Effect of uncertainty of soil parameters on dynamic response of soil using random field theory

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ABSTRACT

Seismic waves caused by earthquakes undergo many changes when passing through different layers of soil. For this reason, the effects of soil parameters on the dynamic response of the ground should be considered. The parameters in a heterogeneous soil layer are affected by a set of uncertainties, which in this research is the inherent variability of the soil shear modulus parameter. In this research, using random field theory and finite difference method in the framework of Monte Carlo simulations, the effect of two-dimensional spatial variability of the soil shear modulus parameter on the magnification factor of the maximum ground acceleration and the surface acceleration response spectrum has been investigated. In the conventional deterministic analysis, only a constant value of the average shear modulus is considered in the dynamic model, but in the stochastic analysis, the parameter of the soil shear modulus is considered as a random variable. The results obtained from the analyzes show that with the increase of heterogeneity and changes in the shear modulus of the soil, the values of the magnification factor of the maximum ground acceleration decrease. Also, with the increase in the coefficient of variation of the soil shear modulus and as a result of the increase in the heterogeneity of the soil profile, the acceleration response spectrum of the surface of the soil profile obtained from random analyzes decreases.

KEYWORDS

Uncertainty; Random field; Monte Carlo simulation; Dynamic magnification factor.

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1. Introduction

Analysis of the dynamic response of the earth is an important method for the simulation of seismic waves that reach the surface of the earth by passing through the soil layers from the bedrock. The dynamic response of the ground is a function of the characteristics of the soil, and the uncertainty in the characteristics of the soil, whose values are different at any point of the soil, has a significant effect on the dynamic response of the ground. In most constructions, local soil properties such as layering, shear wave velocity (V_s), damping curves and shear modulus reduction control the dynamic response of the soil and have a significant effect on ground vibration [1]. For this reason, in this study, by randomly considering the soil shear modulus as an effective parameter on the soil shear wave velocity, the effect of the uncertainty of the shear modulus and, as a result, the soil shear wave velocity on the dynamic response of the soil has been determined.

2. Random Field Theory

As mentioned in the previous section, soil parameters have inherent spatial variability, in the sense that these parameters change from one point to another. If the desired parameter is modeled with only a single random variable, the spatial variation of the parameter cannot be considered. For this purpose, in order to consider the inherent spatial variability of soil parameters, random field theory is used and these parameters are modeled as a random field. The application of random field theory was proposed by Vanmarcke [2]. He stated that three characteristics are needed to express the random parameter of the soil:

- Average soil random parameter (μ)
- The standard deviation (σ) or coefficient of variation (Cov), each of these parameters shows the amount of dispersion and changes of the studied parameter compared to the average value, and the range of coefficient of variation of resistance parameters of all types of soils is usually between 10 and 80%.
- Correlation length (oscillation scale) to calculate the distance that the soil parameter shows relatively high correlation from one point to another.

In this study, the correlation function used is the two-dimensional exponential correlation function, which is defined as the following relationship [3]:

$$\rho(\Delta x,\Delta y)=\exp\left(-\frac{|\Delta x|}{L_x}-\frac{|\Delta y|}{L_y}\right) \tag{1}$$

Correlated random field is a random field in which the soil random parameter values are correlated and dependent on each other in certain correlation lengths along the horizontal and vertical lines. There are different methods to generate the correlated random field, in this research, the covariance matrix decomposition method is used. The reason for using this method in this research is that this method can model a statistically correlated random field with very clear and specific relationships between the assumed statistical parameters and the corresponding random field including the predetermined correlation length. Also, the covariance matrix decomposition method allows considering two-dimensional heterogeneous correlation lengths and coefficients of different changes of soil parameters. In order to generate a random field of shear modulus with normal logarithm distribution, the following relationship is used [4, 5]:

$$G=\exp(\mu_{\ln G}+L.\varepsilon) \tag{2}$$

which is obtained from equations (3) and (4):

$$\sigma^2_{\ln G}=\ln\left(1+\frac{\sigma^2_G}{\mu^2_G}\right)=\ln(1+COV^2_G) \tag{3}$$

$$\mu_{\ln G}=\ln\mu_G-\frac{1}{2}\sigma^2_{\ln G} \tag{4}$$

which μ_G and σ_G are the mean and standard deviation of the soil shear modulus and COV_G is the coefficient of variation of the soil shear modulus, respectively.

3. Dynamic magnification factor

The dynamic magnification factor is the ratio between the maximum acceleration on the ground surface and the maximum acceleration in the bedrock [6, 7]. This parameter coefficient is required to estimate how much the maximum acceleration will increase from the bedrock to the ground surface. This coefficient is also called as the magnification factor of the maximum acceleration of the ground in some articles.

4. Input excitation

In order to perform dynamic analysis in this study, 4 accelerometers from different earthquakes in the world have been selected in two groups of near and far earthquakes. The earthquakes investigated in this study include two earthquakes near Cape Mendocino and Northridge and two earthquakes near Landers and Loma Prieta.

