Technical Addendum to the Winningsplan Groningen 2016

Production, Subsidence, Induced Earthquakes and Seismic Hazard and Risk Assessment in the Groningen Field

PART V
Damage and Appendices

The report “Technical Addendum to the Winningsplan Groningen 2016 - Production, Subsidence, Induced Earthquakes and Seismic Hazard and Risk Assessment in the Groningen Field” consists of five separate documents:

Document 1	Chapters 1 to 5;	Summary and Production
Document 2	Chapter 6;	Subsidence
Document 3	Chapter 7;	Hazard
Document 4	Chapter 8;	Risk
Document 5	Chapter 9;	Damage and Appendices.

Each of these documents is also available as a *.pdf file of a size smaller than 10Mbyte, allowing sharing through e-mail.

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9 Building Damage

Introduction

This section describes the results of an initial technical analysis of received damage claims and building damage observations. This initial focus is on the technical aspects only and reporting building damage observations in the broader public domain requires further work. This assessment provides background to the building damage section in the Winningsplan 2016 and addresses some of the difficulties in a balanced assessment of building damage and proper handling of damage claims.

A damage claim does not necessarily report actual earthquake damage. Not all damage claims report earthquake damage and the reverse is also true: if no damage claim has been submitted for a building, this does not prove the absence of earthquake damage. The occurrence of this latter phenomenon is likely to be considerably less than that of the first.

Factors that appear to play a role in the number of damage reports received in a certain period (examples, not exhaustive):

- The visibility of actual damage
- The ease with which damage can be reported
- Media attention on expected injury
- Calls in media from parties (e.g. VEH, GBB) to report damage
- Someone from the social network or with a house in the vicinity of somebody considering to raise a claim has reported damage or received compensation
- Accumulation of damage (first damage not seen, but noticed after a second earthquake)
- Interacting with overdue maintenance
- Publications that the arrangement to receive support for energy improvements to private houses would be terminated
- Etc.

SBR Guideline Part A

Vibrations in buildings can be result of a number of activities, such as road and rail traffic, construction activities incl. pile driving demolition or rock blasting. Also earthquakes cause vibrations in buildings which may lead to building damage. Several international norms exist incl. DIN-4050 to help assess vibration levels and their impact to buildings. The Dutch equivalent is SBR guideline part A and defines threshold values (depending on frequency) for 3 categories of buildings below which it is considered unlikely (<1% chance) that the vibration will cause/has caused damage. It should be noted that exceeding these values does not mean damage will actually occur, only that there is a possibility that damage cannot be ruled out.

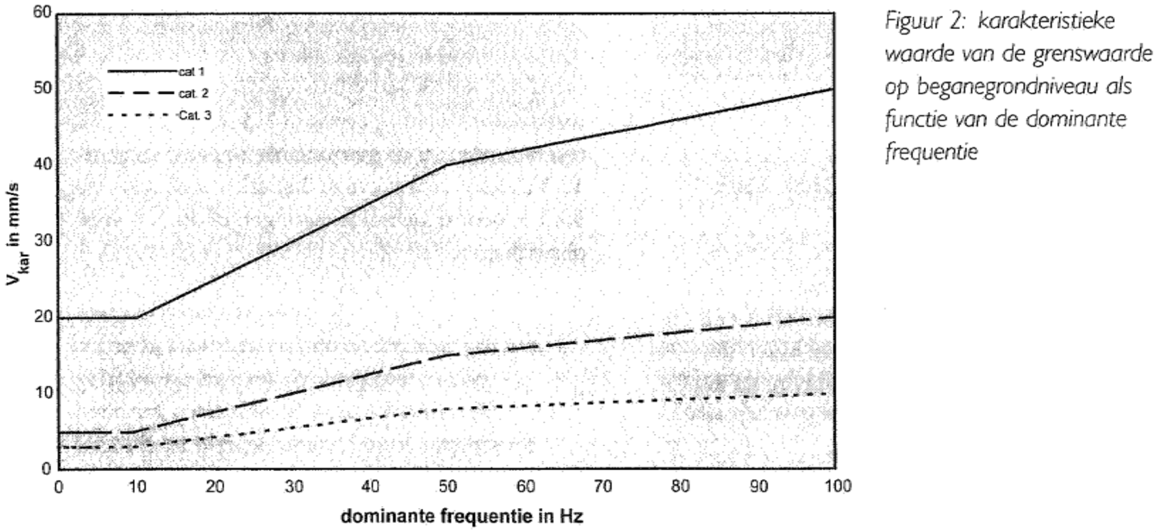

Figure 9.1 Illustration taken from SBR guideline A; Characteristic value of the limit value at ground level as a function of the dominant frequency.

Analysis of Historical Damage Claims

Figure 9.2 shows the cumulative number of damage claims. The increasing rate of received damage claims can clearly be observed. After the Huizinge earthquake on the 16th August 2012 the rate at which damage claims were received initially rose sharply, but tailed off after some weeks.

However, during 2013 and the first three quarters of 2014 on average some 210 damage claims were received each week. In September 2014, this rate suddenly doubled to some 560 damage claims each week. The vertical lines in figure 9.2 indicate significant earthquakes with a magnitude above M=2.5. Although the claim rate seems to increase after each earthquake this is only a small deviation from the (linear) trend in general.

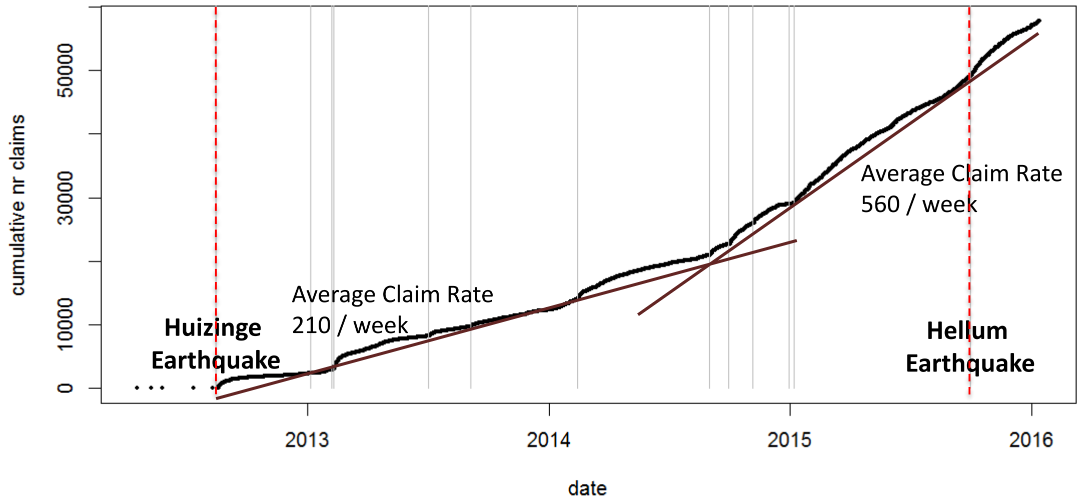

Figure 9.2 Cumulative number of damage claims over time.

