Seismic Response of Pile Foundations in Soft Clays and Layered Soils

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Abstract

Pile foundations are widely used to support large engineering structures by transferring loads to deeper layers of soil. During earthquakes, in addition to the axial loads, pile foundations are subjected to inertial loads and kinematic loads due to the motion of the superstructure and the vibrations of surrounding soil, respectively. Due to the significant damage caused by earthquake induced soil liquefaction, studies in the past few decades have focused more on liquefaction induced effects on pile foundations embedded in sands. However, post-reconnaissance reports of several earthquakes have concluded that pile foundations in soft clays and layered soils with significant stiffness contrast have also undergone severe damage during earthquakes.

In this research, three different series of centrifuge experiments were performed to investigate the dynamic behaviour of soft clays, two-layered soils with significant stiffness contrast and the dynamic response of pile foundations embedded in these soil types. The first series of centrifuge experiments were focused on studying the dynamic response of floating piles in soft clay, which in turn depends on the dynamic behaviour of the soft clay layer around the pile. It was found that the dynamic response of clay depends on the earthquake intensity as well as the shear strength and stiffness of the clay layer. The second and third series of centrifuge experiments were specifically designed to investigate the seismic kinematic and inertial loads acting on pile foundations embedded in two-layered soil models with soft clay underlain by dense sand. The results have shown that obtaining a reliable value for the kinematic pile bending moment using established methods in the literature required accurate assessment of the earthquake-induced shear strain at the interface between the two soil layers. Moreover, it was found that non-linearity effects in soil are significant and need to be accounted for. Further, the phase difference between the kinematic and inertial loads and its influence on pile accelerations, rotations and bending moments was evaluated. This research has revealed that the ratio of free-field soil natural frequency to the natural frequency of the embedded structure might not govern the phase relationship between the kinematic and inertial loads as reported in previous research. Instead, the phase relationship between the two loads agrees well with the conventional phase variation between the force and displacement of a viscously damped simple oscillator subjected to a harmonic force.

Lastly, the pile displacements (y) and corresponding soil pressures (p) were determined from the experimentally measured pile bending moments to establish p-y curves and compared with the corresponding curves recommended by design standards. The drawbacks of adopting p-y curves developed for monotonic or cyclic loading to dynamic loading conditions were highlighted through this comparison. The influence of earthquake characteristics such as frequency and intensity, pile group

effects and soil layering on soil stiffness and ultimate lateral resistance of *p-y* curves were discussed in detail. Eventually, the analysis and interpretation of the centrifuge tests provided a better insight into the previously unexplored aspects of seismic soil-pile-structure interaction in soft clays and layered soils with significant stiffness contrast. This research also highlighted the importance of considering soil non-linearity effects in seismic analysis and design of pile foundations.