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Induced seismicity in the Groningen Field, Netherlands: challenges and lessons learnt

Lucia van Geuns[1]

Extended abstract based on a presentation held for SASEG, Geneva, 14 March 2016

1 Introduction

The Groningen Field in the Northern Netherlands is one of the largest natural gas fields in the world and has been producing since late 1963. Ninety-eight percent of the population of the Netherlands is provided with gas from the Groningen gas field. All domestic appliances are configured for this type of gas[1].

The Groningen gas field is operated by the Nederlandse Aardolie Maatschappij BV (NAM), a joint venture between Royal Dutch Shell and ExxonMobil with each company owning a 50% share.

Since the early nineties, relatively small earthquakes have occurred in the vicinity of the Groningen gas field. The earthquake in the Huizinge area on the August 16th, 2012 was the strongest event recorded to date in the Groningen Province with magnitude $M_L = 3.6$ and caused damage to buildings and raised significant public concerns and subsequent feelings of fear. Following this event the Dutch Minister of Economic Affairs initiated an extensive study program to better understand the occurrence and magnitude of the earthquakes induced by the production of gas from the field and to assess the hazard these impose[2].

Public concern over earthquake risk from the gas extraction at the Groningen field forced the Minister into a succession of policy shifts to balance safety concerns with maintaining supplies to the country's households. In 2013, 53.9 billion m^3 of natural gas was extracted from the Groningen reserves. Early 2014, the maximum volume of gas to be extracted was set at 42.5 billion m^3; the production ceiling is reduced further for the period 2015-2016, to 27 billion m^3 annually. End June 2016, the Dutch Minister of Economic Affairs announced that it would lower the cap on production at the Groningen gas field to 24 billion cubic metres a year for the next five years. The Minister did say that production could be raised up to 30 bcm in the event of exceptionally cold weather.

NAM submitted a new ‹winningsplan› for Groningen and as part of the approval procedure all technical reports became public[3]. These studies mainly cover the relation between production and subsidence and the effect of earthquakes on buildings. Several reports present statistical proof that lowering gas production in the center of the field reduced seismicity.

2 Short Historic overview [4]

The Groningen Gas Field is the largest gas accumulation in Western Europe with initial recoverable reserves of close to 2,800 billion m^3. It represents two thirds of the total

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recoverable proven gas volumes in The Netherlands. From the start of production in 1963 through January 2015, 2,115 billion m^3 (75% of the GIIP) had been produced[5].

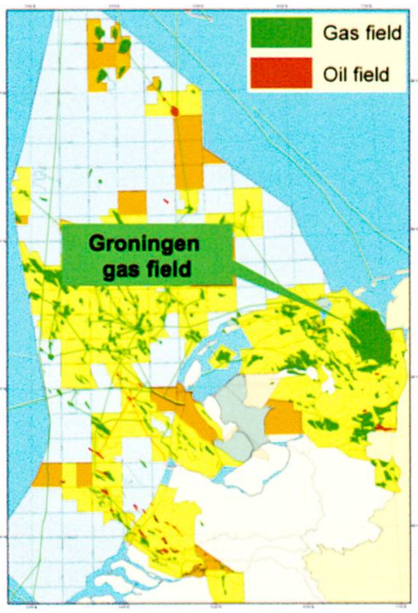
The field was discovered in 1959 by well Slochteren-1, but it's actual aerial extend (862 km^2) was initially not recognised. The original target of the discovery well was the basal Zechstein carbonates in a relative small structural closure, mapped on 2D seismic. However, the underlying Rotliegend sandstones turned out to be gas bearing as well. Only several wells later, it was realised that the small prospect targeted initially forms part of a much larger structural closure.

Start of gas production was in 1963. The initial field development took some 15 years during which 29 production locations were build and some 300 wells were drilled. The development of the field was geared towards production capacity generation in order to provide the swing capacity for North West Europe. By the late eighties, with 50% of the gas resources recovered, two major investment projects were kicked-off. The first project involved the installation of some 20 compressors by 2010. The second project was initiated to realise Underground Gas Storages (UGS) for optimum depletion of the Groningen Field. Currently, the gas is produced through 20 processing locations (clusters), consisting of 8 to 12 wells each, gas treatment facilities and compressors.