This confirms the observation in the introduction, that more factors play a role in whether or not damage is reported. The occurrence of earthquakes is not the only (or even prime) factor influencing the rate at which damage claims are received. This is further supported by figure 9.3 where the number of damage claims received during a year is plotted against the seismicity during the same year. The main earthquakes since the Huizinge earthquake in August 2012 are summarised in table 9.1.

	date	magnitude	place
1	**16/08/2012**	**3.6**	**Huizinge**
2	**07/02/2013**	**3.2**	**Zandeweer**
3	**30/09/2015**	**3.1**	**Hellum**
4	**13/02/2014**	**3.0**	**Leermens**
5	**02/07/2013**	**3.0**	**Garrelsweer**
6	05/11/2014	2.9	Zandeweer
7	30/12/2014	2.8	Woudbloem
8	30/09/2014	2.8	Garmerwolde
9	04/09/2013	2.8	Zeerijp
10	06/01/2015	2.7	Wirdum
11	09/02/2013	2.7	't Zandt
12	07/02/2013	2.7	Zandeweer
13	01/09/2014	2.6	Froombosch

Table 9.1 *Main earthquakes since the Huizinge earthquake in August 2012, in order of magnitude.*

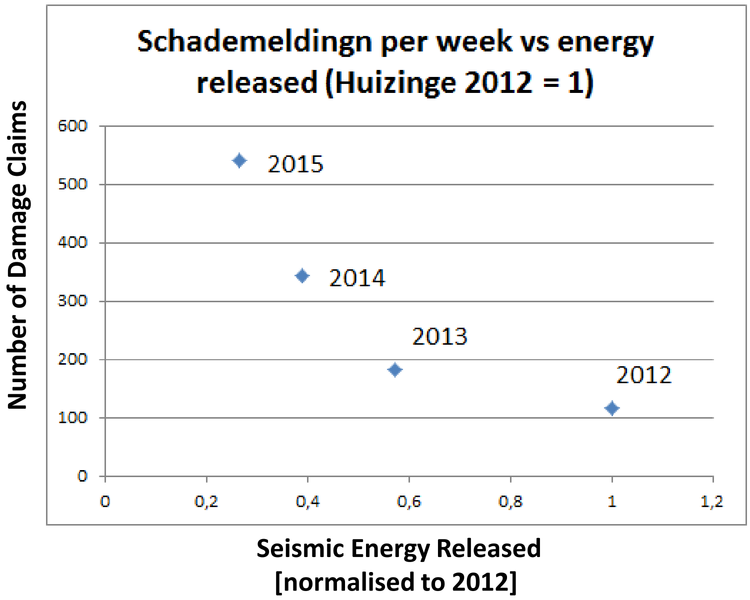

Figure 9.3 *Number of damage claims during a year plotted against seismic energy released during the same year (normalised to 2012).*

While seismic energy released has decreased since 2012, the number of damage claims received during a week has risen sharply.

Comparison Damage Claims after Huizinge 2012 and Hellum 2015

To shed more light on the changes response in damage claims after an earthquake we will compare the damage claims after the Huizinge earthquake of 2012 (M=3.6) with the Hellum earthquake of 2015 (M=3.1). The epicenter of the Huizinge earthquake is located in the seismic active Loppersum area. The epicenter of the Hellum earthquake was located more to the south in an area not earlier exposed to earthquakes of this magnitude. Prior to the Hellum earthquake no significant earthquake with magnitude above M=2 had occurred for 9 months. This made the Hellum earthquake a both laterally and temporally an isolated event.

Temporal Comparison

The rate at which the claims are received after the earthquake is analysed first . The number of damage claims received in the weeks following these two earthquake events is very different (fig. 9.4).

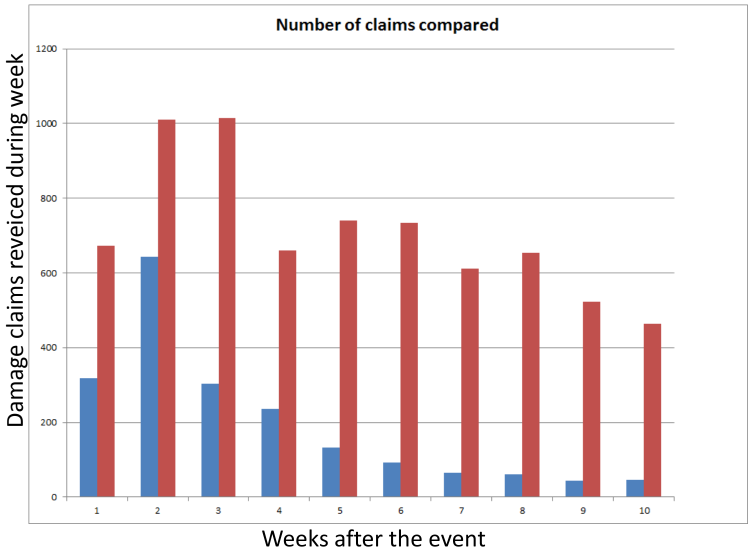

Figure 9.4 Number of damage claims during a week compared for the Huizinge (blue) and Hellum (red) earthquakes.

After the Huizinge earthquake claims received rose sharply only to subside three weeks later (fig. 9.5). The maximum number of claims received was some 600 claims in the second week. After two month the number of claims received each week has declined below 40.

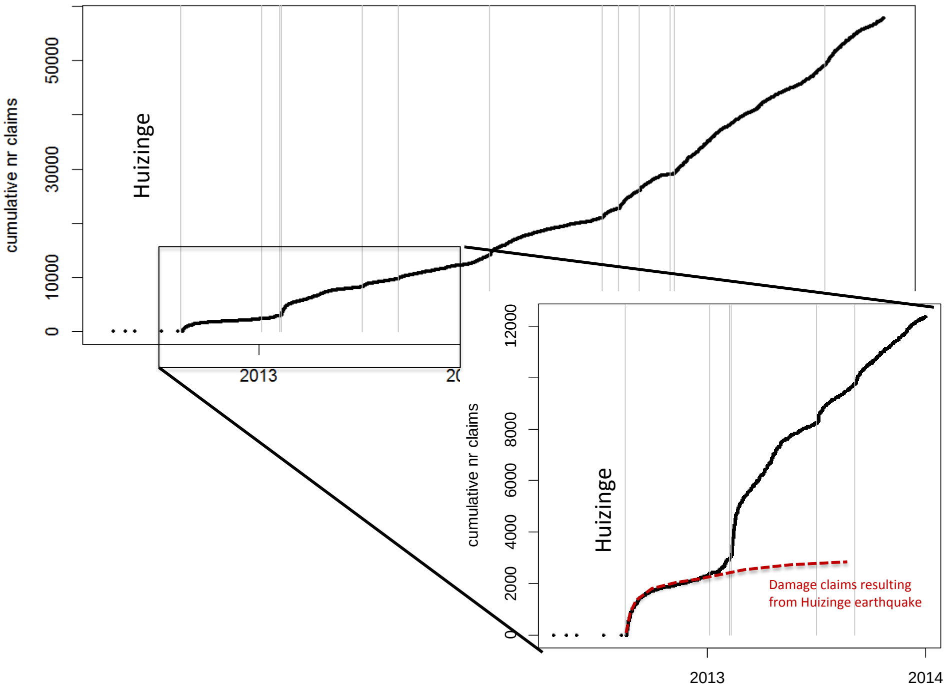

Figure 9.5 Enlargement of figure 9.2; Cumulative number of damage claims over time. Focus on Huizinge earthquake.

