

Abstract

The design of shallow foundations located in seismically active zones typically takes a near zero tolerance approach to allowing relative movements between the foundation and underlying soil. This results in a rigid coupling of the foundation with the soil and hence the full transmission of the seismic energy into the foundation. Consequently the structure located on the foundation either has to be isolated from the shaking through manufactured damping systems or designed to withstand the full force of the dynamic shaking while the energy is dissipated through structural damping. There is, however, an increasing focus on reducing the coupling between the soil and foundation which consequently reduces the demands on the structure. Allowing the foundation to slide and/or rock isolates the foundation from the dynamic shaking and helps to dissipate energy through soil damping. The same level of seismic protection which is currently provided by manufactured solutions is still therefore possible but with the advantage of reduced costs and complexity in construction. This design concept has, however, not been widely adopted due to concerns regarding the possibility for excessive movement of the foundation, resulting in damage to the superstructure or overall toppling of the structure. In addition, the behaviour is currently difficult to model precisely and therefore it is challenging to quantify the exact level of seismic protection achieved. The work presented in this thesis strives to address some of these issues.

A series of ten centrifuge tests were conducted on small-scale model structures founded on dry sand and subjected to a series of simulated earthquakes. The effect of a range of model parameters was investigated including relative density, bearing pressure, structural stiffness, aspect ratio, earthquake strength and earthquake frequency. For six of the tests, the movement of the soil beneath the foundation and the structure itself were monitored by analysing images collected from high speed photography (1000 frames per second) using particle image velocimetry software. In addition to the photogrammetry, a series of miniature measurement transducers were used to record the acceleration in the soil and the structure. Displacement transducers were used to monitor the settlement of the structure and free-field. In total over one hundred earthquakes were carried out resulting in an extensive dataset, against which hypotheses and analytical models could be verified.

It was found that the transition from the structure being stationary to it responding in a steady state fashion can be a critical period in which the response of the soil-foundation-structure system must be carefully analysed. The phase shift between the superstructure, foundation and soil can vary during this period. As a result, different modes of response are adopted by the system which, in certain circumstances, can result in a significant increase in the displacement magnitude experienced by the structure. The behaviour is not unexpected, as the same behaviour

can be observed from the analytical analysis of a simple single degree of freedom system. In addition, a strong correlation between rocking, sliding and settlement was observed, with the degree of lift-off controlling the amount of settlement and sliding which takes place.

A macro-element analytical model has been developed to predict the moment-rotation behaviour of shallow raft foundations. A hyperbolic model, used for predicting the stress-strain behaviour of soil, was adapted and used to create the backbone curve of the moment-rotation cycle. A modification was made to the hysteretic damping rules proposed by Masing which allows the energy dissipation to be included in the model. The model was found to mimic the experimental data accurately, with the correct prediction of the lift-off rotation magnitude, moment magnitude, small-rotation stiffness and energy dissipation.

Finally, the soil deformation mechanism was observed and analysed. It was found that in some scenarios, when the strain level within the deformation mechanism was low, a trapped wedge was apparent under the foundation. The trapped wedge appeared as a triangular zone of low strain (referred to in some literature as a rigid block), with the foundation located along the top edge and two distinct shear bands on either side. However, as strain magnitudes increased, the shear bands appeared to widen and resulted in strain being apparent throughout the previously unstrained wedge. One of the main differences between the theoretical mechanisms proposed in the literature is the inclusion or exclusion of such a rigid block. Given the majority of the analytical mechanisms proposed in the literature are upper bound mechanisms, and therefore are a prediction of the mechanism at failure, it is inadvisable to include the rigid wedge within the analytical mechanism given that the strain magnitudes will inevitably be large at the point of bearing failure. Given complete failure of the supporting soil did not occur during any of the centrifuge tests performed, comparisons between the observed mechanism and one of these theoretical mechanisms is difficult. However, comparisons between the experimental deformation mechanisms and one analytical failure mechanism did show that the depth of the mechanism could be relatively well predicted as could the degree of separation between the foundation and the underlying soil. This information allows design engineers to know to what depth ground should be remediated below a shallow foundation and how strong the foundation needs to be to cope with the lift-off it will experience. The insight provided by this research into the true soil deformation mechanism, combined with the development of an analytical model of the moment-rotation behaviour, paves the way for engineers to implement designs which actively make use of the beneficial characteristics of soil-structure-interaction.