Project phase 1, WP2

Review of the public KNMI induced earthquake catalogue from the Groningen gas field

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NORSAR

Contents

Executive summary

This report covers Work Package 2 (WP2) of the NORSAR project to review the public KNMI induced seismicity catalogue from the Groningen gas field. The objective of the report is to investigate the significance of different seismological parameters related to the induced seismicity catalogue and how they relate to understanding the causes of the seismicity as well as the hazard and risk assessment for the Groningen field, and what further work is needed to improve how these parameters are determined. Understanding the causes of seismicity in this context implies understanding the physical processes involved in the nucleation of seismic events, and their relationship with the production parameters, for example, to assess whether a change in production rate (such as the reduction implemented in 2014) would result in a change in seismicity rates and magnitudes, and if so, over which time scale. Ultimately, the knowledge gained could be used to adjust the production parameters such that the induced seismicity remains as low as possible.

Causes of seismicity: The causes of seismicity are best understood via event detection, magnitude determination and accurate and precise event locations. Moreover, parameters derived from the event magnitude including b-value, seismic moment/released seismic energy, and magnitude of completeness are all important for accurately modelling the seismicity or understanding the seismicity rate without introducing bias from network changes. Improvements to these parameters would aid the establishment of an integrated seismo-geomechanical model, which would better demonstrate how production and induced seismicity are linked.

Earthquake hazard: We consider the maximum magnitude to be the most significant parameter for estimating the hazard of large earthquakes. However, for small to intermediate sized earthquakes, and in the case of Groningen, we consider the κ parameter, the stress parameter $\Delta\sigma$, source mechanisms, and earthquake depth to be more significant. Each of these parameters are not straightforward to determine and require high quality data and detailed analysis. Furthermore, it should be noted that KNMI continue to use a point source approach in the current hazard model, rather than incorporating the fault rupture area - for larger earthquakes this can result in underestimating the seismic hazard. Determination of the source parameters would provide constraints on the fault rupture area, to improve the current hazard models.

Earthquake risk: The building stock for the Groningen region is particularly sensitive to the high frequencies of ground motion from regional and local events, due to the predominant natural resonant frequencies of the buildings. It is therefore required that data are of high quality and recorded with sufficient sampling rate to measure the high frequency ground motion to better understand the seismic risk. Similarly, high quality and good spatial coverage of Peak Ground Acceleration (PGA) measurements are required. Additional parameters that effect the sensitivity of any risk analysis

include focal mechanism solutions, location precision (epicentral and depth), maximum magnitude, horizontal-to-vertical shaking amplitudes, stress drop, and the κ parameter. Analysis of these parameters would add value to the seismic risk analysis for Groningen.

Relative importance of seismological parameters: Ranking the relative importance of seismological parameters is strongly dependent on the objectives of a study. When considering the causes of seismicity, and both hazard and risk assessments together, earthquake location, focal depth, stress drop, and source mechanism are all regarded as significant parameters that influence all three study areas. The parameters: maximum magnitude Mmax; the stress drop or stress parameter $\Delta\sigma$; κ; and the ratio of horizontal to vertical shaking and their phase shift all influence both hazard and risk assessments; while the placement of faults, event magnitudes, and seismicity rates prove to be influential for both understanding the causes of seismicity as well as the seismic hazard assessment.

Assessment of earthquake-related core parameters: In terms of the three areas of interest for this report - causes of seismicity, seismic hazard assessment, and seismic risk assessment - we have highlighted the main parameters that are either used as input or add to the understanding of these topic areas. From these parameters we have identified tasks that we deem high priority and those tasks that we recommend in addition. The high priority tasks include the estimation of earthquake depth, source mechanism determination, moment magnitude estimates, and temporal changes of the magnitude of completeness. The additional tasks comprise of improved determination of epicentral locations, estimation of stress drop, and estimation of the ratio of the horizontal to vertical components of motion and their potential phase shifts. These tasks partially follow the recommendations given by the SSHAC expert panel with the aim to reduce uncertainties in the estimation of the maximum magnitude (Coppersmith et al., 2016).

Overall, taking into account that the KNMI induced seismicity catalogue covers the complete time period of seismicity occurring within the Groningen field, in which both the instrumentation of the field as well as methodologies for data processing changed considerably, we consider the catalogue as extensive and of high quality and as such, a sound basis for the tasks of seismic hazard and risk assessment as well as any studies aimed at resolving the underlying causes of seismicity.