Soil Dynamics and Earthquake Engineering 115 (2018) 183–197

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Reliability analysis of unsaturated soil sites based on fundamental period throughout Shiraz, Iran

A. Johari[*], H. Golkarfard

Department of Civil and Environmental Engineering, Shiraz University of Technology, Shiraz, Iran

ARTICLE INFO

Keywords:
Fundamental period
Unsaturated soil
Soil Water Retention Curve
Shear wave velocity
Reliability analysis

ABSTRACT

The soil profile fundamental period is an essential parameter for estimation of site effects on ground motions. However, in most sites, the water table is at a considerable depth and the fundamental period of the unsaturated soil has to be obtained through geotechnical procedures. On the other hand, this parameter is strongly influenced by the uncertainty associated with the site soil properties. In this paper, to assess the influences of non-homogeneity of sites with unsaturated soil, a reliability analysis of fundamental period is presented. For this purpose, a model for predicting unsaturated shear wave velocity using extracted data from six boreholes in three real sites throughout the city of Shiraz in Iran is developed. For the sake of modelling, the soil suction at each depth is calculated from the Soil Water Retention Curve (SWRC) based on the Grain Size Distribution (GSD) of the soil sample. In order for reliability analysis of the sites, constituent variables of the developed model are considered as uncertain and the reliability indices of the fundamental period of the sites boreholes are determined through the Monte Carlo Simulation (MCS) method. The representative reliability indices are combined using the Sequential Compounding Method (SCM) considering the boreholes as parallel components of the system, and the most reliable site is eventually determined.

1. Introduction

The existing seismic design procedures in geotechnical earthquake engineering are developed without consideration of unsaturated soil expression. For example, seismic site response analysis, soil–structure interaction analysis and soil profile fundamental period determination are typically performed regardless of the role of unsaturated soil conditions. Recently, several attempts have been made on understanding the effect of partial saturation on dynamic soil properties (e.g. [1,2])

The fundamental period of local soil deposits is an essential parameter for estimating the site effects on ground motions. The characteristics of soil-structure interaction are strongly controlled by proximity of the fundamental periods of the structure and the soil profile.

Determination of the fundamental period of unsaturated soil profiles mainly depends on the shear wave velocity through the unsaturated soil which can be mostly predicted by experimental and empirical methods. Not enough experimental data is at hand for shear wave velocity. This is mainly due to the difficulties in measurement of shear wave velocity at low pressures, as transmission of shear waves through a sample requires a firm contact between the transducers and the end surface of the specimen. In empirical approaches, correlations have been reported during the last decades to estimate the shear wave velocity from soil physical properties (e.g. [3,4]).

Conventional approaches for fundamental period determination cannot reflect the uncertainty of the underlying parameters [5]. This is while characterization of a soil deposit is subject to uncertainties due to the inherent variability of the properties within it. No significant attempt on this subject has been cited in the literature. A Stochastic-source model to simulate ground motion and response spectra has been used by Hung and Kiyomiya [6].

Because no significant research has been done in the field of stochastic analysis and calculation of the fundamental period, the application of stochastic analysis in geotechnical earthquake in other nearly relevant areas is initially presented. Researches focusing on the effects of ground randomness in geotechnical earthquake are rather recent [7]. These researches can be divided into random loading, random soil properties and random boundaries.

Among the important contributions to the field of random loading, researches carried out by Vanmarke [8] and Liang et al. [9] can be named. Vanmarke [8] suggested several possible applications of the random vibration theory for solution of soil dynamics problems, including determination of non-linear soil response and assessment of liquefaction potential. Liang et al. [9] investigated experiments on

---

[*] Corresponding author.
E-mail address: johari@sutech.ac.ir (A. Johari).

https://doi.org/10.1016/j.soildyn.2018.08.012
Received 15 March 2018; Received in revised form 11 June 2018; Accepted 10 August 2018

liquefaction under random loads. Applicable researches in the field of random loading have been performed most of which regard liquefaction discussions. Greco and Marano [10] proposed a method to develop stochastic response spectra on the basis of the random vibration theory. Recently, Xu and Feng [11] assessed seismic response analysis of non-linear structures stochastically applying the ground motion.

As far as the geotechnical basics in the field of random material properties are concerned~~,~~ stochastic differential equation solution procedures have been investigated by Adomian [12] and Askar [13]. Adomian [12] represented a key assumption in the solution procedure that is the decomposition of the differential operator into deterministic and random parts. Askar [13] investigated approximate solutions that can be generated directly using various closure approximations. Manitaras et al. [14] examined the shear wave propagation in soils and in a stochastic context considering spatial variability of the shear modulus soil parameter. Ciancimino et al. [15] presented a stochastic analysis of ground response for verification of site classification methods. Verification of some existing sub-soil classification procedures and ideal identification of the optimal scheme was the target of their research.

