NAM

Supplement to Special Report on the Zeerijp Earthquake Swarm starting 4th October 2021

Datum November 2021

Editors and

Contents

Summary and Conclusions

This note presents further comparison of the ground motions recorded during the Zeerijp earthquake swarm starting 4th October 2021 with the models supporting the operational strategy 2021-2022.

An important observation is that the motions recorded in the Zeerijp earthquake are consistent with the predictions from the ground motion model GMM V6 deployed in SDRA-2021 and GMM V7 currently deployed in the seismic hazard and risk modelling for Groningen.

Although at the higher end of range for the predicted event rate for SDRA-2021, the number of earthquakes is within the predicted range.

1 Introduction

1.1 Reports submitted November 2021

On 19th November 2021, NAM has submitted two reports to both SodM and the ministry of Economic Affairs and Climate Policy:

- Special Report on the Zeerijp Earthquake Swarm starting 4th October 2021 en
- Rapportage Seismiciteit Groningen – November 2021

Both reports were required to be submitted under the Mining Law. When larger earthquakes have occurred or other remarkable events have happened (like a swarm of smaller earthquakes), NAM publishes a report within two weeks after the event. NAM has over the last five years prepared and submitted thirteen special reports (Table 1.1).

Title	Date
Rapportage recente aardbevingen Wirdum en Garsthuizen 2016/2017	Mar 2017
Ground Motions from the M_L 2.6 Slochteren Earthquake of 27th May 2017	June 2017
Special Report on the earthquake density and activity rate following the earthquakes in Appingedam (M_L=1.8) and Scharmer (M_L=1.5) in August 2017	Sept 2017
Special Report on the Loppersum earthquakes – December 2017	Dec 2017
Special Report on the Zeerijp Earthquake	Jan 2018
Short special report Exceedance Activity Rate - February 2018	Feb 2018
Special Report - Westerwijtwerd Earthquake - 22nd May 2019	May 2019
Analyse overschrijding MRP-grenswaarde Aardbevingsdichtheid 9 september 2019	Sept 2019
Analyse overschrijding aardbevingsdichtheid - 3 december 2019	Dec 2019
Special Report on the Zijldijk M_L = 2.5 Earthquake of 2nd May 2020	May 2020
Special Report on the Loppersum M_L=2.7 earthquake of 14th June 2020	Aug 2020
Special Report on the Zeerijp Earthquake Swarm starting 4th October 2021	Nov 2021
Special Report on the Garrelsweer Earthquake 16th November 2021 with M_L = 3.2	Nov 2021

Table 1.1 Reports analysing remarkable events in the earthquake record, like larger events or earthquake swarms.

Together with the special report the monitoring report for November 2021 was submitted. NAM has submitted these reports at 6-month intervals since submitting Winningsplan 2016 (table 1.2).

Title	Date
Analyse Seismiciteit	Nov 2016
Rapportage Seismiciteit Groningen - November 2017	Nov 2017
Rapportage Seismiciteit Groningen - Juni 2018	July 2018
Rapportage Seismiciteit Groningen - November 2018	Nov 2018
Rapportage Seismiciteit Groningen - Mei 2019	May 2019
Rapportage Seismiciteit Groningen - November 2019	Nov 2019
Rapportage Seismiciteit Groningen - Mei 2020	Apr 2020
Rapportage Seismiciteit Groningen - November 2020	Nov 2021
Rapportage Seismiciteit Groningen - Mei 2021	June 2021
Rapportage Seismiciteit Groningen - November 2021	Nov 2021

Table 1.2 Half-yearly surveillance reports issued by NAM to SodM and published on the NAM onderzoeksrapporten-webpage.

1.2 Reason for this Supplement

In the Special Report on the Zeerijp earthquake swarm, the earthquakes are evaluated and compared to model predictions and exceedance values in the monitoring protocol. The Mining Regulation stipulates the following:

Artikel 1.3a.7

1 Bij overschrijding van de parameters, bedoeld in artikel 1.3a.6, eerste lid, onderdelen b en d, analyseert de houder van de winningsvergunning Groningenveld de ontwikkeling van de seismiciteit en toetst hij of deze significant afwijkt van de gegevens die zijn verstrekt ter onderbouwing van de operationele strategie.

2 De houder van de winningsvergunning Groningenveld rapporteert binnen twee weken aan de minister en de inspecteur-generaal der mijnen over de analyse en de toets, bedoeld in het eerste lid.