3 Induced Earthquakes and Seismic Hazard [6]

Small earthquakes have occurred in the vicinity of the Groningen gas field since the early nineties. It is recognized that these events are induced by the production of gas from the field. In 1993, a geophone monitoring network, operated by KNMI (Royal Dutch Meteorological Institute), was installed in the field. This was extended several times and has a detection limit of M_L = 1.5 since 1996. Several cases of earthquakes induced by gas production have been recorded in literature. A possible analogue for larger earthquakes in the Groningen area is the 2004 earthquake of magnitude M_L = 4.4 in the Rotenburg gas field (Germany), which also produces from the Rotliegend. The earthquake in the Huizinge area, Groningen Province, on the August 16th, 2012 was the strongest event recorded to date with magnitude M_L = 3.6.

A renewed focus on the issue of seismicity



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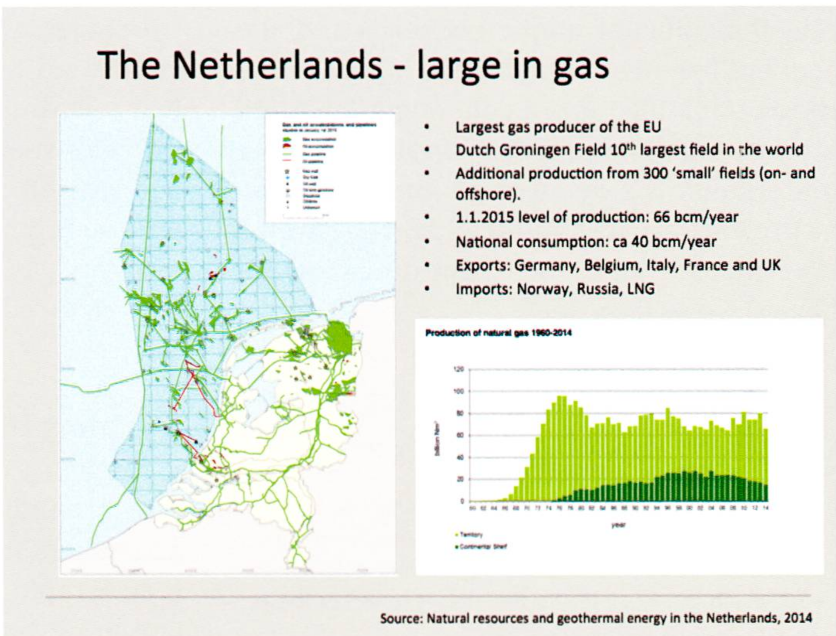
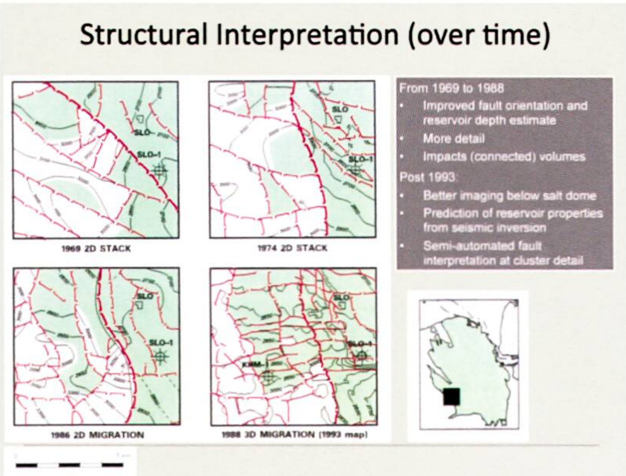


induced by gas production in Groningen started in 2012 and was triggered by three factors. First, the earthquake near Huizinge was felt as more intense and with a longer duration than previous earthquakes in that area. Compared with previous earthquakes, significantly more building damage was reported as a result of this earthquake. Second, a general realization had started to materialize that over the past few years seismicity in the Groningen area had increased beyond statistical variation. Third, and most important, studies by SodM (National Mines Inspectorate), TNO (Geological Survey of the Netherlands), KNMI, and NAM concluded that the uncertainty associated with the earthquake hazard in the Groningen field was larger than previously thought. It was realized that the earthquakes could pose a potential safety risk.

