LIQUEFACTION HAZARD DUE TO INDUCED SEISMICITY: OVERVIEW OF THE PILOT STUDY BEING PERFORMED FOR THE GRONINGEN REGION OF THE NETHERLANDS


ABSTRACT

The Groningen gas field is one of the largest in the world and has produced over 2000 billion m³ 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 M₃.6. In response to concerns about the induced earthquakes, the field operator is leading an effort to quantify the seismic hazard and risk resulting from the gas production operations, to include the assessment of the liquefaction hazard. 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. The liquefaction hazard is being calculated using a Monte Carlo method, wherein for each event scenario, the Groningen-specific relationships are being used to compute the factor of safety (FS) against liquefaction as a function of depth and corresponding Ishihara Inspired Liquefaction Potential Index (LPIₗₗ) hazard curves are being computed. This overall approach is particularly well suited to the specific nature of the time-dependent induced seismicity being considered and is forming the basis on which decisions will be made regarding the need for implementing mitigation measures.

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Liquefaction Hazard due to Induced Seismicity: Overview of the Pilot Study Being Performed for the Groningen Region of the Netherlands


EXTENDED ABSTRACT

This extended abstract focuses on a pilot study that is assessing the liquefaction hazard in the Groningen region of northern Netherlands due to induced seismicity, resulting from natural gas production. The Groningen gas field (Fig. 1) is one of the largest in the world and has produced over 2000 billion m³ of natural gas since the start of production in 1963. Gas production has led to compaction of the reservoir which has reactivated mainly normal faults that traverse the reservoir layer. The first earthquakes linked to the gas production in the Groningen field occurred in 1991, with the largest event to date being the 16 August 2012, M₃.6 Huizinge earthquake [1], and peak ground accelerations of up to 0.11 g have been recorded in a more recent, smaller magnitude event. 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

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the gas production operations [2], to include an assessment of the liquefaction hazard. Towards this end, a liquefaction hazard pilot study is being performed, wherein the study area was selected to simultaneously satisfied three criteria: (a) proximity to the region of highest shaking hazard; (b) sampling of areas with thick, shallow young loose sand deposits; and (c) sampling of multiple site response zones used in developing application-specific ground motion predictive equations (GMPEs) [1]. The location of pilot study area is shown in Fig. 2, along with the cumulative thicknesses of the Holocene sand deposits that comprise the Naaldwijk formation.

Due to the unique characteristics of both the seismic hazard and the geologic profiles/soil deposits in Groningen [4], direct application of existing liquefaction evaluation procedures in the study was deemed inappropriate. Accordingly, efforts were first focused on reanalyzing the liquefaction case histories that were compiled for natural earthquakes to remove bias in their interpretation. Towards this end, new a depth-stress reduction factor ($r_d$) [5] and number of equivalent cycles ($n_{eq}$) [6]/magnitude scaling factor (MSF) relationships for shallow crustal active tectonic regimes were developed and used in the reanalysis of the cone penetration test (CPT) liquefaction case histories compiled by Boulanger and Idriss [7]. These case histories were then used to regress a new liquefaction triggering curve (or cyclic resistance ratio curve: CRR), shown in Fig. 3. Next, using
similar approaches to those employed to develop the new \( r_d \) and MSF relationships for natural earthquakes occurring in shallow crustal active tectonic regimes, Groningen-specific relationships were developed for evaluating liquefaction triggering due to induced seismicity in Groningen for magnitudes ranging from \( M_w 3.5 \) to 7.0 [8]. These efforts significantly benefited from the broader efforts to assess the regional seismic hazard in Groningen, to include the development of a regional geologic model [3,9], stochastic source model [10], site response model [11], and GMPE [1].

The liquefaction hazard is being calculated using a Monte Carlo method wherein probability distributions for activity rates [12], 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 [2] up to a maximum event, the size of which is defined by a logic-tree [13]. For each event scenario, the developed Groningen-specific relationships are being used to compute the factor of safety (FS) against liquefaction as a function of depth for \(~100\) profiles across the pilot study area and corresponding Ishihara Inspired Liquefaction Potential Index (LPI\(_{ish}\)) [14] hazard curves are being computed for each profile (e.g., Fig. 4). This overall approach is particularly well suited to the specific nature of the time-dependent induced seismicity being considered and is forming the basis on which decisions will be made regarding the need for implementing mitigation measures.

Figure 3. CRR curve regressed from liquefaction case history data from Boulanger and Idriss [7] that were reanalyzed using new \( r_d \) and MSF relationships [5,6].

Figure 4. Liquefaction hazard curve computed for a site in the liquefaction pilot study area in Groningen.

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