Article 1.3a.7 first clause stipulates the that the check is performed to ensure the development of seismicity does not significantly deviate from the data provided in support of the operational strategy. As the operational strategy was supported by the SDRA prepared by TNO, the data will in effect have to be checked against the models supporting this hazard and risk assessment.

1.3 Content of this supplement

In this document the comparison of the data obtained for the earthquakes of the Zeerijp swarm are further compared with supporting models for SDRA-2021 prepared by TNO. In the Special Report the ground motions for the Zeerijp earthquake of 4th October 2021 were compared to the latest model for ground motions, GMM V7. However, in the preparation of the SDRA-2021 the previous version of the model for ground motion, GMM V6 was used. In chapter 2 of this supplement this comparison between the ground motion recording for the Zeerijp earthquake and GMM V6 is presented.

In the half-yearly seismic monitoring report for November 2021, the development of the earthquakes is evaluated and compared to exceedance level prescribed in the monitoring protocol, which is included in the Mining Law. As part of this evaluation the development of the b-value is tracked. This did not show a significant deviation since the seismological model was developed. The event rate is in the half-yearly seismic monitoring report tracked against the prescribed monitoring levels. In chapter 3 the event rate is additionally compared to the event rate predicted by TNO in SDRA-2021.

2 Evaluation of observed ground motions for the earthquake Zeerijp earthquakes based on GMM V6

The GMM V7 superseded and replaced the GMM V6 (Bommer *et al*., 2019); the extensive additions, improvements and changes that the GMM V7 has in comparison to V6 are described in detail in Bommer *et al*. (2021). However, for completeness, and because the GMM V6 was used in the TNO-SDRA on which the current operational strategy for the Groningen field is based, we repeat the comparisons of Figures 2.13 to 2.17 in the Special Report on the Zeerijp earthquake swarm for the GMM V6 in Figures 2.1 to 2.5 below.

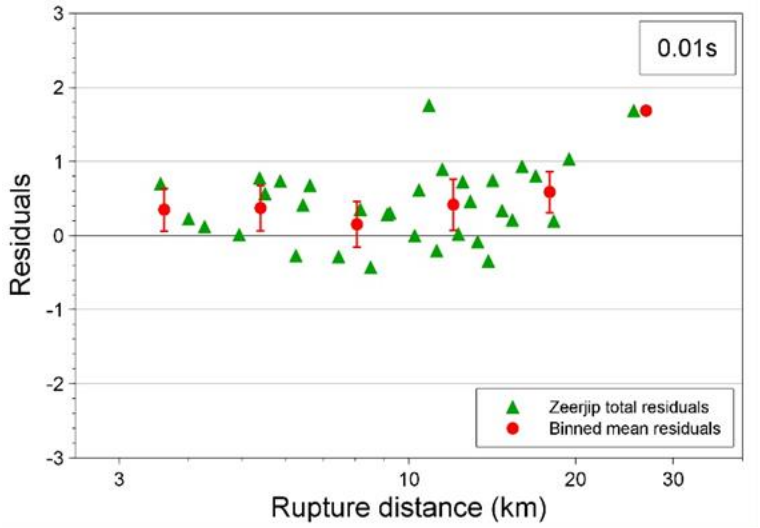


Figure 2.1 Residuals of Sa(T) with respect to the central branch of the GMM V6 at 0.01 seconds

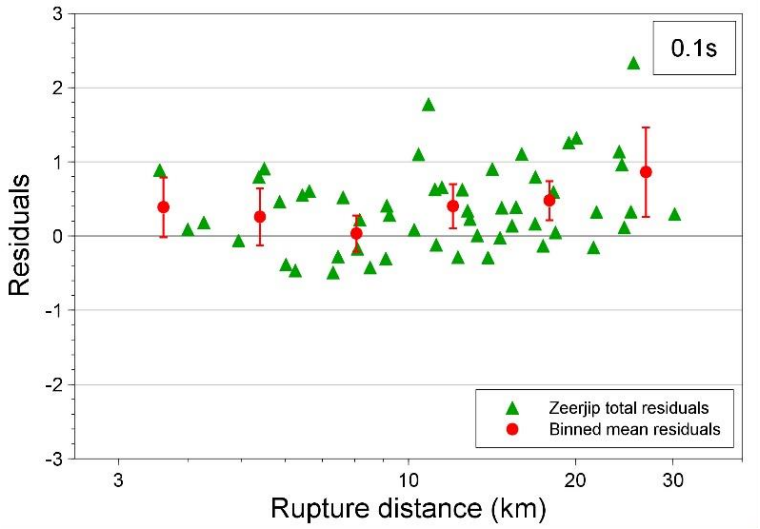


Figure 2.2 Residuals of Sa(T) with respect to the central branch of the GMM V6 at 0.1 seconds.