After the Huizinge event, NAM set up an extensive accelerated research program, at a cost of approximately 100 mln € in the period 2014 to 2016, to provide a detailed seismic hazard and risk assessment. Approx. 25 universities and knowledge institutes around the world are involved in the program. This research program has produced many important new insights in seismicity and seismic risk.

4 Subsidence, Compaction & Seismicity [7, 8]

The Groningen surface subsidence has shallow and deep causes. Shallow subsidence is caused by the compaction of clay, oxidation of shallow peat, and artificially modified groundwater levels. Deep subsidence results from reservoir compaction related to gas production. The elastic properties of the



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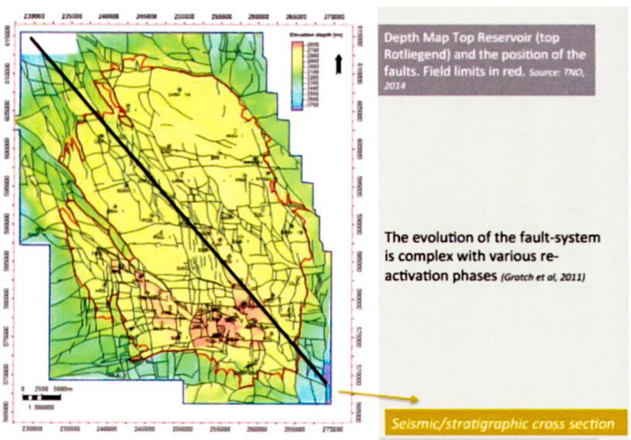
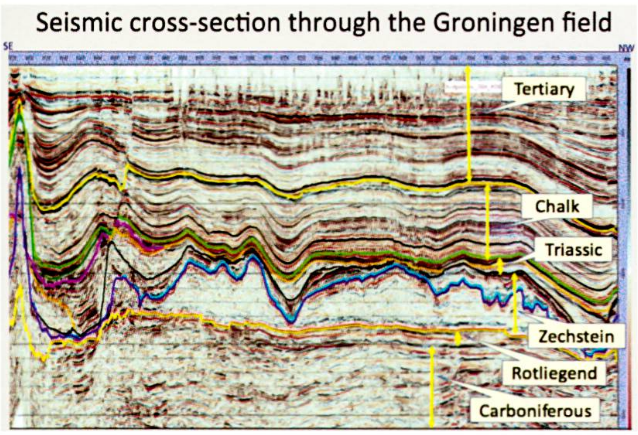
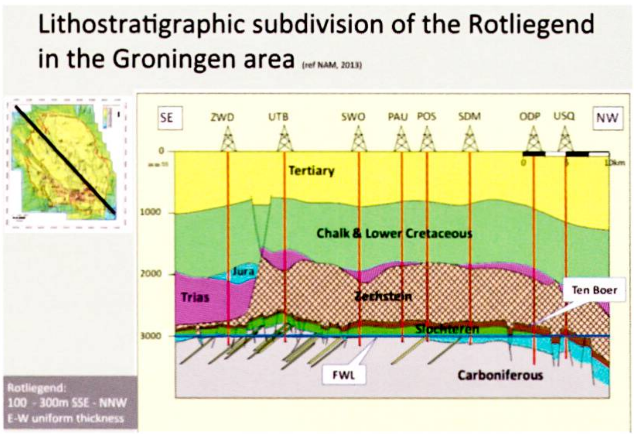


