Simulation of liquefaction-induced damage of the Port of Long Beach using the UBC3D-PLM model

PI: Luis G. Arboleda-Monsalve
Department of Civil and Construction Engineering Management
California State University Long Beach
Long Beach, CA 90840
Email: Luis.Arboleda@csulb.edu

Project Objective

This research studied numerically the detrimental effects of liquefaction-induced ground movements during a seismic event at the Port of Long Beach, which is vital for the California freight network. The research included: i) the calibration of constitutive model parameters after a compilation of published subsurface investigation reports of the POLB and to determine the suitability of these parameters to reproduce laboratory tests following different stress paths and shear strain levels; ii) the assessment of the use of advanced constitutive models like the UBC3D-PLM to predict the behavior of the POLB Pier S when a seismic event induces liquefaction; iii) the recommendations regarding the resulting permanent deformations and residual strength of soils which could compromise the resiliency of the port.

Problem Statement

Historically Southern California has been seismically active for a radius of 300 km around the POLB. At least 189 earthquakes were registered from year 1800 until present. Expansion projects of port facilities in California have been completed by placing hydraulic fills. These loose man-made fills and even their subjacent natural estuarine and marine deposits, have shown to be susceptible to liquefaction. The case of study of the Port of Long Beach (POLB), Pier S, which is located within a few miles of the Newport-Inglewood and the Palos Verdes faults, offered a unique opportunity to use advanced constitutive soil models to study liquefaction. The Port of Long Beach (POLB), which is the second busiest seaport in the United States, is located near the San Pedro Bay in the city of Los Angeles (CA). The port is an important transportation center moving a great variety of goods including but not limited to clothing, furniture, machinery, and petroleum. This research focused on the Pier S, which is a 290 ha area of the POLB located on the eastern half of the bay. Future expansion projects of the port are proposed in the location of Pier S. The proposed 65 ha expansion would result in the world's greenest shipping terminal. This construction includes the development of a wharf and terminal infrastructure at Pier S including some buildings and minor structures.

Research Methodology

Herein, a site response analysis for the specific case of the Port of Long Beach (POLB) Pier S, located in the greater Los Angeles area is developed following these steps: i) determination of the geotechnical and groundwater characteristics of the soil deposit describing the static and cyclic behavior of soils using boundary value simulations; ii) determination of the seismic input motions based on previously reported site specific and probabilistic studies; iii) determination of the type of numerical and constitutive model to be used in free-field response analyses of the POLB subsurface conditions subjected to Operating Level (OLE) and Contingency Level (CLE) earthquakes; and iv) evaluation of free-field settlements due to post-earthquake excess pore water pressure dissipation and behavior of simplified hypothetical structures with similar frequencies of the dominant earthquake frequencies to analyze the detrimental consequences when liquefaction is induced. For this evaluation, the particle size and shape, gradation and plasticity as well as the earthquake magnitude, duration and peak acceleration play an important role. Two different technics are used to determine the susceptibility to liquefaction of the proposed site. First, semi-empirical approaches are considered by calculating factors of safety against liquefaction computed as the ratio of cyclic shear stresses to cause liquefaction (i.e., Cyclic Resistant Ratio) and equivalent cyclic shear stresses induced by the earthquake input motion (i.e., Cyclic Stress Ratio). Then, numerical models are employed based on the dynamic propagation of waves through the continuum soil profile quantifying liquefaction in terms of pore water pressure ratios (r_u) as the earthquake occurs.

Results

After the assessment of liquefaction susceptibility based on semi-empirical methods using the results of field testing, it was found that Unit B is the only liquefiable layer under both earthquake levels studied in this research. For Unit B, the factors of safety against liquefaction were computed as 0.89 and 0.28, respectively. These values represent a high likelihood of liquefaction to be induced in this soil layer if an earthquake of such magnitude strikes the area. SPTs, CPTs and Vs semi-empirical triggering methods are commonly used to predict only liquefaction onset of soils and are not intended to provide insight about post-liquefaction effects on soil or structures. Liquefaction-induced settlements using state-of-the-practice classical approaches were evaluated for free-field conditions. Using the results of SPTs, settlements of about 24 and 76 cm were computed for the OLE and CLE conditions, respectively. Using the CPTs, settlements of about 10 and 32 cm were computed for the OLE and CLE conditions, respectively. The numerical simulations showed that Unit B for all earthquake motions developed pore water pressure ratios larger than 85%, which caused significant reductions of the vertical effective stresses. Relative shear stresses computed for Unit B indicated that the OLE conditions are capable to mobilize about 70% of the soil shear strength. The CLE earthquakes mobilized almost the entire soil shear strength of Unit B. Liquefaction mobilizes large amounts of shear strength and causes local failures in the soil mass. Analyses of liquefaction-induced settlements for free-field conditions showed maximum settlements of 28 and 45 mm, respectively, after dissipation of excess pore water pressure generated during the cyclic loading. Numerical simulations of 1, 2, and 3-story hypothetical structures founded on shallow footings on saturated granular soils suggested that most of the total liquefaction-induced settlements were caused during the earthquake motion with minor contribution arising from dissipation of the excess pore water pressure generated during the cyclic loading. Larger excess pore water pressures were generated under the structure than those developed for the free-field conditions. For Unit B, the numerical simulations showed large values of earthquake-induced shear stresses that fully mobilized the soil shear strength especially in the zones located below the hypothetical structures.