In contrast the development of damage claims received after the Hellum earthquake (fig. 9.4) was very different. After 2 months still some 500 claims were received each week.

Spatial Comparison

We expect that buildings located closer to the epicentre and exposed to higher peak ground accelerations would have an increased chance of being damaged and that therefore an increased probability for a damage claim bear the epicentre would exist. This is clearly seen for the Huizinge earthquake (fig. 9.6), where the percentage of buildings where damage was reported is very low (a few percent) for buildings exposed to accelerations smaller than 15 cm/s^2. Buildings exposed to higher ground accelerations show an increasing percentage of damage claims. Of the buildings exposed to an acceleration of 40 cm/s^2, some 25 % showed damage (or at least a damage claim was made).

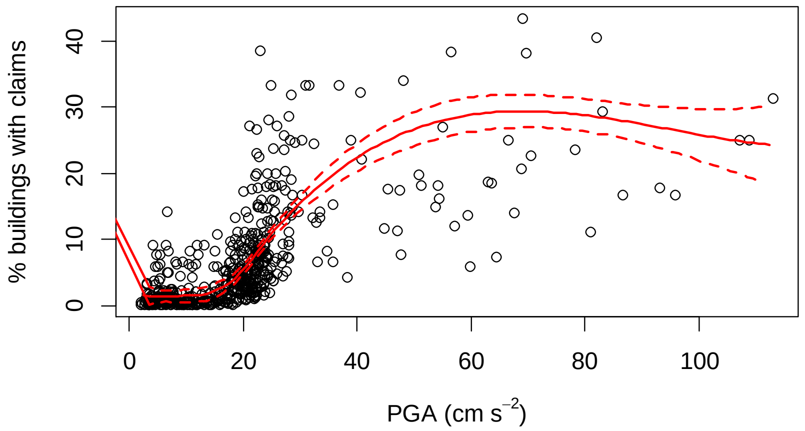

Figure 9.6 Percentage of claims for building exposed to the ground acceleration for the Huizinge earthquake of August 2012.

Damage claim rates after later earthquakes show a different trend. For these earthquakes, buildings exposed to accelerations above 10 cm/s^2 have same a 10 – 25 % damage claim fraction independent of the ground acceleration the building was subjected to in the earthquake (fig. 9.8).

Predicting chance of Building Damage; Kalibratiestudie schade door aardbevingen

Research into building damage commenced in 2006 commissioned by NAM BV, BP Nederland Energy BV (later TAQA), Vermilion Oil&Gas Netherlands BV and Wintershall Noordzee BV. The objective of this study was to establish the distance from the epi-centrum, where damage can be expected based on the earthquake magnitude (expectation of outer limit for damage). The research was conducted by TNO and published in a report named “Kalibratiestudie schade door aardbevingen” in 2009.

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Kalibratiestudie schade door aardbevingen

Datum 11 november 2009

Figure 9.7 Cover of "Kalibratiestudie schade door aardbevingen" published by TNO in 2009.

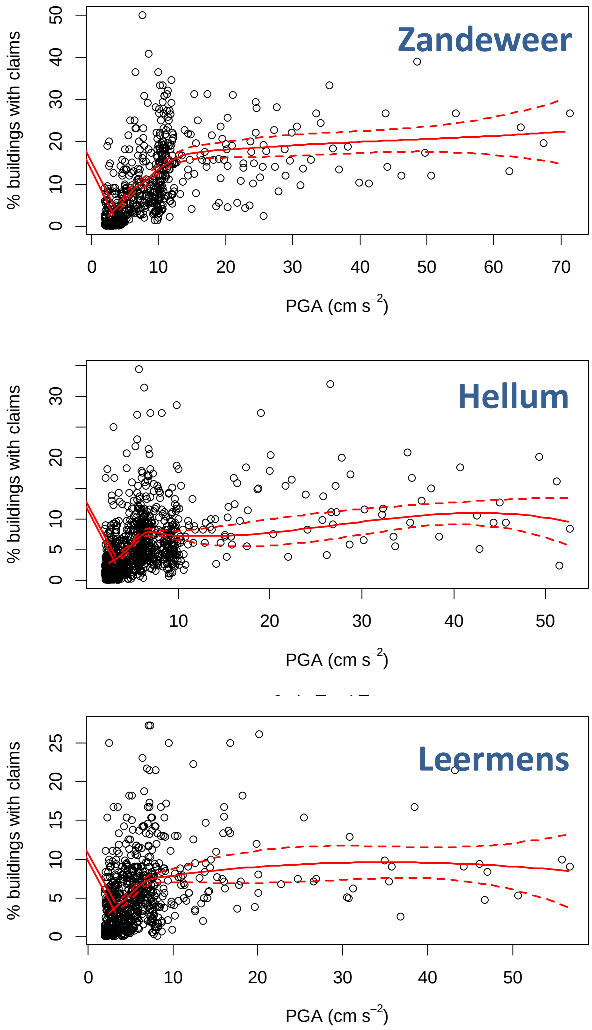
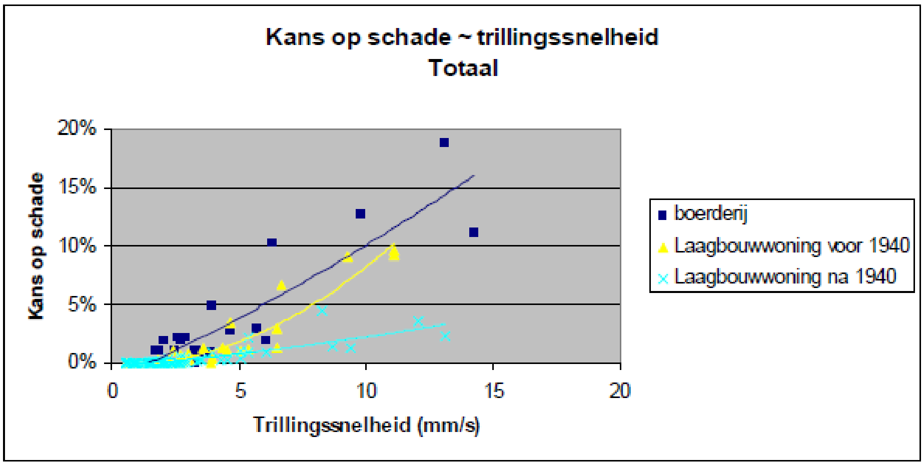


Figure 9.8 Percentage of claims for building exposed to the ground acceleration for three earthquakes: Zandeweer, Hellum and Leermens.

