Performance of caisson foundations subjected to flood-induced scour

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Abstract

This dissertation deals with the impact of foundation scour on the static and cyclic performance of bridge piers supported on caisson footings. Among the natural hazards, scouring is recognized as one of the main causes of bridge failure. The erosion of soil by flowing water changes the supporting conditions of the structure, deteriorating, in turn, its static and seismic performance. It is then of paramount importance to be able of quantifying its mechanical consequences on the response of the structure.

The first goal of this research was to investigate experimentally the two aspects of the problem: the hydraulic phenomenon, which concerns the erosive process around the foundation, and its mechanical consequences which affect the performance of the structure. A hybrid 2-step experimental methodology was developed to this end. The first step studies the hydraulic process of local scour around a bridge pier in *1g* using a Miniaturized Tidal Generator (MTG) recently developed at the ETH Zurich. The results of the experimental tests are used to produce a 3D-printed mould of the scour hole to recreate the actual shape of the scour hole in physical models suitable for testing in a geotechnical drum centrifuge. The mechanical consequences of scouring are then investigated in the second step through *Ng* models, thus achieving proper stress scaling.

The methodology was applied to study the performance of a caisson foundation supported on dense sand before and after local scour. The centrifuge tests consisted of vertical, lateral monotonic, and slow-cyclic pushover tests. In addition to the impact of local scour, the effects of general (uniform) scour were also investigated by removing a soil layer of constant thickness. The results of the vertical tests showed that local scour has a minor effect on the vertical bearing capacity. Conversely, the lateral response of the structure is significantly affected in terms of both moment capacity and monotonic (or cyclic) rocking stiffness. General scour is even more detrimental, leading to a massive reduction of the foundation capacity and a substantial increase in the rate of cyclic settlement accumulation.

The experimental tests provided relevant insights regarding the effects of scouring. Nevertheless, some aspects required further investigation. The subsequent step of the research was then to calibrate a numerical model able to reproduce the main features of the phenomenon. The constitutive model employed to simulate the stress-strain response of the soil is the Severn-Trent sand model. The constitutive

parameters were firstly calibrated on a set of element tests performed on the same sand used in the physical model tests. The numerical model was then validated against the results of the centrifuge tests. The comparison between the simulations and the centrifuge tests proved the ability of the numerical model in capturing the response of the foundation for a wide range of problems. The outcomes of the analyses have confirmed what speculated from the experimental tests: local scour mainly affects the resistance exerted by the soil along the sides of the caisson, whereas general scour has also a major impact on the bearing capacity mechanism developing below the foundation.

The abovementioned conclusions are valid for the specific situation investigated through the experimental tests. A parametric study was then performed to extend the results of the analyses to more general conclusions. In particular, the study focused on the effects of scouring on the performance of bridge piers characterized by different vertical loads (and, thus, vertical safety factors FS_v) and slenderness ratios (i.e. the embedment-to-diameter ratio of the caisson d/D_f). The results revealed that the differences between local and general scour are less pronounced for lightly loaded foundations, where the sides resisting mechanism becomes more relevant. Conversely, the effects of local scour on the response of the foundation are less significant (but still relevant) for heavily loaded piers, where the bearing capacity mechanism is predominant. However, this holds as long as FS_v (computed for the unscoured reference situation) is larger than 3. For very heavily loaded piers, the asymmetry of the local scour hole leads to the accumulation of permanent rotations under just the dead load of the superstructure and, eventually, to its collapse. At the same time, the reduction of the vertical bearing capacity due to general scour leads to instability of the heavily loaded pier which may result, again, in the collapse of the structure. Interestingly, local scour has proven to strongly affect also the response of slender caisson foundations. With increasing d/D_f, the prevailing resisting mechanism under lateral loadings becomes the lateral mechanism mobilized along the sides of the caisson. The soil thrusts substantially decrease due to scouring, even if the scour depth is relatively small compared to the embedment depth of the footing. As a consequence, the entire moment capacity of the caisson is severely reduced.

Overall, the research shows that the effects of local scour differ substantially from those of general scour, recalling attention to the common simplification of ignoring the geometry of the scour hole. Realistic modelling of the physical phenomenon should therefore link the hydraulic scenario which leads to foundation scour to its mechanical consequences on the performance of the structure.