Random boundaries seems to be of minor importance compared to material properties and loading randomness. Sobczyk [16] and Park et al. [17] have done researches in this area. Most of the researches in this field have been on wave propagation. Sobczyk [16] investigated wave propagation as an interesting phenomenon, especially when it comes to acoustic and electromagnetic wave propagation, mountainous topography and the presence of scatters with very irregular surfaces. Park et al. [17] probed the research from a mathematical viewpoint and concluded that this approach requires the use of stochastic functional calculus.

The common feature of the mentioned unsaturated shear wave velocity studies was the consideration of linear formulation [18], or, in case of non-linearity formulation [19], need to calculate multiple fitting parameters. On the other hand, determination of the fundamental period of unsaturated soil profiles mainly depends on the shear wave velocity in this type of soil which also relates considerably to the heterogeneity of the soil. To the best of our knowledge, the stochastic analysis of the fundamental period of unsaturated media by developing a shear wave velocity model has not been estimated yet. The main objective of this paper is to overcome the mentioned limitations and develop a method for stochastic analysis of the fundamental period of unsaturated soil profiles. For this purpose, an unsaturated shear wave velocity model has been developed based on the extracted data from three real sites throughout the city of Shiraz located in the southern region of Iran. Such uncertain aspects of soil properties as plastic index, vertical stress and suction are assessed through MCS and the reliability index of the fundamental periods of the sites are determined.

2. Available methods for determination of soil profile fundamental period

Generally, the estimation fundamental period of local soil profiles, without considering the effect of degree of saturation and soil suction, can be classified into closed form, approximate, analytical, experimental and numerical methods which are described following:

2.1. Closed form solutions

These methods obtain simple distributions of shear wave velocities with depth. This group, categorized to five closed form solutions, is represented in charts by Dobry et al. [20]. In this method, the basic equation for determining the fundamental period is shear wave motion equation as follows:

$$\rho\frac{\partial^2 x}{\partial t^2} = G\frac{\partial^2 x}{\partial z^2} \tag{1}$$

where G, ρ, z, t and x are shear modulus, density, vertical coordinate, time and the horizontal soil displacement,respectively.

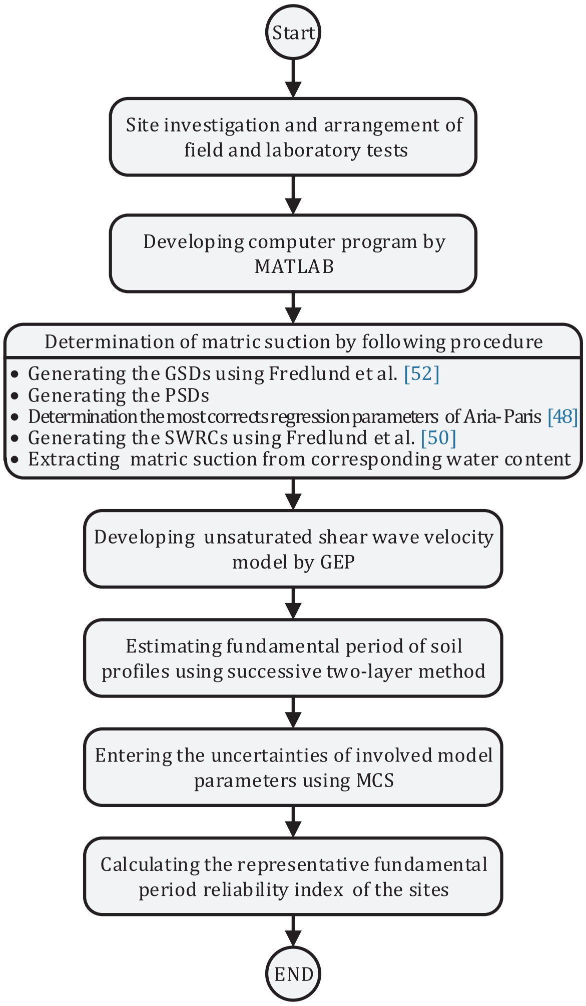

Fig. 1. Flowchart of the proposed method for reliability analysis via case study.

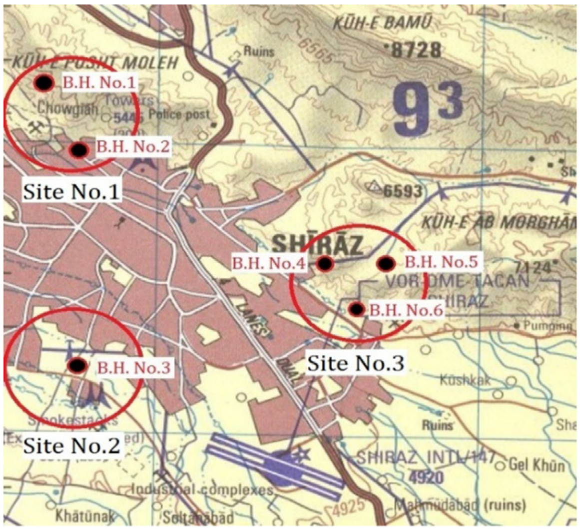

Fig. 2. The sites and boreholes locations throughout Shiraz.

2.2. Approximate methods

The methods are presented in simpler cases to rapidly estimate the