The methodology in this TNO report has been applied to estimate the expected number of damaged buildings as a result of the Huizinge and Hellum earthquakes and compare this with the actual number of damage claims. Based on experience in The Netherlands prior to 2007, this report contains a relationship between the ground acceleration a building is exposed to and the probability of damage (damage state 1). This relationship is developed for three different building typologies. In the remainder of this report, we will conservatively use for all buildings the relationship for farmhouses ("boerderijen"), the weakest of the three typologies (fig. 9.9). This relationship states there is a 1% chance of damage at a velocity of 2.4 mm/s.

The velocities buildings are exposed to are in this assessment based on the ground motion prediction equation (version 1). This equation gives a good fit with the velocities measured by the TNO network (fig. 9.10).

In the next sections we will use this methodology to estimate the number of damaged buildings after the Huizinge and Hellum earthquakes and compare this with the number of damage claims received within 10 weeks after the seismic event. In this comparison, we should keep in mind that the Hellum earthquake was roughly 5,5 times weaker in terms of energy release.



Figuur 15 Kans op schade bij een bepaalde trillingssnelheid op basis van gegevens uit de aardbevingen Roswinkel 1997 en 1998, Hoeksmeer, Stedum en Westeremden ~ waarbij de categorie boerderijen niet is onderverdeeld naar bouwjaar

Figure 9.9 Figure taken from "Kalibratiestudie schade door aardbevingen" published by TNO in 2009.

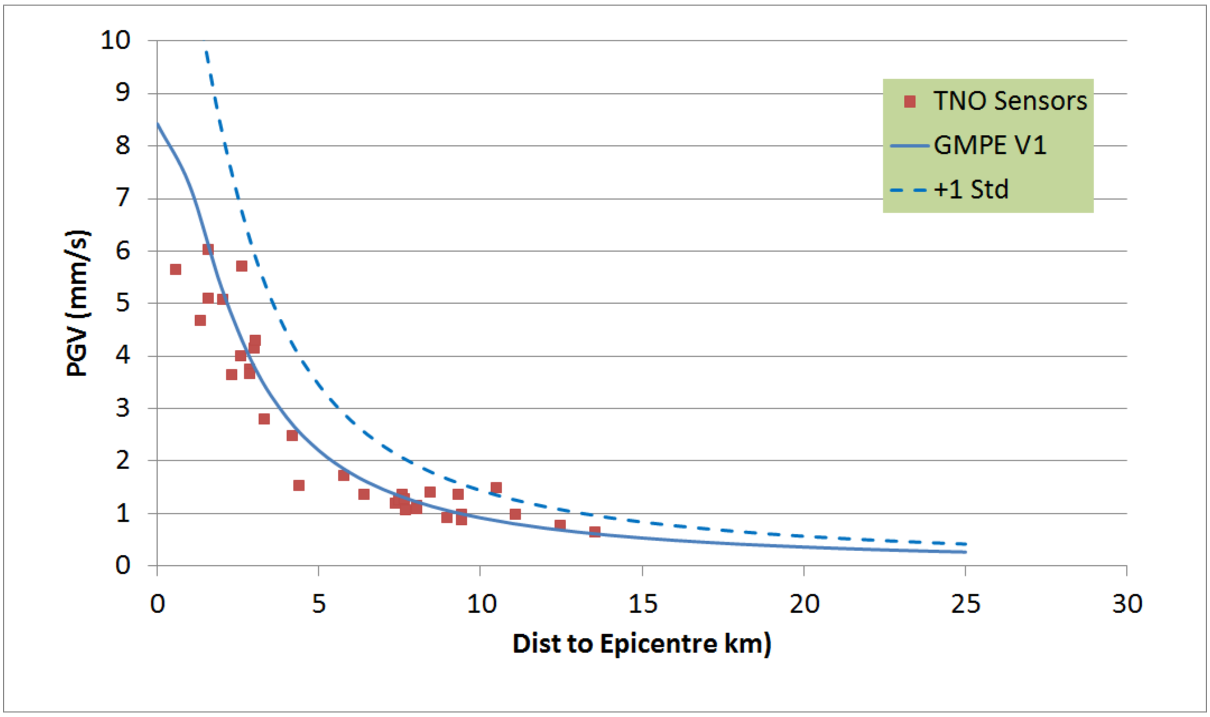


Figure 9.10 *Comparison of the velocities calculated using the ground motion prediction equation (version 1) and the velocities measured by the TNO network.*

Damage Huizinge Earthquake

The Huizinge earthquake had a magnitude of M=3.6 and affected a large area of the Groningen province. Figure 9.11 (left) shows in yellow the large areas where buildings have a 1% probability of damage based on the methodology developed by TNO based on damage data from before 2006. This corresponds quite well with the area of the damage claims received in the 10 weeks after this event. Also the comparison between the number of forecasted damaged buildings (some 2,500) and damage claims in the 10 weeks following the earthquake (some 2,000 but likely still increasing after the 10 weeks) is very close.

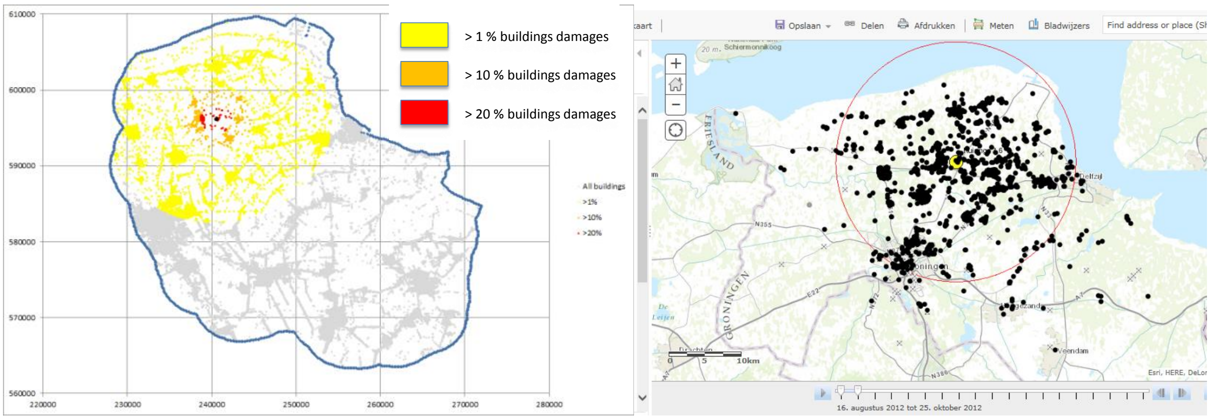


Figure 9.11 *Prediction of chance of building damage using the TNO methodology (left) compared with actual damage claims (right) for the Huizinge earthquake.*

These results give confidence that the methodology developed based on damage data from before 2006 is also applicable to the 2012 Huizinge earthquake.