5. Dynamic modelling

In this research, the finite difference model used is a soil profile with a probability distribution of dimensions 60 meters long and 30 meters deep, which is shown in Figure 2. The behavioral model used in the modeling is the Simplified cysoil (CHSoil) behavior model presented in the FLAC 2D software. Figure 1 shows an example of the realization of the random field of the shear modulus of the soil profile in the FLAC 2D software for the coefficient of variation of 40%.

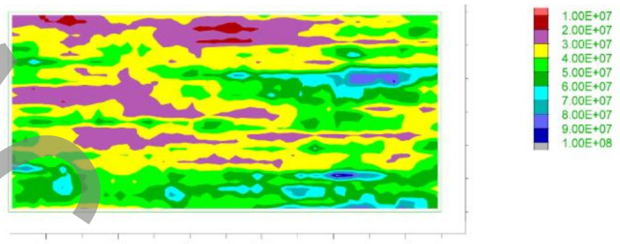

Figure 1: Realizing the random field of the shear modulus (Pa) of the soil profile for the coefficient of variation of 40%

The random analyzes performed in this study fall into four general groups (related to four incoming earthquakes). Each group includes the coefficient of variation of the shear modulus of 20, 40 and 50%, considering the correlation lengths of the horizontal shear modulus of 25, 35 and 40 meters and the vertical correlation lengths of 1, 2 and 3 meters, which is a total of 36 different states ready for dynamic analysis and for each mode, 500 analyzes have been performed using Monte Carlo simulation, based on which 18,000 random analyzes have been performed. The graphs of the average magnification factor of the model compared to the shear modulus change factor for the Loma Prieta earthquake are shown in Figure 2.

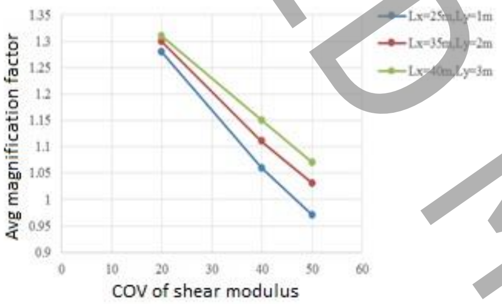

Figure 2: The graph of changes in the average magnification factor of ground acceleration compared to the coefficient of variation based on different correlation lengths of the shear modulus

6. Conclusion

According to the results of the random analysis, the dynamic magnification factor and its comparison with the deterministic analysis, it can be concluded that in the conventional deterministic analysis where a fixed average value of the shear modulus is used in the model, the values of the magnification factor remain constant and do not change in any way. The effects of heterogeneity and spatial variability of soil properties (coefficient of variation and correlation length of shear modulus) are not considered, but in random analysis, considering the parameter of shear modulus as a probability parameter in the soil that has spatial variability, in each coefficient of variation and correlation length, The shear modulus of the magnification coefficients of ground acceleration is different and this indicates the effects of heterogeneity and spatial variability of soil properties on the magnification coefficient of ground acceleration and generally on the dynamic response of the ground. The comparison of the results of deterministic analyses with random analyzes conducted in this research shows that ignoring the spatial changes of soil shear modulus in deterministic analyses leads to overestimation of the magnification factor of ground acceleration and the acceleration response spectrum of the profile surface. It will be dust. The results show that with the increase of the coefficient of variation of the shear modulus and as a result of the increase of heterogeneity in the soil profile, the values of the magnification factor of the ground acceleration and also the response spectrum of the surface acceleration of the soil profile decrease. Also, with the increase in the correlation length in the horizontal and vertical directions and as a result of the reduction of the heterogeneity in the soil profile, the magnification coefficients of the ground acceleration increase. By examining the average acceleration response spectra of the soil profile surface obtained from random analysis and comparing them with the acceleration response spectrum of the bedrock, it can be concluded that the acceleration response spectra of the soil profile surface with the passage of earthquake waves Through the soil profile and reaching the surface, they increase in relation to the acceleration response spectrum of the bedrock.

7. References

[1] T.-T. Tran, S.R. Han, D. Kim, Effect of probabilistic variation in soil properties and profile of site response, Soils and Foundations, 58(6) (2018) 1339-1349.

[2] E.H. Vanmarcke, Probabilistic modeling of soil profiles, Journal of the geotechnical engineering division, 103(11) (1977) 1227-1246.

[3] H.S. Lizarraga, C.G. Lai, Effects of spatial variability of soil properties on the seismic response of an embankment dam, Soil Dyn Earthq Eng, 64 (2014) 113-128.

[4] H. Kim, Spatial variability in soils: stiffness and strength, PhD Thesis, Faculty of Civil and Environmental Engineering, Georgia Institute of Technology, 2005.

[5] R. Alaie, Slope Stability Analysis in Heterogeneous and Anisotropic Soils using Random Field Theory, Master's thesis, Guilan University, 2012.

[6] A. Tuncel, Ö.C. Özdag, E. Pamuk, M. Akgün, Comparison of the soil dynamic amplification factor and soil amplification by using microtremor and MASW methods respectively, in: IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2017, pp. 032006.

[7] P. Plengsiri, L.Z. Mase, S. Likitlersuang, Influence of ground variation on site amplification factor of Bangkok subsoils, Master's thesis, Department of Civil Engineering, Chulalongkorn University, 2018.