Non-linear seismic interaction between soil and slender structure

The dissertation provides theoretical and experimental support to the concept of deliberately seismically under-designing shallow foundations to invoke strong below-groundnonlinearity in the form of rocking, and thereby render RC structures safe under intenseseismic excitation. To this end,(I) A series of small-scale (1-g) and centrifuge tests are conducted investigating the performance of elastic single bridge pier models supported on shallow foundations of different sizes. Static and seismic loading scenarios explore the potential benefits andlimitations of under-designed rocking foundations in comparison to conventionalalternatives. (II) A validated nonlinear numerical method is developed to provide further insights on the different shallow foundation response mechanisms with emphasis on soil failure. Themethodology of Anastasopoulos et al. [2010] is incorporated and extended to account forscale effects in cohesionless soil. (III) For a realistic modelling of the nonlinear response of the superstructure, the novelsmall-scale physical model of Knappett et al [2011] is utilized and further developed to fabricate 1:50 scaled replicas of well-confined modern RC bridge piers. A total of 26 suchpiers were constructed. The validity of their response was verified by a number of 4-pointbending tests. (IV) Four shaking table centrifuge tests investigate and compare the performance of two RC model bridge piers, having the same structural section in each case, but with two different foundation designs — a conventional design and a rocking isolation design. Each alternative is tested under two different seismic loading scenarios, where the sequence ofreal ground motions was imposed at the soil model base in such an order as to allow also investigation of the effect of the exact seismic history. (V) To improve rocking isolation design so as to avoid large foundation settlements, an additional set of 9 centrifuge tests (4 static and 5 dynamic) are conducted involving several hybrid foundation schemes. In these schemes the shallow rocking footing is suitably“strengthened” by geometrical modifications or various means of soil improvement: (i) avariable–geometry foundation, whose small rocking stiffness and capacity increase with foundation rotation after some threshold angle; (ii) a rocking-isolated footing standing ontop of an appropriately designed “cofferdam”, which provokes uplifting by hindering the formation of bearing capacity failure mechanisms under the footing; (iii) combineddensification with a 2 x 2 group of unconnected piles (one under each foundation corner);and (iv) a grid of micro-pile inclusions. The results demonstrate the virtues of rocking-isolation shallow foundations, which stem from: (i) reducing accelerations transmitted onto the deck; (ii) increasing system ductility; (iii) limiting permanent deck drifts; and (iv) increasing resistance against damage accumulation in successive earthquakes. Yet, these tests also highlight the main drawback of rocking isolation. That is, the so called “sinking response”, or in other words the gradual accumulation of settlement caused by strongly inelastic soil behaviour. The four new concepts for improving the performance of rocking foundations that were introduced and tested in this dissertation prove capable of ameliorating this drawback while retaining the benefits of rocking isolation.