Earthquake	Magnitude	Actual Damage Claims	Forecasted Damage

Huizinge 16 Aug 2012	3,6	1,937	2,450

Table 9.2 Comparison between the number of forecasted damaged buildings and damage claims in the 10 weeks following the Huizinge earthquake.

Damage Hellum Earthquake

However, if we apply the same methodology to the Hellum earthquake the comparison gives different results. Due to the lower energy released during the Hellum earthquake, the area where the earthquake could potentially cause damage, as shown by the smaller yellow area in figure 9.12 (left). However, the area from which damage claims have been received in the 10 weeks after the event is much larger.

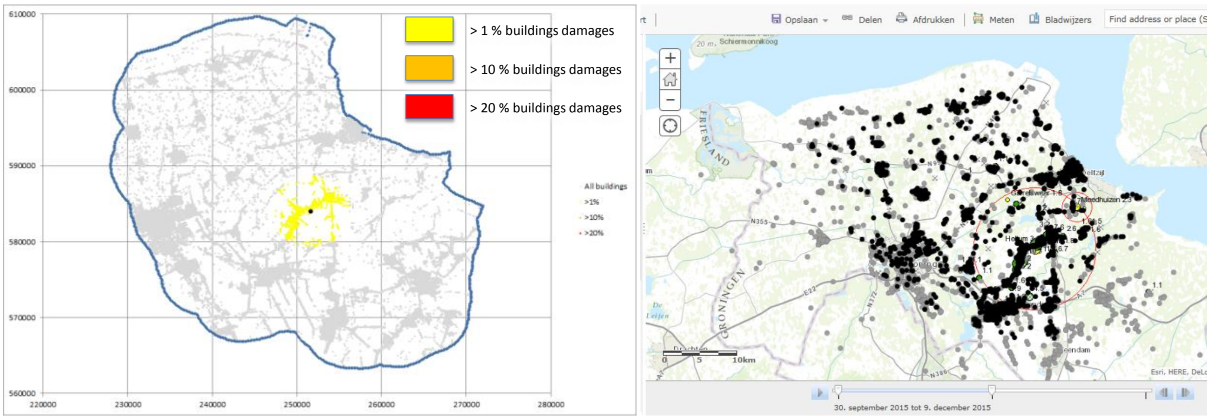


Figure 9.12 Prediction of chance of building damage using the TNO methodology (left) compared with actual damage claims (right) for the Hellum earthquake.

Table 9.3 shows that the number of damage claims after the Hellum earthquake exceeds the number of buildings with expected damage.

Earthquake	Magnitude	Actual Damage Claims	Forecasted Damage
Hellum 30 Sep 2015	3,1	6,921	170

Table 9.3 Comparison between the number of forecasted damaged buildings and damage claims in the 10 weeks following the Hellum earthquake.

For the Hellum earthquake, the methodology seems to have failed to predict the expected number of claims. This could be a result of a different claim behaviour than before, possible reasons for this have been mentioned in the introduction of this chapter.

A growing trend toward C-damage

Since January 2015, building damage claims (reported damage by property owner) are submitted to the *Centrum voor Veilig Wonen* (CVW). CVW inspects the buildings for which claims have been raised and determines whether the identified damage (individual defects found during the damage assessment) are A-, B- or C-damage. A-damage can be fully attributed to earthquakes. B-damage is only partially due to earthquakes (i.e. existing damage that is amplified by earthquake energy) and C-damage which is not related to earthquakes. For each claim, CVW prepares an individual report with the results of the damage assessment (identification and categorisation of damages at owner's property). Since multiple damage claims can be filed for a single property, several damage claims may have been raised for the same address.

A few months into the inspection process, CVW started combining the information from these individual inspection reports into a single cumulative data file. This has made it possible to conduct some explorative analysis on the claims reports. Throughout 2015, CVW received 28,680 damage claims and conducted a total of 24,561 damage assessments. Out of these damage assessments, 13,208 were available for further analysis, containing 94,033 individual damages. Figure 9.13 shows a breakdown of these 13,208 reported damage claim assessments. On average, almost 6 out of 10 inspected damages were assessed as C-damage, i.e. not related to earthquakes. One out of 10 assessed damages indicated earthquake-related A-damage and 3 out of 10 damages were assessed as partially earthquake-related B-damage.

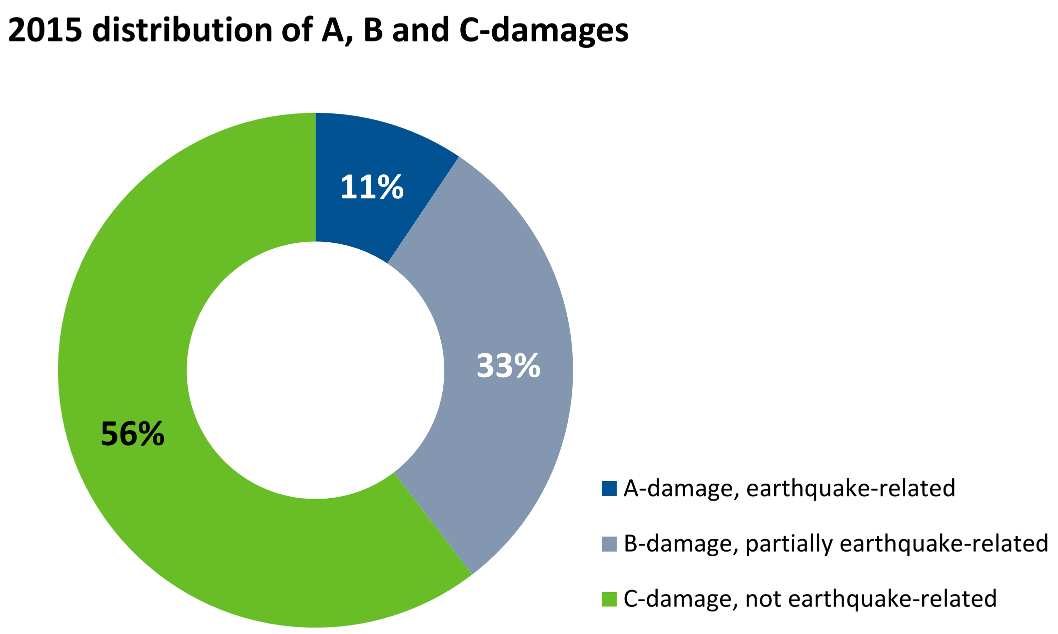


Figure 9.13 Distribution of A, B and C-damages in 2015 based on the sample data. Source: CVW, ABC-data. N=13,208. Scores are averaged scores of monthly data. This gives each month an equal weight and helps to counter selection effects due to an inability from under- or overrepresentation in the data file. Number of assessed damages per month: January: 52; February: 54; March: 112; April: 185; May: 421; June: 1,476; July: 1,438; August: 1,453; September: 2,044; October: 2,969; November: 1,975; December: 1,029. Most recording difficulties occurred in the first five months of the year, when internal administrative procedures at CVW were still in flux. There is also a drop-off in November and December. This is due to the time lag between receiving the damage claim and the actual damage assessment.

