3D Seismic Response Analysis of Shallow Foundation Resting on Sandy Soil

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ABSTRACT

In the present study, an attempt has been made to study the response of a shallow foundation resting on medium dense sandy soil under seismic excitation. Numerical analysis of the soil-foundation system has been carried out using 3D finite element software OpenSeesPL. The effect of boundary conditions (shear beam and rigid box type) and the water table (0 m, 1 m and 2 m below the ground surface) on the response of soil-foundation system under seismic excitation have been analysed. The responses of the soil-foundation system are presented in the form of acceleration, displacement, excess pore pressure, excess pore pressure ratio and settlement variations at different locations in the soil domain. The results of the numerical analysis indicate that the peak acceleration, displacement, excess pore pressure and settlement values are found to be more in shear beam type boundary condition than that of a rigid box type boundary condition. Hence, rigid confinement and lower water table can reduce the liquefaction potential of the soil-foundation system under seismic excitation.

KEYWORDS

Boundary Condition, Finite Element Analysis, Liquefaction, Sandy Soil, Seismic Loading, Shallow Foundation, Soil Foundation Interaction

1. INTRODUCTION

The overall performance of a foundation during earthquake shaking is characterized by the interaction between foundation and the complex geological media. Seismic excitation can cause permanent displacement, distortion and distress of the foundation. The excess pore pressure develops during earthquake loading causes liquefaction and reduces bearing capacity of the saturated soil. A significant cause of damage of the structure during earthquake is displacement and sinking of foundation in saturated sand. There are many ground-damaging activities observed during the great Bihar-Nepal earthquake of 1934, which gives the best examples of widespread liquefaction. Tilting of building into the alluvium soil of Ganga Plains was continued for several days even after the earthquake. The chief criterion adopted in the demarcation of this slump belt was seismic response of the built environment (Auden et al., 1939). The foundation failure during Alaska and Niigata, 1964 earthquake has increased the knowledge of soil liquefaction phenomenon. During these earthquakes approximately 340 reinforced concrete buildings were damaged in Niigata city (Ohsaki 1966, Seed and Idriss, 1967). Settlement of 0.25 m to 2.5 m was noticed in the damaged buildings of Dagupan City area (Adachi et al., 1992). Most of these buildings were founded on shallow foundations supported by uniform fine clean sand. The thickness of liquefiable sand layer was in the range of 6 and 10 m. From the study of 120 damaged reinforced concrete buildings in Dagupan City, Tokimatsu et al., (1991) observed that

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most of the buildings were two to four stories and rested on shallow footings without any piles. Most significant settlement were observed in corner buildings, in buildings without adjacent structures on one or both sides, in buildings surrounded by lightweight structures, and in those parts of the areas where there was greater separation between the adjacent buildings. All these observations have pointed out the importance of the external confinement effect on reduction of foundation damage. Studies on the influence of boundary condition or confinement and water table on seismic response of shallow foundation are limited. Past researchers have reported very few experimental investigations on confinement effect on behavior of soil-foundation system. Hence, in the present study an attempt has been made to study the effect of different boundary condition/confine factors and water table on seismic response of soil-foundation system. A square shaped shallow foundation resting on sandy soil has been adopted for the analysis. Two different cases have been considered here. In first case, effect of boundary condition on seismic response of soil-foundation system has been studied by assigning rigid box and shear beam type boundary conditions to the soil domain. Comparison has been made between ‘Rigid Box’ and ‘Shear Beam’ type boundary conditions. In second case, effect of water table position on seismic response of soil-foundation system has been studied by varying the water table level below the ground surface (0 m, 1 m and 2 m) with shear beam type boundary condition.

2. BACKGROUND

Many experimental and numerical studies have been done to investigate the response of foundation on liquefiable soil deposit during an earthquake (Bouckovalas et al. 1991, Liu and Dobry, 1997). A liquefiable soil deposit can be treated before building a new structure on it, by providing confinement to the base of the foundation (Yoshimi and Tokimatsu 1977). Marques et al. (2012) carried out dynamic centrifuge tests focusing on centrifuge modeling of seismic liquefaction effects and its mitigation for shallow foundations. They found that the excess pore pressure at different depth was influenced by the initial static shear stress generated by the footing. Shahir and Pak, (2009) investigated the dynamic response of shallow foundation on liquefiable soil using both 3D fully coupled dynamic analysis and centrifuge experiments. They observed that the occurrence of initial liquefaction was at shallow depth. Matinmanesh and Asheghabadi, (2011) studied two-dimensional plane strain finite element seismic soil-structure interaction on dense and loose sand, by considering three actual ground motion records with low, intermediate and high frequency content of earthquakes. Almani et al. (2012) investigated the mechanism of liquefaction-related large settlements of the soil-structure system during earthquake. They noticed that, the settlement of footing in the initial phase of cyclic loading was mainly due to large shear deformations at constant volume conditions. The settlement of footing in later phase of cyclic loading was due to reconsolidation of soil caused by the fast pore pressure dissipation at the time of cyclic loading. Asgari et al. (2014) performed set of numerical simulations for sands containing plastic/non-plastic fines, and silts with relative densities of approximately 30% to 40% under different surcharges on the shallow foundation. They found that, the excess pore pressure ratio plays a major role in the prediction of liquefaction. Reddy et al. (2016) reported a comparative study of dynamic response of shallow foundation in layered soils. They concluded that, the peak response of acceleration, displacement and excess pore pressure were found to be more for partially saturated soil. Kumar et al. (2018) performed parametric study on seismic response of shallow foundation resting on different sandy soil. Many researchers have investigated liquefaction behavior of soil and its effects on footings and buildings (Kishida 1966; Seed and Idriss, 1967; Ishihara et al., 1993; Elgamal et al., 2005). Dynamic response of shallow foundation under earthquake loading have been reported by many researchers but the influence of boundary condition with water table variation has not been focused much. Hence, in the present study an attempt has been made to investigate the effect of boundary condition and water table on seismic response of soil-foundation system.
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