Earthquake-induced liquefaction of sand and response of structures with shallow foundations

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The 2010-2011 Christchurch earthquakes in New Zealand offered stark reminders of the risks that structures with shallow foundations face in the event of earthquake-induced liquefaction and exemplified the need for further research to assess the vulnerability of existing structures and guide the design of new ones.

Currently, state of practice methodologies can not offer reliable estimations of settlement, while numerical modelling of liquefaction still faces shortcomings. Our understanding of the problem is limited. In this thesis, centrifuge modelling was used to garner reliable insight on the behaviour of liquefiable sand and on the deformation mechanisms that develop below shallow foundations.

Examining liquefiable sand, it was found that the undrained hypothesis is not realistic for sand layers and could be uncorservative when predicting strength. Changes in compressibility and hydraulic conductivity at low effective stresses were shown to be crucial for the accuracy of numerical modelling of post-liquefaction reconsolidation.

Particle Image Velocimetry was used to depict deformation mechanisms below shallow foundations. Two parameters were examined: the depth of the layer and the bearing pressure of the structure. Sedimentation and consolidation, mechanisms given predominant weight in state of practice methods, did not contribute to structural settlement, which was rather due to shear strains. The establishment of a bulb of low excess pore pressure below the foundation was found to control the response. Its formation depended on dilation and was faster for heavier structures, where driving shear stresses in the soil were higher. When this bulb of low excess pore pressure did not reach the base of the layer, soil softening occurred below it, leading to limited loading of the structure and diminishing vibration. Settlement was generated as soil got displaced from around the bulb. If either due to increased bearing pressure or due to reduced layer depth higher accelerations reached the structure, a rocking response was gradually established. Settlement during rocking was generated as soil got displaced from under the edges of the foundation.