When plotted on a monthly basis, the damage claim assessment data indicate a growing trend toward C-damage content. This number, represented by the green bars in figure 9.14, has increased from 44 percent the first four months of 2015, to 82 percent in December 2015.

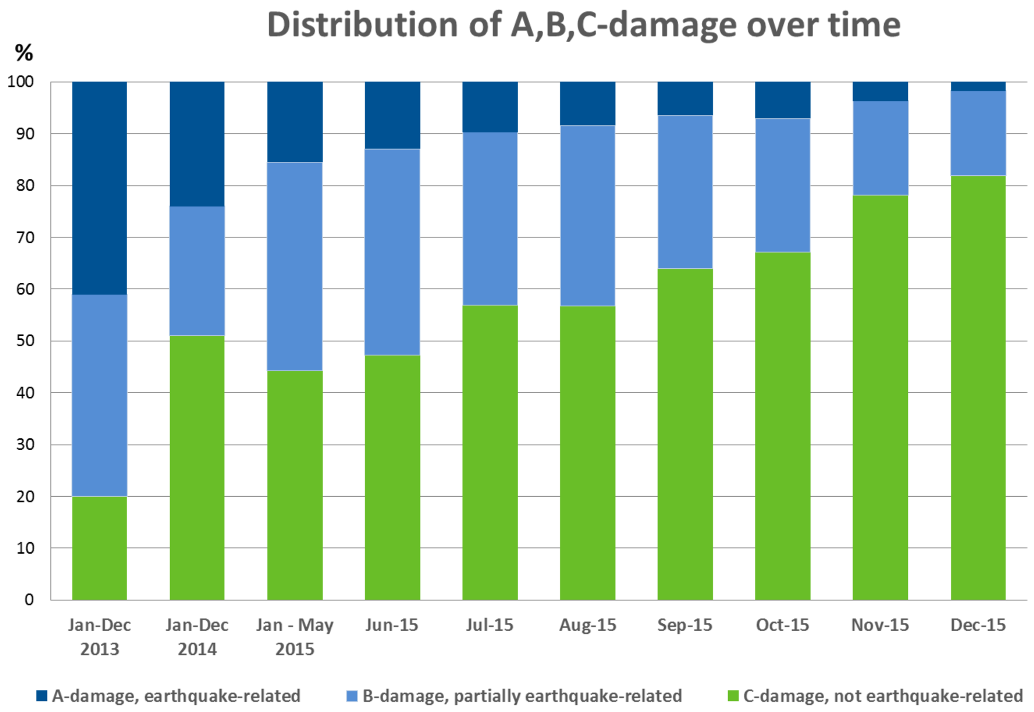


Figure 9.14 Trend proportion A, B and C damage. Source: CVW, ABC-data, N=13,208 and Arcardis, damage assessment data for 2013 and 2014, N=12,537. January to May 2015 data has been aggregated into 1 period due to data availability. The data for 2013 and 2014 are represented as two periods for increasing the readability. Reading example: In June 2015, 47 percent of all damage claims received constituted C-damage (not related to earthquakes), 40 percent constituted B-damage (partially related to earthquake) and 13 percent constituted A-damage (fully related to earthquakes).

A damage claim may consist of any combination of A, B or C damage. Figure 9.15 shows the proportion of the damage claims in the sample data with C-damage only. In January-May, 2015, 15 percent of all inspected addresses had an exclusive C-profile. By December, 2015, this number has more than quadrupled to 63 percent, implying that for almost 2 out of 3 damage claims, no relation with earthquakes could be established.

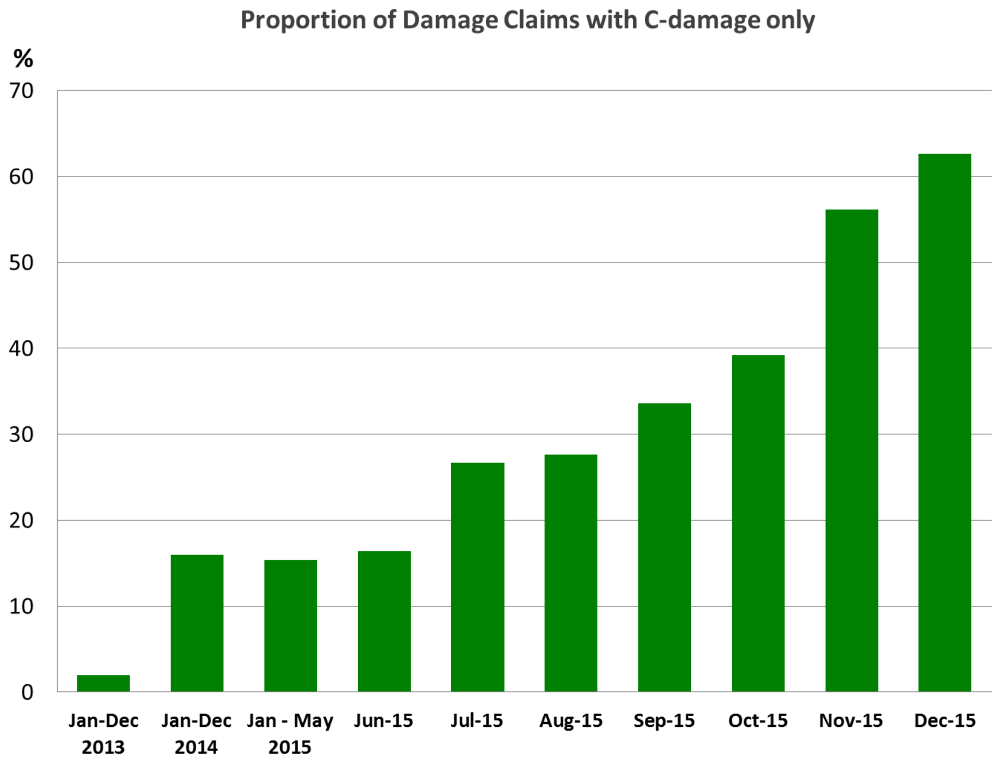


Figure 9.15 *Proportion of damage claims with only C-damages over time., Sources: CVW, ABC-data. N=13,208 and Arcardis, damage assessment data for 2013 and 2014, N=12,537January to May 2015 data has been aggregated into 1 period due to data availability. The data for 2013 and 2014 are represented as two periods for increasing the readability. Reading example: In June 2015, 16 percent of the received damage claims had C-damage only; that is, damage not related to earthquakes.*

An earthquake damage handling process in which only 1 out of 3 received damage claims attributed to earthquakes cannot be very efficient and increases the demand on counter-assessments, complaints institutes, etc. This causes unnecessary effort for many parties involved, and more importantly, delays claim handling. Further study is needed into the specific causes of this trend and ways to improve this situation, to allow us to focus on those activities where support is most required.

