STATIC AND DYNAMIC INSTABILITY OF LIQUEFIABLE SOILS

José Andrade and Ronaldo I. Borja

Liquefaction is a state of instability at which loose, saturated cohesionless soils are exposed to a rapid increase in pore pressure, causing a reduction of the effective normal stresses, which are directly proportional to the strength of the soil. This increase in pore pressure can be due to static or cycling external loading of the two-phase (e.g. solid and water) system at the structural level. The key to reach pressures that would render the system unstable is to have undrained conditions. Undrained conditions can be attained either locally (e.g. low local permeability) or globally (i.e. impermeable sample boundaries). It is possible to have locally drained conditions (high permeability) and still reach liquefaction if the system is globally undrained. On the other hand, the system can be globally drained and still liquefy if the local permeability is low enough as to preclude fluid flow and consequently allow pore pressure buildup.

Liquefaction phenomena can be divided into two main groups: flow liquefaction and cyclic mobility. By definition, flow liquefaction is related to a state of instability at which the static shear stresses in the soil matrix have exceeded the residual shear strength of the soil. On the other hand, cyclic mobility is the result of cumulative displacements due to cyclic loads below the residual shear strength. Flow liquefaction is the focus of our study and defines the scope of this investigation.

Of all liquefaction-related phenomena, flow liquefaction is the one that produces the most dramatic effects. It occurs when the static shear stresses acting in the soil matrix exceed the shear strength of the liquefied soil. This usually leads to a state of instability in the sense that a “small” perturbation in the form of stresses can lead to a “large” response in the form of strains. Evidence of this type of instability can be seen in typical failures associated with flow liquefaction such as bearing capacity and slope stability failures.

The images shown after the Niigata earthquake in 1964 in Japan provide enough evidence of the devastating effects associated with flow liquefaction and loss of bearing capacity. Several buildings failed due to loss of bearing capacity. The soil beneath the foundations liquefied and produced excessive displacements at the base and ultimately the collapse of otherwise structurally intact buildings.

Another dramatic example of the effect of flow liquefaction is the near failure of the Lower San Fernando Dam. This dam was constructed using a hydraulic fill, and as a result, the site contained three of the usual four ingredients for flow liquefaction: loose, saturated, cohesionless soils. In 1971 the 6.2 magnitude Sylmar Earthquake provided the fourth ingredient. The entire upstream side of the dam slid into the reservoir, leaving a mere 1.5 m of overboard.

After observing the devastating effects due to flow liquefaction, it is clear that understanding this phenomenon is of uttermost importance in order to be able to predict its occurrence and thereby protect civil infrastructure and reduce human casualties after earthquakes. The difficulty lies in the fact that flow liquefaction is a fairly misunderstood, complex phenomenon that involves pore pressure generation and distribution, stress redistribution, large displacements, and reconsolidation. A robust model based on mechanical principles is needed to be able to predict the onset of instability and the subsequent displacements associated with the phenomenon.

The objective of this research project is to develop a finite element (FE) model for the analysis of flow liquefaction incorporating material and geometric nonlinearities. The mechanisms governing the process need to be understood and included in the model. Furthermore, the FE model must be able to predict the onset of flow liquefaction and capture the behavior of the system post-instability.