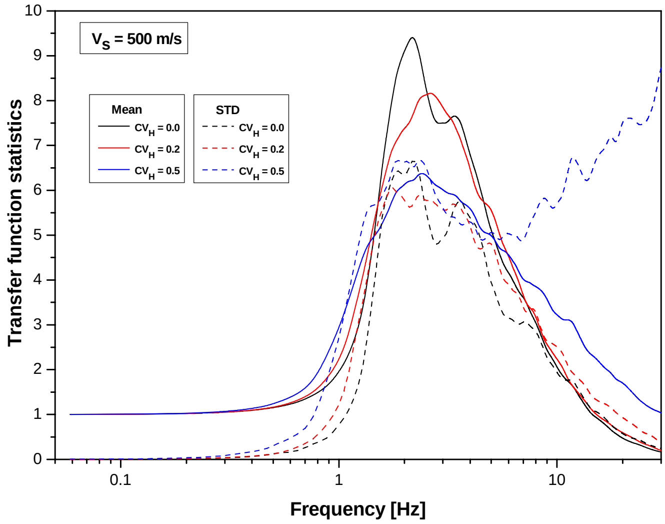

Figure 3 Transfer function statistics

One observes that as CV_H increases, the fundamental frequency is shifted to the right and the mean transfer function amplitude is significantly attenuated with an extension of the frequency content. This implies that a greater number of structures will be concerned by the phenomenon of resonance.

The behavior of the response spectra resulting from the variation of the depth to bedrock uncertainty is considered in this section. Statistics of the response spectra for great earthquake case are shown in figure 4. For increasing CV_H, the response spectra increase for periods up to the fundamental one and decreases for higher ones.

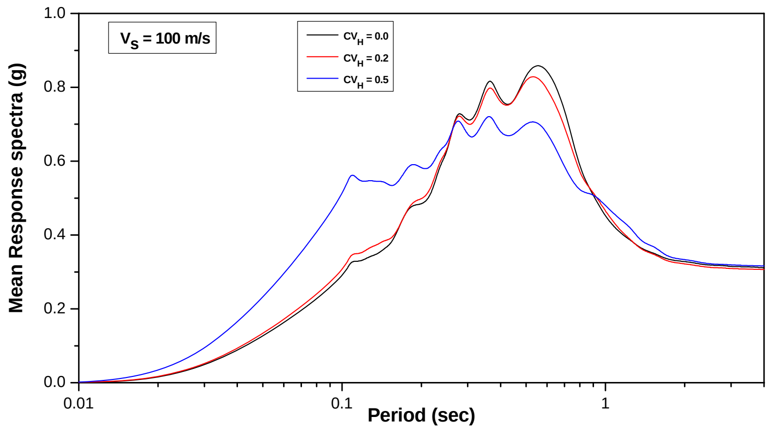

Figure 4 Mean response spectra

4. CONCLUSION

This paper deals with the seismic behavior of a heterogeneous multilayered soil profile, having random properties. Stochastic soil profile seismic analysis is carried out via Monte Carlo simulations combined with the Thin Layer Method (TLM). Soil property of interest is the depth to bedrock, modeled herein as a random variable, by choosing the uniform distribution. The analysis considers also shear wave velocity as uncertain.

It is found that as heterogeneity level of the depth to bedrock increases, an amplification of the maximum ground accelerations occurs for low shear wave velocity and an important attenuation for high ones.

As the depth to bedrock variation coefficient increases the mean transfer function amplitude gets significantly attenuated with an extension of the frequency content implying that a large number of structures will be affected by the resonance phenomenon. This extension to the frequency content with the heterogeneity must be considered in the code spectrum. A shift to the left of the fundamental frequency is also observed, which indicates that the soil becomes hard.

The analysis carried out in this study sheds light on the importance of accounting for the uncertainty regarding bedrock depth in any soil dynamics investigation. Despite the fact that the model used is this paper is simple, as 1D configuration is adopted, it provides valuable guidance for sophisticated models to achieve more realistic modeling of soil media.

REFERENCES

Badaoui, M., Berrah, M.K. and Mébarki, A. (2008). Influence of the soil profile randomness on the seismic response of multilayered soils with a rigid inclusion. *Communications in Numerical methods in Engineering* **24:4,** 321-334.

Fenton G.A. (1999). Estimation for stochastic soil models. *Journal of Geotechnical and Geoenvironmental Engineering* **125:6,** 470-485.

Kausel, E. and Roësset, J.M. (1981). Stiffness matrices for layered soils. *Bulletin of Seismological Society of America* **71:6,** 1743-1761.

Kausel, E. and Peek, R. (1982). Dynamic loads in the interior of a layered stratum: An explicit solution. *Bulletin of Seismological Society of America* **72:5,** 1459-1481.

Manolis, G.D. (2002). Stochastic soil dynamics. *Soil Dynamics and Earthquake Engineering* **22:1,** 3-15.

Nikolaou, S., Mylonakis, G. and Edinger, P. (2001). Evaluation of Site Factors for Seismic Bridge Design in New York City Area. *Journal of Bridge Engineering* **6:6,** 564-576.

Rieck, P.J. and Houston, T.W. (2003) .Statistical soil-structure interaction response of a containment building considering soil property variability. *Transactions of the 17th Int Conf Str Mech Reactor Tech* (SMiRT 17), Paper # K04-1. Prague, Czech Republic, August 17 –22.

Sabetta, F. and Pugliese, A. (1996). Estimation of Response Spectra and Simulation of Nonstationary Earthquake Ground Motions. *Bulletin of the Seismological Society of America* **86:2,** 337-352.

Wang, S. and Hao, H. (2002). Effect of random variations of soil properties on site amplification of seismic ground motions. *Soil Dynamics and Earthquake Engineering* **22:7,** 551-564.