TNO building sensors register earthquakes and more

A large network of digital accelerographs has been installed in the Groningen gas field region by TNO on behalf of NAM. These instruments are high-quality accelerographs (AS-73 accelerometers with GMS-plus recorders, from GeoSig) recording at a high sampling rate (250 per second, or a time interval of 0.004 s). The instruments are mainly installed in private houses and a few more in public buildings like municipality offices. The network now comprises nearly 300 instruments and hence provides a valuable database to understand building movement caused by Groningen Earthquakes and also other sources of movement.

In case a sensor registers a velocity in any of the main directions x, y, z exceeding 1 mm/s (trigger value) the measurement is recorded and sent to a central TNO repository for further analysis.

Since first installation of the sensors around mid-2014, the TNO sensors have registered 12 earthquakes events ranging in strength from Magnitude 1.9 to 3.1. Only 298 or less than 2.5% of all trigger events have been matched to these 12 earthquake events as identified by KNMI. This indicates that far more vibrations are sensed in buildings than those induced by earthquakes.

The following graph shows that the smaller earthquakes are not picked up by the building sensors as the trigger value is not exceeded. Based on the SBR-richtlijn these are unlikely to have cause damage. It should be noted that during the 3 smaller earthquakes no ground velocities V_{top} above 2 mm/s have been measured.

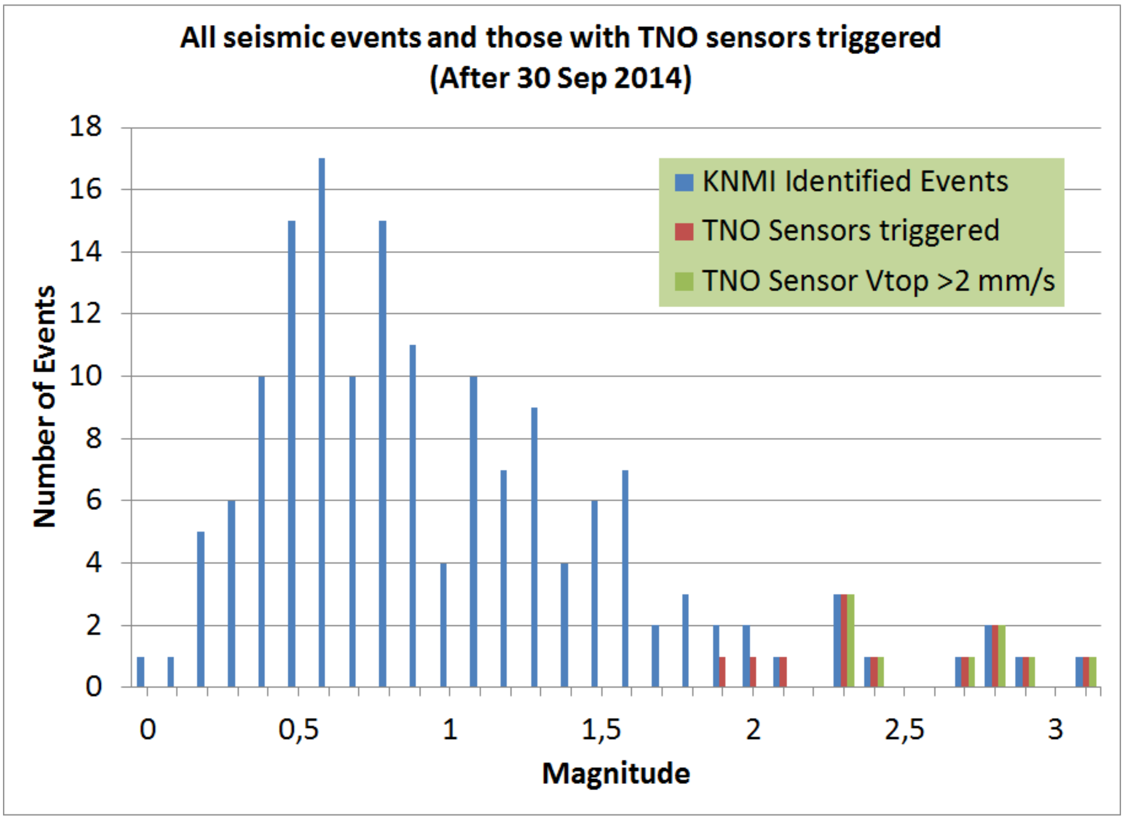


Figure 9.16 *Number of seismic events since 10th June 2014 as detected by the KNMI geophone network (bleu – bar). Events that also triggered the TNO sensors are shown with an additional red bar, while events that trigger a TNO sensor with V_{top}> 2 mm/s are shown with an additional green bar.*

Apart from seismic events, around 2/3 of all sensors have registered almost 12,000 events that could not be linked to any seismic event. The measured values ranged from 1 mm/s (trigger value) to as high as 100 mm/s or more. This range is much larger than that for the seismic event related measurements.

