Seismic behaviour of structures with basements in liquefiable soil

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Earthquake induced liquefaction can cause significant damage in the built environment. Structures on shallow foundations can suffer large settlement and rotation, and light underground structures can uplift. The performance of structures with basements, which intuitively combines these two problems, is not understood.

In this thesis, the seismic behaviour of structures with basements in liquefiable soil has been investigated. A series of highly instrumented dynamic centrifuge tests showed that the presence of a basement can reduce the liquefaction induced settlement of a structure whilst maintaining the natural isolation provided by liquefied soil. The generation of positive excess pore pressures during shaking increased the buoyancy force provided by the basement. When the ratio of uplift to total weight during liquefaction was controlled, this buoyancy reduced settlement compared to structures with shallow foundations without basements.

The centrifuge test data showed that structures with basements were susceptible to suffer a large accumulation of rotation during earthquake induced liquefaction. Compared to structures without basements, resistance to rotation provided by the soil decreased because the buoyancy provided by the basement reduced the vertical effective stresses below the structure. Rotation was exacerbated by an increase in the moment loading imposed by the structure due to the presence of the basement. An increase in the plan area of the basement was found to reduce residual rotation.

A mechanical model for displacement and rotation in liquefiable soil was developed using data from the centrifuge test series. It was based on a traditional mass-spring-damper model, with the addition of slider elements to incorporate accumulation of displacement and rotation. The model was able to replicate the centrifuge test results when liquefaction occurred. Parametric studies using the model found that residual rotation was highly sensitive to the basement width and height of the centre of gravity of the structure.

In summary, liquefaction induced settlement and rotation, and seismic demand of a structure can be minimised by including a basement and controlling the basement geometry, mass distribution, and total weight of the structure. The increase in usable space that a basement provides in a building is anticipated to make this mitigation method an attractive option compared to conventional alternatives such as soil improvement.