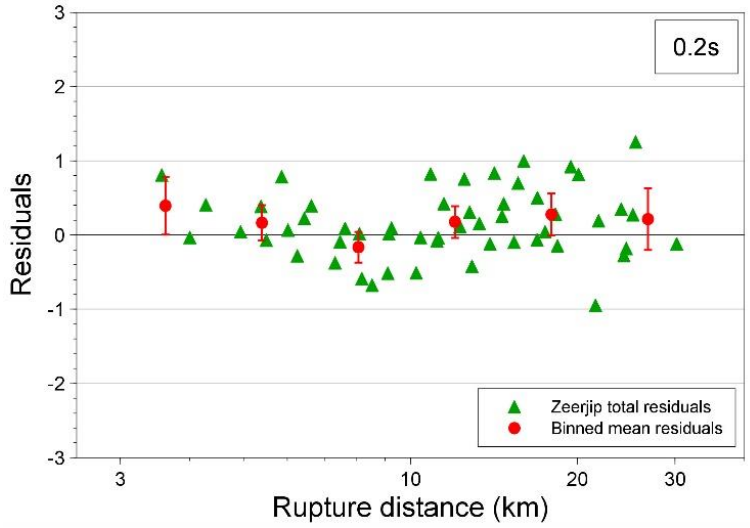


Figure 2.3 Residuals of Sa(T) with respect to the central branch of the GMM V6 at 0.2 seconds.

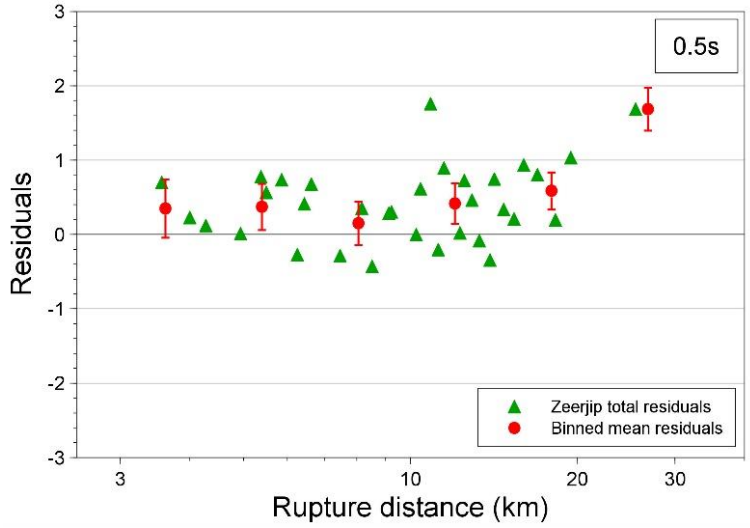


Figure 2.4 Residuals of Sa(T) with respect to the central branch of the GMM V6 at 0.5 seconds.

