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Seismic hazard due to small-magnitude, shallow-source, induced earthquakes in The Netherlands

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Abstract

The Netherlands has large on-land gas reservoirs, which are being exploited since 1960. Small-magnitude ($M_L \leq 3.5$), shallow (depth < 4 km) events induced by this gas exploitation cause light damage and much concern to the regional population. As one of the consequences the Dutch law requires since 2003 seismic hazard and risk estimates for each mining concession. Up to now only general quantitative hazard estimates, maximum possible earthquake and maximum possible intensity were available. Here we provide more specific quantitative hazard estimates. A long-term monitoring program shows a stationary rate of seismicity since 1992, probably coupled to a stationary production rate. Based on this we present a first order site-specific hazard estimate using a Probablistic Seismic Hazard Analysis (PSHA). We predict, and observe, relatively high Peak Ground Accelerations (PGA). PGA above 0.2 g is not unusual, but damage has so far been restricted to non-structural damage, mainly cracks in masonry. Relevant hazard estimates for the local, mostly low-rise buildings are given in terms of Peak Ground Velocity (PGV) or the maximum in the 50% damped response spectra at 10 Hz. For example, above the largest Dutch gas field, the Groningen field, we expect that peak values of 20 and 30 mm/s may be exceeded with a 10% probability in 1 and 10 years, respectively. Above some small (about 3–4 km^2) gas fields, Roswinkel and Bergermeer, we expect values around 35 and 60 mm/s, respectively. These values, which exceed the Dutch building research (SBR) vibration guidelines, are obtained using simple model assumptions and are accompanied by an uncertainty analysis. The PSHA provides an important additional insight for the decision maker as to which relevant uncertainties may be decreased and which not. This information can be and is being used to set research and monitoring priorities.

Keywords: Induced seismicity; Small earthquakes; Seismic hazard; Peak Ground Velocity; Peak Ground Acceleration; PSHA; The Netherlands; Gas exploitation

1. Introduction

Earthquakes in the north of The Netherlands induced by the exploitation of gas fields are small, but they occasionally cause non-structural damage (Dost and Haak, 1997; Haak et al., 2001). This is of concern to the regional population and the Dutch government. On the other hand, the Dutch gas reserves on land are of considerable national economic importance. Therefore both the exploitation companies and the Dutch government aim at a balanced policy to meet both concerns. Since January 1, 2003 the new Dutch mining legislation requires, among others, a hazard and risk analysis for each new exploitation license (Staatsblad, 2002). However, hazard and risk analysis are usually not developed in such detail

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for small and shallow earthquakes, whether natural or induced by exploitation of hydrocarbons. Therefore, all involved parties in The Netherlands (exploitation companies, government and research institutes) jointly worked out an acceptable long-term approach. It was agreed that this approach should reflect the state-of-the-art knowledge

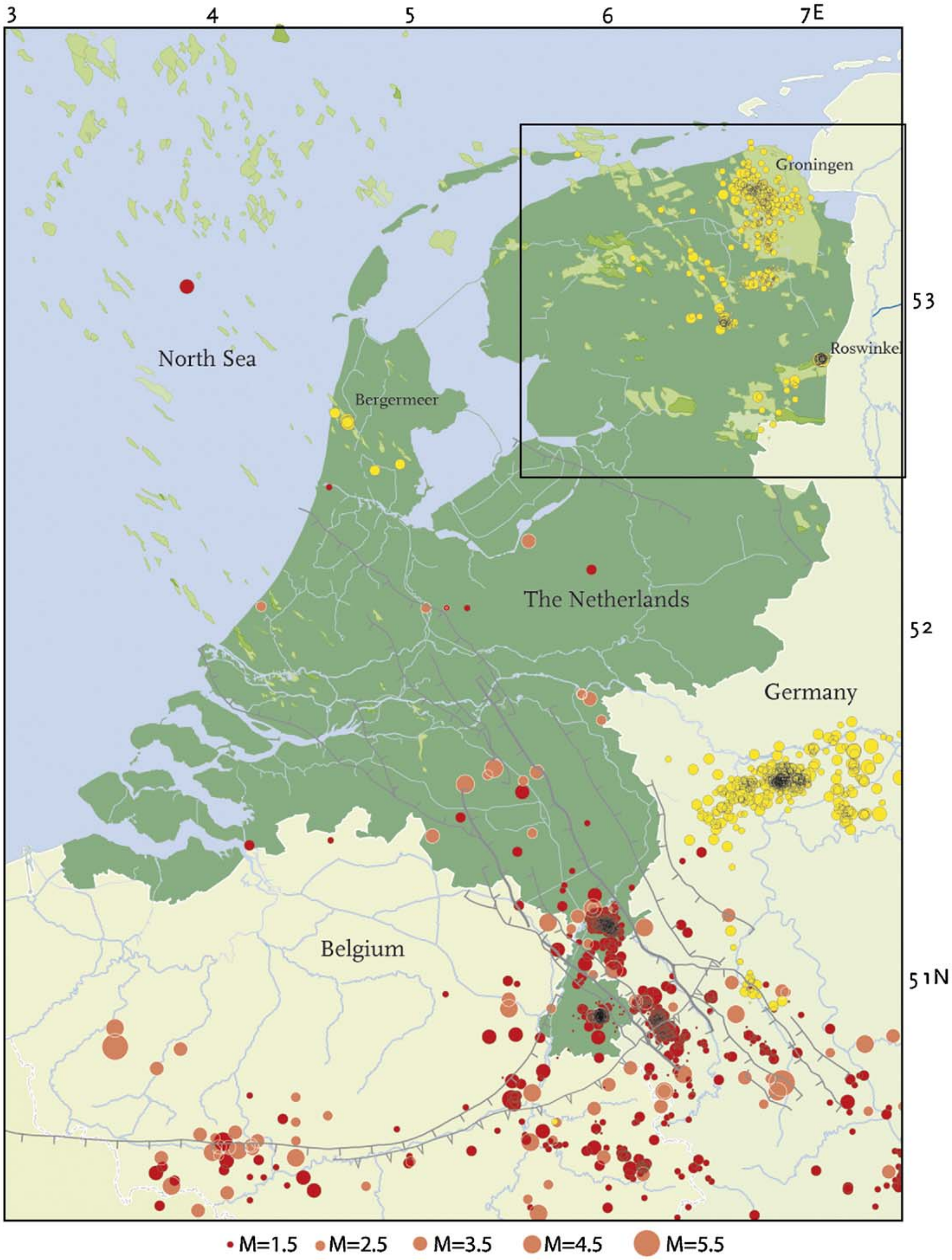

Fig. 1. General overview of the seismicity in The Netherlands and its immediate surroundings since 1900. Red circles indicate natural tectonic earthquakes. Yellow circles indicate earthquakes caused by man-made activities, classified by the KNMI, usually mining or gas exploitation. The earthquakes are scaled according to magnitude. Grey solid lines indicate mapped faults in the upper-north-sea formation according to the NITG. Light green indicates the approximate contours of the gasfields. A more detailed map (inset) for the northern part of The Netherlands is shown in Fig. 4.