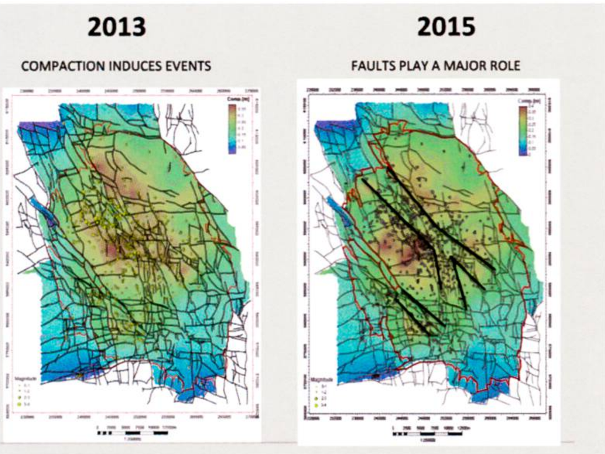


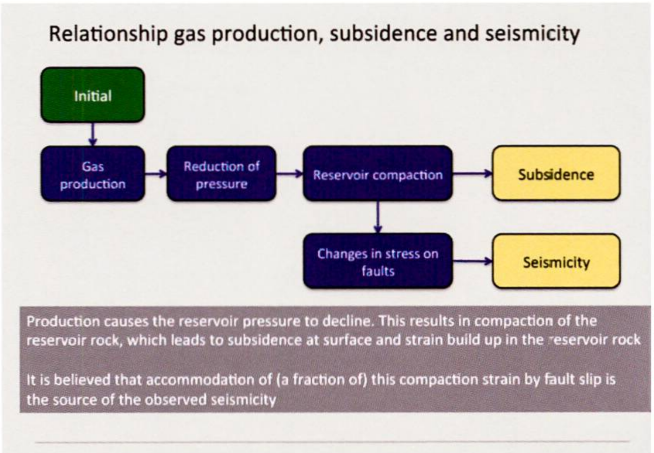


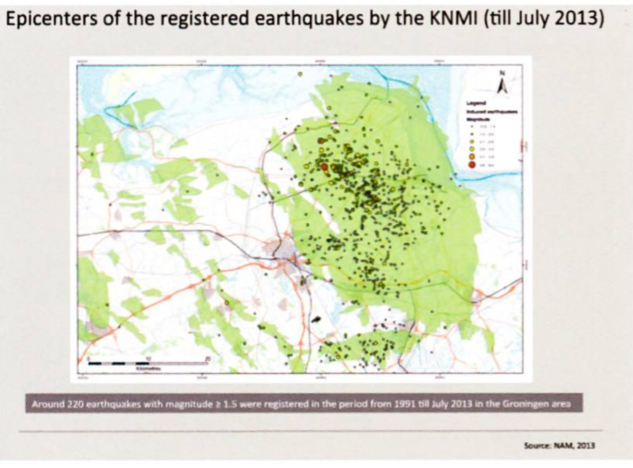
overburden transfer the compaction almost instantaneously to the surface, and this is measurable as subsidence. Subsidence caused by compaction of the Groningen field has been measured since 1964 by using optical leveling. InSAR (Satellite Radar Interferometry) data have been available for the region since 1996, which has improved the frequency and spatial coverage of the subsidence measurements. InSAR uses persistent scatters, typically buildings, to measure subsidence rates. Currently, optical-leveling campaigns and InSAR are performed to check for consistency[9]. In 2013 and 2014, 12 GPS stations were installed over the field to monitor subsidence in real time. The results of these measurements can be monitored online[10]. Observed mismatches between modelled and measured subsidence were explained by porosity anomalies and aquifer activity, illustrating the need for high-quality static and dynamic models.