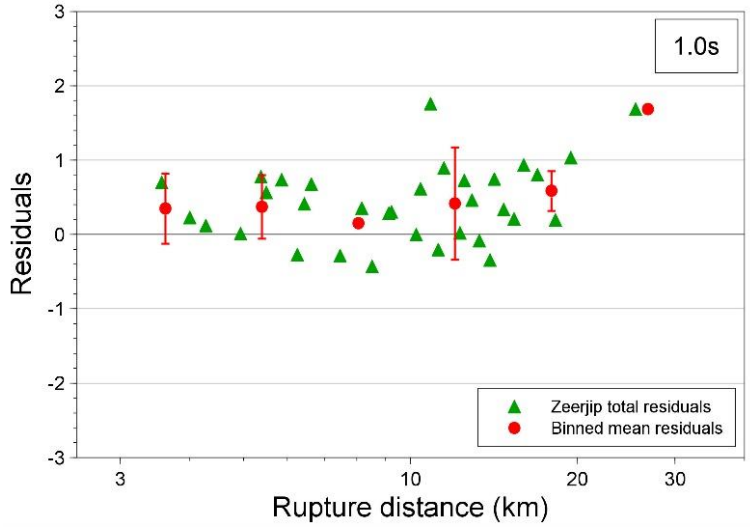


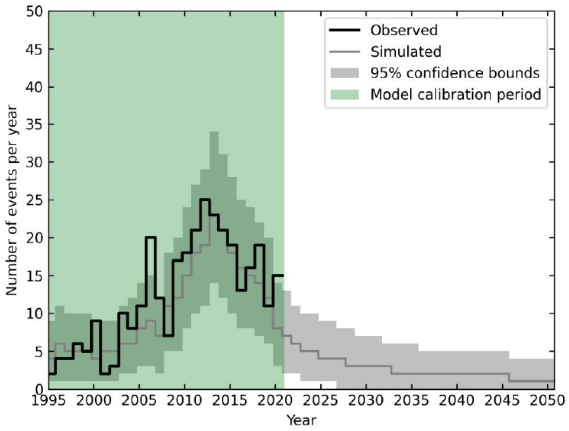
Figure 2.5 Residuals of Sa(T) with respect to the central branch of the GMM V6 at 1 second.

With the exception of the residuals at the period of 0.2 seconds, which are reasonably well centred on the zero line, the GMM V6 model has a clear tendency to under-estimate the ground-motions from

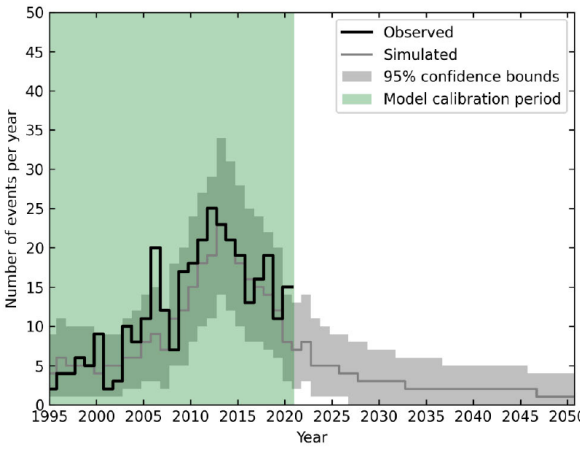
this event. The comparison of recorded ground motion data and GMM V6 included in Figures 2.1 to 2.5 is based on the most recent processing methodology (Edwards, B. & M. Ntinalexis, 2021). This is a more advanced processing than used in development of the ground motion database used in the development of GMM V6. This comparison of recorded ground motion data with the GMM is only provided for earthquakes with magnitude $M_L \geq 2.5$, as these eartquakes are the basis for the development of the GMM. This is also the range where for Groningen earthquakes the local magnitude, M_L, has been shown to be equivalent to the moment magnitude, **M** (, and , 2016).

3 Comparison of earthquake event rate

In the Seismic Monitoring Report for November 2021 recent earthquake event rates were compared to set monitoring values in the Mining Law. Here we will compare against the number of events predicted in the SDRA prepared by TNO. The graphs for the event rate predictions in the SDRA have been replicated in figure 3.1.



Figuur 3.1 Verwachte seismische activiteit en variatie per gasjaar voor een gemiddeld temperatuurverloop. Op de horizontale as staat het kalenderjaar (bereik 1 januari 1995 tot 1 oktober 2050). Op de verticale as staat het aantal bevingen met een magnitude gelijk aan of hoger dan 1.5 opgeteld per gasjaar. De zwarte lijn geeft het aantal observaties in het verleden weer. De donkergrijze lijn geeft het verwachte aantal bevingen in de toekomst weer. De lichtgrijze band om de grijze lijn is de onzekerheidsband. Het groene vlak geeft aan dat het model gekalibreerd is op de periode tot 1 januari 2021.



Figuur 3.3 Verwachte seismische activiteit en variatie per gasjaar voor een koud temperatuurverloop. Onderschrift als in Figuur 3.1.

Figure 3.1 Reproduction of figures 3.1 and 3.3 from report "Publieke Seismische Dreigings-en Risicoanalyse Groningen gasveld 2021 - TNO2021 R10441" prepared by TNO.

The SDRA predicts between 2 and 13 earthquake events with a magnitude $M_L \geq 1.5$ in calendar year 2021. To date 12 earthquakes with a magnitude $M_L \geq 1.5$ have been recorded.

For gas-year 2020-2021 the SDRA also predicts between 2 to 13 earthquake events. In gas-year 2020-2021, 10 earthquakes were recorded. The Zeerijp earthquake swarm fell in gas year 2021-2022. For gas-year 2021-2022 the predicted number of earthquakes with magnitude $M_L \geq 1.5$ is between 3 and 14.

Although at the higher end of range for the predicted event rate, the number of earthquakes is within the predicted range.

4 References

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