Region-Specific Probabilistic Liquefaction Hazard Analysis: Overview of the Liquefaction Study Performed in the Netherlands Due to Induced Seismicity

Professor Russell A. Green, PhD, PE
Charles E. Via, Jr., Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA; rugreen@vt.edu

The Groningen gas field in the Netherlands is one of the largest in the world and has produced over 2000 billion m^3 of natural gas since the start of production in 1963. The first earthquakes linked to the gas production in the Groningen field occurred in 1991, with the largest event to date being an M_L3.6. However, the largest recorded peak ground acceleration (PGA: 0.11g) to date is associated with motions recorded during the January 8, 2018, M_L 3.4 Zeerijp earthquake. In response to concerns about the induced earthquakes, the field operator Nederlandse Aardolie Maatschappij (NAM) is leading an effort to quantify the seismic hazard and risk resulting from the gas production operations. Because of the widespread deposits of saturated sands in the region and because liquefaction triggering and associated phenomena are important threats to the built environment, the risk due to liquefaction triggering was evaluated as part of this effort. However, due to the unique characteristics of both the seismic hazard and the geologic profiles/soil deposits in Groningen, direct application of existing liquefaction evaluation procedures was deemed inappropriate. Accordingly, efforts were first focused on developing Groningen-specific relationships for evaluating liquefaction potential of the region. Using the Groningen-specific relationships, a comprehensive probabilistic liquefaction hazard analysis (PLHA) was performed for an area that encompassed the region of highest shaking hazard and soils with the highest liquefaction susceptibility. Liquefaction damage-potential hazard curves were developed using a Monte Carlo method wherein probability distributions for seismic activity rates, event locations and magnitudes, and resulting ground motions are sampled such that the simulated future seismic hazard is consistent with historical seismic and reservoir-compaction datasets.

Consistent with the requirements of governing building code, liquefaction damage indices corresponding to an annual frequency of exceedance (AFE) of $\sim 4 \times 10^{-4}$ (or a 2475-year return period) were of particular interest. However, the approach used in this study, wherein the liquefaction hazard was assessed by determining the liquefaction damage indices for the specified return period, goes well beyond the building code requirements, which allows a pseudo-probabilistic approach to be employed to assess liquefaction hazards (i.e., assessing the liquefaction triggering potential for a ground motion having a 2475-year return period). The liquefaction damage indices for the vast majority of the sites across the study area are less than 5, indicating no to minor surficial liquefaction manifestations. The only sites within the study area that had liquefaction damage indices greater than 5, which is the threshold between no to minor surficial liquefaction manifestations and moderate surficial liquefaction manifestations, were in the small town of Zandeweer, with only some of the sites in Zandeweer exceeding this threshold value. No sites across the study are predicted to have severe surficial liquefaction manifestations. The framework used in this study can serve as a model for other liquefaction studies worldwide.