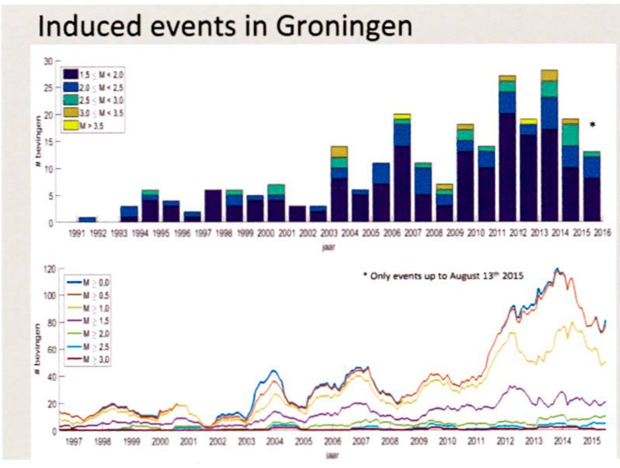
NAM reported in their latest technical reports[11] that both the Time decay and the RTCiM (Rate Type Compaction isotach Model) compaction models result in a good overall fit to the observed subsidence data above the Groningen field. The RTCiM compaction model is chosen as the base-case compaction model because it results in the best fit to the temporal and spatial observed response of the subsidence to production changes. Maximum observed subsidence above the center of the field was around 33 cm in 2013. The forecasted maximum subsidence at the end of field life is approximately 50 cm.

The production from the field causes the reservoir pressure to decline. This results in compaction of the reservoir rock, which leads to subsidence at surface and strain





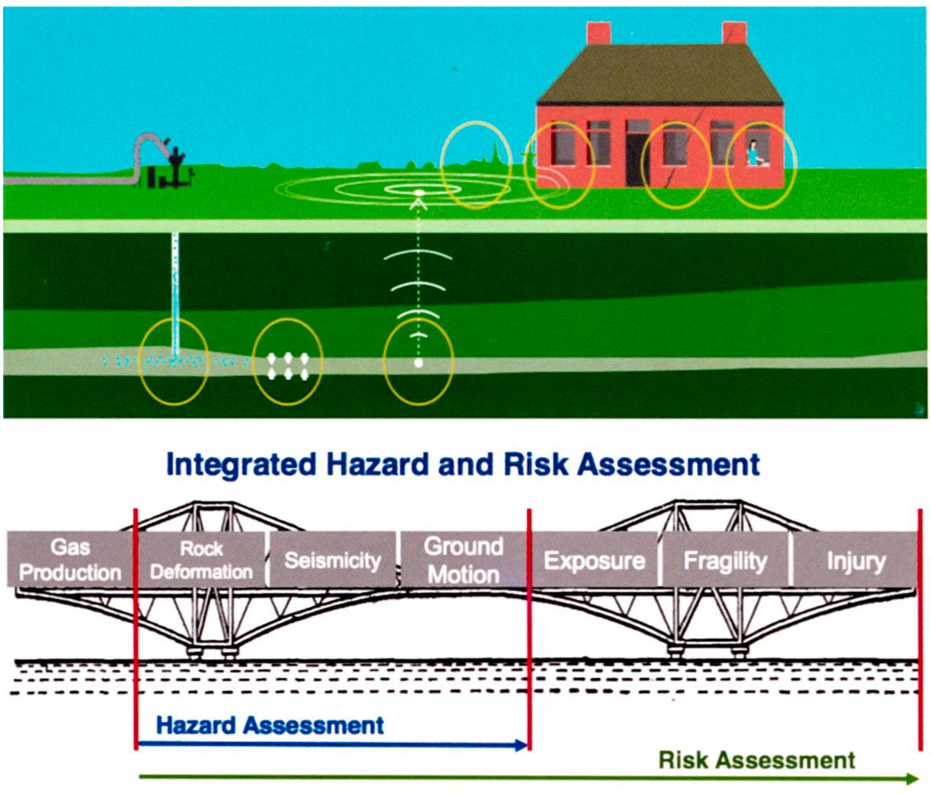




build-up in the reservoir rock. It is believed that accommodation of (a fraction of) this compaction strain by seismogenic fault slip is the source of the observed seismicity.
A number of alternative seismological models, describing the relationship between compaction and seismicity, have been prepared. In 2013, a strain-partitioning seismological model was presented in the technical addendum to the winningsplan 2013[12]. The activity rate seismological model is based on a statistical analysis of the historical earthquake record data of Groningen, in combination with the measured subsidence above the Groningen field. The model uses a Poisson Point Process model to describe the nucleation rate of earthquakes in response to reservoir compaction and the Epidemic Type Aftershock Sequence model to describe the triggering of additional events. This activity rate seismological model achieves more reliable parameter estimates and therefore more precise forecasts than the strain-partitioning model[13].

