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Probabilistic assessment of ground motions intensity considering soil properties uncertainty

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ABSTRACT

This paper aims to evaluate the effects of soil uncertainty and soil depth to bedrock on the ground motions intensity. For this, three different depths are considered and the variability of the ground motions characteristics traveling from depth to surface is investigated. Soil maximum shear modulus, G_0, which mainly controls soil stiffness and strength characteristics is considered as the uncertain soil material property. By employing the Monte Carlo (MC) simulation technique and for a defined soil depth, the effect of G_0 variability on the ground motions intensity is investigated. Furthermore, the accuracy of approximate method of First Order Second Moment (FOSM) for response variability estimation is evaluated. Using an approximate method is important because probabilistic analysis methods are commonly very time consuming. By conducting investigations, it's observed that the seismic responses of soil domain including PGA, Amplification Factor (AF) and spectral responses of Single Degree Of Freedom (SODF) system are strongly dependent on the soil depth. Moreover, by comparing the results of FOSM with MC, it is observed that FOSM is able to estimate the responses' variability with acceptable accuracy. Thus, FOSM method could be reasonably used instead of MC simulation technique for predicting the seismic response of the soil domain considering soil G_0 uncertainty.

1. Introduction

In the recent years, consideration of uncertainties has played an increasing role in the geotechnical engineering. Uncertainties are due to the lack of knowledge of physical phenomena and should be properly considered to achieve acceptable accuracy in seismic assessments. The evaluation of the structural response when the dispersion of the modeling parameters is included is of a great importance since it is directly correlated with the structural destruction and damage. The geotechnical characteristics of a site, which control the dynamic response of soil domain at the time of the earthquake, are not certainly known in most cases. The importance of the issue has motivated researchers to examine the effect of the geotechnical parameters on the seismic motions intensity [1–7], as well as the structural responses [8–12] in the framework of the probabilistic seismic assessment.

Local ground characteristics and underlying soil layers' depth at a site can alter the intensity and frequency content of ground motions. Soil is a natural material that experiences uncertainty in its physical and mechanical properties. The soil properties uncertainty arises from the estimation of the basic soil stiffness and strength parameters. The proper determination of them depends on the inherent uncertainty of soil as a natural material-mostly known as a heterogeneous material-as well as soil specimens sampling, testing methods and measurements in field and laboratory. However, soil depth to bedrock is mainly known as a varying parameter from one place to another rather than an uncertain parameter. Earthquake uncertainties are attributed to two main items: (1) choosing of a proper Intensity Measure (IM) as an indicator of earthquake intensity and (2) selecting a set of earthquake records as seismic excitations that could properly represent the seismicity specifications of a particular site. The involved uncertainties in the process of analysis and design may lessen the trust in the accuracy of the computed results. In order to achieve a proper seismic assessment, the impact of the involved uncertainties should be properly considered.

In this paper, the seismic response of soil domain considering three different depths is investigated. For this purpose, the dynamic analysis is carried out for soil medium with depths of 10, 30 and 100 m. Amplification factor, PGA and spectral responses of SDOF system, as representative characteristic parameters of earthquake, at the soil surface are the interested quantities to study. The term AF is defined as the ratio of spectral acceleration of

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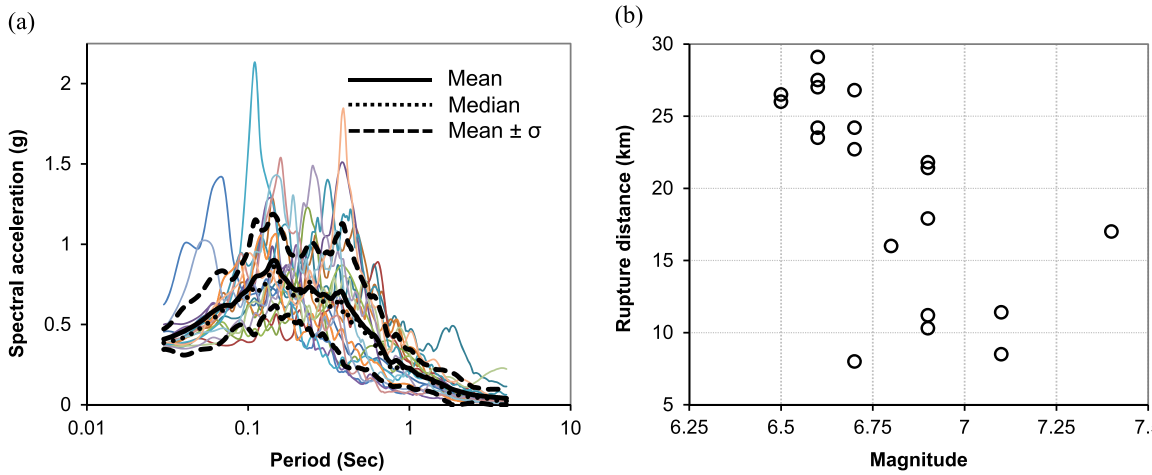

