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Benefits of Probabilistic Soil-Foundation-Structure Interaction Analysis

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ABSTRACT

The present article highlights the beneficial effect of considering soil and structure parameters uncertainties on the soil-structure response. The impedance functions of a circular foundation resting on a random soil layer over a homogeneous half-space were obtained by using cone models. The obtained results showed that the randomness of the layer's thickness and the shear wave velocity significantly affected the mean spring coefficients whereby coefficients of variation (COV) of 10% and 20% in these parameters reduced the mean spring coefficients about 32% and 40%, respectively, for the horizontal motion and about 12.5% and 25%, respectively, for the rocking motion. The sensitivity of the mean structural response to the randomness effect was obtained to be more pronounced to structural parameters than to soil parameters. In addition, 20% COV in both soil and structure parameters reduced the mean structural response about 39%, translated by an increase in the damping of the coupled system which may be considered as a beneficial effect from code provisions point of view.

KEYWORDS

Cone Model, Impedance Function, MCSs, Randomness, Structural Distortion

INTRODUCTION

The seismic response of buildings and other structures depends on the nature of the ground motion and mechanical and physical properties of the structure and the soil around the foundation. This phenomenon, known as soil-foundation-structure interaction (SFSI), is important for performance-based design (Bolisetti & Whittaker, 2015) and major design codes such as ASCE Standard 7 (ASCE, 2010) and FEMA 440 (FEMA, 2005) provide guidelines to include its effects in design. This interaction comprises two components: (i) the inertial interaction which refers to changes in the dynamic behaviour of the structure, namely, period lengthening and damping increase and (ii) the kinematic interaction related to the modification of the input ground motion with respect to free field. Moreover, the beneficial or detrimental effects of SFSI on the seismic response of structures still a controversial issue and neglecting SFSI in the analysis may lead to un-conservative design (Abdel Raheem et al., 2015).

To highlight the effects that SFSI plays on the seismic behaviour of structures, various studies have been conducted with different calculation methods. The first methods which are often known

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as complete methods feature in analysing the responses of the soil and the structure simultaneously and require special boundaries to simulate the unbounded soil outside the region of the analysis. In contrast, the analytical methods, namely substructure methods, consist to analyse the soil and the structure separately (Chen & Shi, 2007; 2013) in order to simplify the calculation task. In the substructure method, the interaction between the soil and the foundation may be modelled by springs and dashpots elements with mechanical properties depending on the soil and foundation characteristics and on the excitation frequency.

Though, the soil exhibits spatial heterogeneities resulting from its deposition history. This inherent or natural variability may induce a loss of capacity for reinforced concrete infrastructures which leads to a reduction in all the service life, failure of members and even collapse of the whole structure (Bezih et al., 2015). So, to ensure reliable and economic design, it is important to take into account the variability of soil properties in the soil-structure system analysis and design.

On the other hand, the properties of geotechnical materials are disreputably difficult to obtain precisely since it is almost impossible to obtain undisturbed samples or perfect empirical correlations to other measured quantities (Kramer et al., 2014). This inherent uncertainty due to the spatial variability in soil parameters as one of three main sources of uncertainty: (i) inherent or intrinsic variability, (ii) measurement errors and (iii) transformations uncertainty described in more details by Phoon and Kulhawy (1999) leads to difficulty in the foundation design. Accounting for the inherent uncertainty called aleatory or active (Bezih et al., 2015), is one of the tasks of stochastic or probabilistic mechanics. The uncertain soil parameters are modelled by probability distributions using the second moment profile showing means and standard deviations of soil properties with depth in a formation (Phoon et al., 1995).

However, most soil-structure interaction (SSI) analyses are conducted semi-probabilistically incorporating uncertainty in soil properties and neglecting uncertainty in structural properties due mainly to the prohibitive calculation cost of the incorporation of complete probabilistic approaches (Elkhoraibi et al., 2014). Uncertainties which also exist in the case of the materials of a structure may be taken into account by considering the parameters of structures as aleatory variables in the framework of probabilistic methods which can be introduced in design calculation of structures in order to obtain the uncertainty attached to this design.

Mehanny and Ayoub (2008) have shown that uncertainties incorporated into structural and geotechnical properties play an important role in predicting the performance of seismically excited structures. Lutes et al. (2000) have quantified the effect of uncertain parameters of the soil-foundation-superstructure system on the structural response under seismic excitations. They have concluded that near the resonant frequencies, a significant uncertainty in the structural response may occur due to significant uncertainties in the parameters of either the soil or the superstructure. Raychowdhury et al. (2014) have shown that the behaviour of a shallow foundation under significant loadings can vary significantly due to the uncertainty in both the soil and modelling input parameters.

Giocel (2015) have carried out a probabilistic-deterministic SSI studies for surface and embedded nuclear structures resting on soil and rock sites based on ASCE 04-15 standard recommendations and highlighted the significant modelling limitations in the deterministic SSI analysis.

The underlying goal of the present study is to assess and to quantify the influence of the randomness of soil and structure parameters on the dynamic response of the soil-foundation-structure (SFS) system using Monte Carlo Simulation (MCSs). Also, it is intended to point up the beneficial or detrimental effect of incorporating uncertainties around parameters in the soil-structure interaction analysis according to major codes provisions (FEMA 440, ATC-72-1) and current researches on the controversy about the effects of seismic SSI analysis (Abdel Raheem et al., 2015). This study is restricted to a soil-shallow foundation-structure response to a vertically incident SH wave and only the inertial interaction part will be analysed. In order to achieve the planned goal, a mechanical model consisting of an equivalent single-degree-of-freedom (SDOF) system is used. This model is commonly used to account for the inertial interaction (Wolf, 1985; Maravas et al., 2014) and is

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