ABSTRACT

Soil is a naturally formed material, and due to the presence of different types of organic and inorganic matter in it, the inherent soil properties change spatially. Due to this uncertainty, it is essential to consider the risk involved during the analysis of any geomechanics problem. Hence, the prime focus of this research is to investigate the performance of heterogeneous soil under various physical conditions that include the load directions (vertical, horizontal and inclined loads), load locations (centric and eccentric loads), load types (static and cyclic loads), seismic disturbance and the influence due to the presence of void or tunnel beneath the structure. To impose these physical conditions on soil, diverse geomechanics problems such as (i) bearing capacity of strip footing subjected to eccentrically inclined loads, vertical load with seismic effect, vertical load in presence of an underlying tunnel, (ii) passive resistance of retaining wall subjected to earthquakes, and (iii) one-dimensional and two-dimensional shakedown limit of pavements due to cyclic loading of moving vehicles, are considered for the study. The seismic waves are generated using modified pseudo-dynamic (MPD) approach. The above-mentioned geomechanics problems, except the pavements with cyclic loading, are modeled using lower bound finite element limit analysis (LBFELA), along with second-order conic optimization. The pavement problems that involve cyclic loading are studied using lower bound finite element shakedown analysis (LBFESA), which is an extension of the LBFELA method, to accommodate the elastic stress field into the model for obtaining elastic shakedown limit. For all these geomechanics problems, the inherent variability of soil properties is modeled by random field simulation using a single exponential (Markovian) autocorrelation function. The discretization of autocorrelation matrix into discrete random variables at each finite element node is performed using Karhunen-Loéve (KL) expansion method. The process of determining the uncertainty using a large number of realizations with varying random fields at each realization is implemented using Monte Carlo Simulation (MCS) technique. The stochastic characteristics such as the mean, coefficient of variation, and failure probability are recorded for different spatial variability parameters corresponding to various physical conditions. Design charts and failure patterns are reported to investigate the significance of soil uncertainty on the stability of the structure. For the structures that experience seismic disturbance, the change in the stress influence zone with time is vividly depicted using failure patterns.

It is found that the area of stress influence zone is the major factor which influences the failure probability, due to the fact that the increase in stress influence area increases the effect of uncertainty in soil parameters. Another key finding is that the factor of safety for a zero probability of failure due to soil uncertainty reduces, if the direction of loading is parallel to the direction of stratification. For a horizontally stratified soil, the vertical loading case is more vulnerable compared to the lateral loading case. The results clearly imply that the estimation of capacity of a structure may be uneconomical and sometimes even unreliable, if a factor of safety is considered without accounting the degree of soil heterogeneity. Whereas, by testing the parameter uncertainty on the field and with the allowable failure probability, one can design a more economical and reliable structure using the probabilistic analysis. Hence, it can be concluded that the safe and economical design of structure may be achieved by considering the degree of soil heterogeneity into account.

Keywords: Spatial variability; Probabilistic analysis; Different loading; Monte Carlo Simulation; Lower bound finite element limit analysis