# MONTE CARLO SIMULATIONS OF SOIL AMPLIFICATION FUNCTIONS FOR SITE-SPECIFIC SEISMIC HAZARD ANALYSIS – CASE STUDY: TEHRAN, THE CAPITAL CITY OF IRAN

Hamed TAHERI
*PhD Candidate, Hong Kong University of Science and Technology, Hong Kong*
*hamedsamira@ust.hk*

Ali BEITOLLAHI
*Professor, Building and Housing Research Centre, Tehran, Iran*
*beitollahi@bhrc.ac.ir*

**Keywords:** Monte Carlo Simulation, Uncertainty, Soil Amplification, Tehran

To design earthquake resistant buildings and structures, strong ground motions' accelerations and their uncertainties should be estimated. Nevertheless, the effect of soil-profile amplification needs to be evaluated for a complete site-specific seismic hazard estimation. Despite all uncertainties in hazard analyses phases including source, magnitude and attenuation equations, soil profiles are of high deviations in properties and characteristics in a study area. To tackle soil profile uncertainties in the site-specific seismic hazard estimation results, in the present work, a Monte Carlo simulation (MCS) approach has been proposed and examined to evaluate soil amplification function at each soil profile location or borehole. In the proposed approach, shear modulus, damping ratio, soil density and layer thickness are considered as random variables, which follow their corresponding probability distribution functions. The method includes 1000 times randomising soil layer thicknesses as well as shear modulus reduction models, damping increase models and unit weights for each soil profile. In the present paper, soil amplification functions are achieved utilising SHAKE91 while an in-house subroutine generates a mega-input (containing 1000 random profiles) file for MCS at each soil profile.

Furthermore, greater Tehran, the capital city of Iran and one of the most seismically active urban areas in the world, has been considered as a case study for the proposed method. Analyzing the soil borehole data received from the governmental authorities (Building and Housing Research Centre of Iran), MC simulated mean soil amplification functions as well as the transformed surface uniform hazard spectrum from the bedrock spectrum have been presented respectively, for a borehole in the Tehran area.

Soil properties of interest are shear modulus, fraction of critical damping, unit weight and thickness of layers modeled as random fields (Bergamo et al., 2011). The shear modulus is modeled using the lognormal distribution. This choice is motivated by the fact that this parameter is positive, and the lognormal distribution enables analyzing its large variability (Nour et al., 2003). The thickness of each type of textural layers is fitted with a lognormal distribution as well (Li et al., 1999; Rota et al., 2011). The predicted mean values and standard deviations of the shear modulus reduction curves and the damping increase curves accounting for the uncertainty in the values of model parameters and variability due to modeled uncertainty, presented by Darendeli (2001), have been considered here as the required random variables for creating the MC simulated mega-input file for SHAKE91. Furthermore, the related correlation matrix of values standard deviation at different strain levels has been considered in the proposed modeling and simulations as well.

In addition to the inherent uncertainty of soil parameters, the uncertainty of input motion in the soil amplification analysis can play an important role.

In summary, all stages of randomization process and the Monte Carlo simulation for the ground response analysis for each borehole can be presented as follows:

1. Soil profile parameters' randomization, which includes shear wave velocity, unit weight and thickness of each layer in the soil profile. The randomization is conducted 1,000 times according to the MCS sample size.
2. Soil dynamic models' randomization in which shear modulus curve and damping curve are randomized in 1,000 times.

3. Input motion randomization. In this stage, for any random set of soil profile and dynamic behavior curves, one of the spectrum-compatible acceleration records for the under analysis borehole is randomly selected. In other words, each of 1,000 random runs is associated with a randomly selected motion from the pool.
4. Producing input files for the repetitive ground response analyses utilizing SHAKE91.
5. Conducting the ground response amplification analysis 1,000 times and extracting 1,000 amplification functions and the surface acceleration response spectra for the under study borehole (see Figure 1).

As conclusions, in this paper the soil amplification due to the impedance contrast and the frequency content filtering, is investigated and evaluated in the city of Tehran utilizing Monte Carlo simulation technique to overcome the inherent uncertainties in the aforementioned analyses. To simulate numerically one-dimensional seismic soil response, the equivalent-linear approach is adopted and applied in form of SHAKE91 for the ground response analysis in the Tehran area. The results manifest that the peak amplification factors occur around the natural periods of vibration of soil profiles with a standard deviation factor. These amplification factors can magnify the amplitudes of ground acceleration record in the frequency domain several times. Therefore, a fully probabilistic consideration of amplification functions is recommended for the ground response analysis of the site-specific seismic hazard assessment to be utilized as the intensity measures for the performance-based design practices.

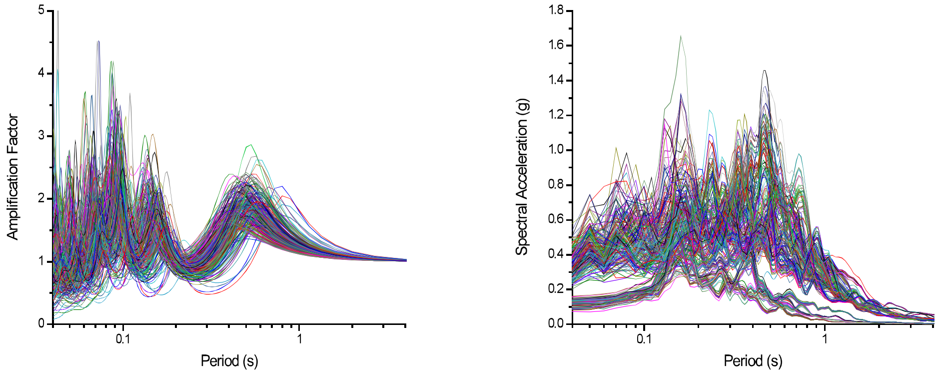


Figure 1. Amplification functions and response spectra at the ground surface resulting from the MCS for the ground response analysis at BH23 (borehole no. 23 from the database). Sample size is equal to 1000

## REFERENCES


Bergamo P, Comina C, Foti S and Maraschini M (2011) Seismic characterization of shallow bedrock sites with multimodal Monte Carlo inversion of surface wave data, *Soil Dynamics and Earthquake Engineering*, 31: 530-534

Darendeli MB (2001) Development of a New Family of Normalized Modulus Reduction and Material Damping Curves, PhD Thesis, University of Texas at Austin, Austin, USA

Li W, Li B and Shi Y (1999) Markov-chain simulation of soil textural profiles, *Geoderma*, 92: 37–53

Nour A, Slimani A, Laouami N and Afra H (2003) Finite element model for the probabilistic seismic response of heterogeneous soil profile, *Soil Dynamics and Earthquake Engineering*, 23: 331-348

Rota M, Lai CG and Strobbia CL (2011) Stochastic 1D site response analysis at a site in central Italy, *Soil Dynamics and Earthquake Engineering*, 31: 626-639