5 Integrated Hazard and Risk Assessment

To characterise the seismic hazard in a manner that is relevant to the potential impact of the earthquake on the built environment, it is necessary to quantify the hazard in terms of the nature of the ground shaking produced at any given surface location. The simplest and most widely-used of these parameters is the maximum amplitude on the acceleration time series, the peak ground acceleration (PGA). Using collections of ground-motion recordings, empirical equations have been developed, relating PGA to variables like the magnitude and the distance between the earthquake and the site of recording. These relationships are generally called ground-motion prediction equations, or GMPEs. Existing appropriate GMPEs derived from recordings of tectonic earthquakes in Europe and the Middle East, adjusted to provide a good fit to the Groningen data at smaller magnitude levels, were adopted for the prediction of PGA.
A Monte-Carlo approach to Probabilistic



Seismic Hazard Assessment (PSHA) was identified as being best suited to the analysis of the Groningen field's induced seismicity[14].

Various scenarios for the gas production from the reservoir and an updated assessment of the consequences of the production for each scenario in terms of subsidence and induced seismicity have been analysed by NAM in their latest Winningsplan Groningen 2016. For each scenario, the hazard and risk (including damage) resulting from induced seismicity are assessed and forecasts are presented[15].

6 Concluding remarks

The scientific knowledge and uncertainties described reflects the current level of understanding, but not necessarily the true physical uncertainty. Significant epistemic uncertainties exist in the seismic hazard assessment for the Groningen Field; these are primarily associated with strain partitioning, the GMPE and reservoir compaction.

A logic-tree approach, in which each branch of the logic-tree represents a distinct scenario of a particular model and associated parameter values, was used to explore the impact of the key epistemic uncertainties on the estimated hazard. It was found that the strain partitioning uncertainty has the largest impact of those considered. Further earthquake, surface acceleration, and subsidence monitoring within the Groningen Field in combination with additional geomechanical studies will provide more information that may help to better constrain these uncertainties.

All of the above is work in progress and highlights the operational fact that risk management will be a learning process, informed by feedback in the light of new data and the actual outcomes[16].

Fact and Figures[17, 18]

All data are well documented and publicly accessible through various useful websites of stakeholders in the process:

- National Mines Inspectorate (Staatstoezicht op de Mijnen, SodM): www.sodm.nl. *The National Mines Inspectorate (SodM) supervises compliance with statutory regulations governing the exploration, production, storage and transportation of minerals. The organisation focuses on the aspects of health, safety, the environment, efficient production and ground subsidence.*
- Royal Dutch Meteorological Institute (KNMI): www.knmi.nl. *KNMI is responsible for measurements, data and prognoses relating to air quality and soil mechanics.*
- Geological Survey of the Netherlands (TNO): www.tno.nl. *TNO acts as the Geological Survey of the Netherlands and it manages data and information supplied by mining companies to the Minister of Economic Affairs, Agriculture and Innovation.*
- Nederlandse Aardolie Maatschappij (NAM): www.nam.nl. *NAM explores for and produces oil and gas onshore and offshore in the Netherlands.*

Links and references

[1] http://www.namplatform.nl/english-information.html

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[15] Production, Subsidence, Induced Earthquakes and Seismic Hazard and Risk Assessment in the Groningen Field – Part I (Summary & Production), 2016: Technical Addendum to the Winningsplan Groningen 2016. NAM report, April 2016.

[16] Study and Data Acquisition Plan Induced Seismicity in Groningen; Update Post-Winningsplan 2016, NAM Report, April 2016.

[17] http://www.namplatform.nl/feiten-en-cijfers/feiten-en-cijfers-onderzoeksrapporten.html

[18] http://www.nlog.nl/nl/hazards/subsidence.html


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