Fig. 1. (a) Spectral acceleration response and (b) scatter gram of the magnitude and rupture distance of input records.

a specific record at the surface to the spectral acceleration of the same record at the bedrock at corresponding periods which shows how a record is amplified as it reaches the surface from depth. PGA is a common informative parameter of earthquake intensity and SDOF spectral responses are presenters of frequency content of ground motion records. This paper also studies the influence of soil maximum shear modulus, G_0, uncertainty on the ground motions characteristics. Utilizing MC simulation technique, stochastic soil samples with varying G_0 values and defined 30 m depth are simulated and analyzed. In order to perform such analyses, a sufficient number of random possible soil samples are generated and the variability of the soil medium response under seismic excitation is studied. Furthermore, considering the time-consuming feature of probabilistic analyses, the efficiency of FOSM as an approximate analytical tool, which needs fewer simulations and less analysis time in comparison to MC, in predicting the probabilistic seismic response of soil, is investigated.

The soil medium is modeled using COM3 [13], a finite element code developed at the University of Tokyo, Japan, which is able to simulate the high nonlinear soil model. The soil profile is modeled using 8-node cubic elements defined as Solid elements in the software. Solid element is capable of assuming plane strain condition in order to consider the infinity effects of the soil medium. It can also take the homogeneity of soil into account and simulate the nonlinear mechanics of soil by taking its mechanical and physical properties. This software provides a model that can study the nonlinear response of the soil domain under the earthquake excitation [13,14].

The scientific interest of this kind of studies is to acquire the variability of ground motions that hit the structure at the time of earthquake as a design input variable, which will definitely affect the structural response.

2. Input ground motions' characteristics

In order to account for the variability of input seismic motions, a set of 20 real rock records from 8 different earthquakes was used as seismic excitation for probabilistic analysis. This number of adopted records was found to be sufficient to meet the goal of the nonlinear soil dynamic analysis in this research work. The records are acceleration time histories and selected based on moment magnitude of the event (M) and closest distance to the rupture zone (R) according to Shome and Cornell observations [15]. The selected records are rather strong ground motions which belong to the category of large magnitude (> 6.5) with small rupture distance (< 30 km) records according to Shome and Cornell. The range of records' magnitude was between M6.5 to M7.4 and the range of distance to rupture zone was between R8.0 to R 29.1 km.

The major horizontal component of all records was scaled to single defined value (0.35*g* in this case) and used as input seismic excitation. The purpose of scaling was to eliminate the effects of the varying PGA of the records on the PGA values obtained on the soil surface since we intend to study the changes in the PGA value as an informative intensity measure of earthquake due to the soil depth variability and soil uncertainty in the forthcoming sections. It is to be noted that the soil medium is affected by the all characteristics of seismic excitation like PGA, energy and frequency content as the applied records reach the surface from depth. Choosing 0.35*g* as the scaling acceleration, regardless of its effects on the energy and frequency content of records, was according to the seismic zoning of Iran (the country in which this study was implemented). On the basis of the seismic zoning maps of Iran, the major part of the country area is of high seismic hazard regions for which the local seismic references propose the PGA of 0.35*g* as the earthquake acceleration.

The accelerograms were directly applied to the bottom boundary at the soil medium base where connected to bedrock. The surface motion was then recorded on the soil surface while the shear wave was propagating upward through the soil profile. Fig. 1 displays the 5% damped acceleration response spectra of the selected input records along with mean, median and mean ± σ curves and the scatter gram of the M and R of records. The standard deviation, σ, measures the amount of variation from the mean value. The σ quantity was calculated by taking the square root of the mean of the squared differences of the spectral acceleration response values at each period from their mean value at the same period. The information belonging to earthquake records could be found in Table A1 in the Appendix A.

3. Soil medium description

3.1. Soil medium finite element modeling

The studied soil site consists of single layer of non-cohesive and relatively dense sand. The soil deposit is dry and non-liquefiable and is underlain by the bedrock. The soil medium is assumed homogenous in the whole depth and length and the physical and mechanical properties of soil are constant throughout the entire