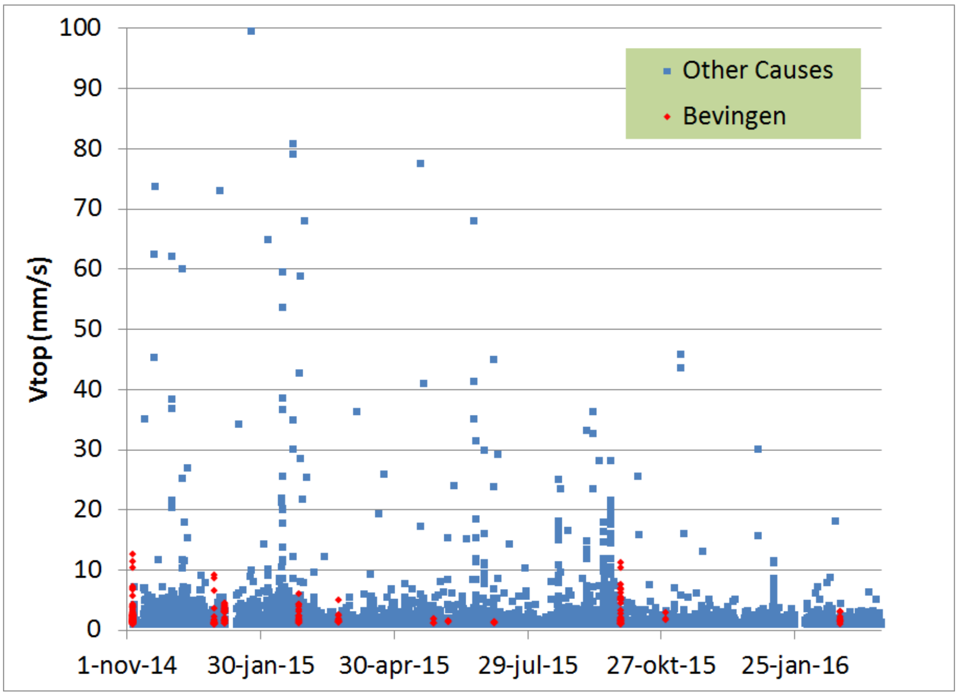


Figure 9.17 *Velocoites registered by the TNO network. The red dots indicate velocity measurements associated with earthquakes. The events indicated by blue dots could not be associated with an earthquake.*

The cumulative distribution of all TNO triggers is shown below:

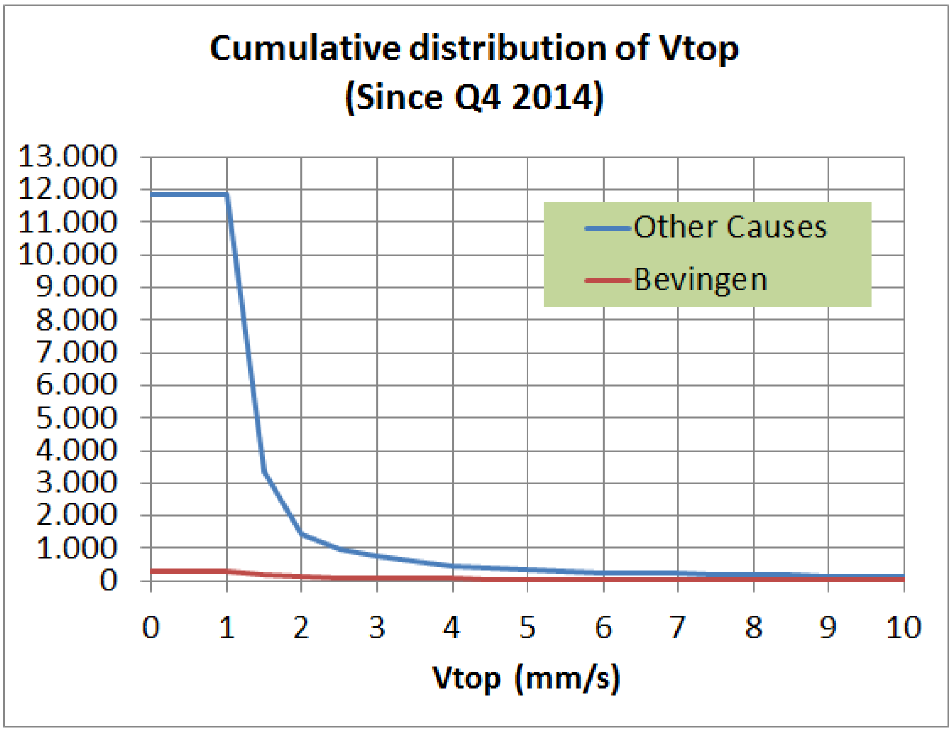


Figure 9.18 *Cumulative distribution V_{top} for all 12,128 triggered TNO sensors. In red due to seismic events and in blue due to other causes.*

Building owners have the option to provide information as to what caused the trigger/movement. These responses (40%) are roughly divided as follows:

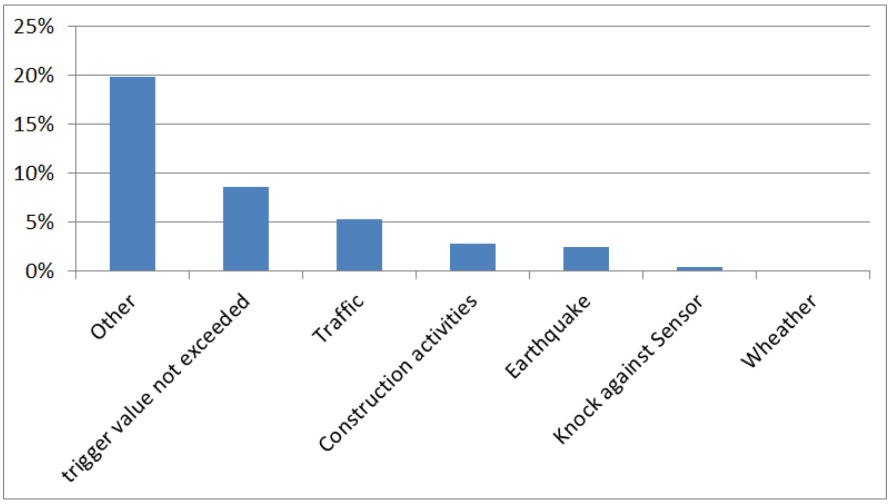


Figure 9.19 *Responses from building owners on cause of building movement.*

The following table shows maximum (nb: minimum is 1 mm/s), the average and median values for events with main causes of building vibration identified.

	Max (mm/s)	Average (mm/s)	Median (mm/s)
Traffic	10	1,3	1,2
Construction activities	80,1	3,8	1,6
Earthquakes	16.1	3,1	1,9

Table 9.4 *Max. mean and median value of building movement for the main three causes of building movement.*

The above information clearly demonstrates that buildings in the Groningen earthquake area (or anywhere else) are subject to movement on a regular basis due to non-earthquake related causes, especially in the range below ca. 3 mm/s. It is therefore unlikely that the movement of the buildings to earthquakes with magnitude smaller than M=2 will contribute significantly to building damage.

Conclusions

- A simple forecasting method for D1 damage state, based on 2009 Kalibratiestudie by TNO/KNMI, was used to forecast the chance of damage based on hazard data. These forecasts were compared with historical damage claim data (period 2012- 2015). This study is calibrated on damage data from before 2007 and also provides good results for building damage (claims) for the Huizinge 2012 earthquake. However, for earthquakes after 2012, this method is not able to match building damage claims.

- The relationship between seismic activity and damage claims appears to be complex.

- Empirical evidence pointing to strong increase in the number of claims post-Huizinge (early-2013).

- Further research is required into:
    - The area where earthquakes could release sufficient energy to cause damage
    - the precise relationship between damage claim reports and actual damage,
    - The assessment of claimed damages as A-, B- or C-damage, or combinations thereof

- There appears a growing trend in the content of C-damage (damage which cannot be attributed to earthquakes) in damage claims from mid-2015 onwards.

- The TNO sensors show that buildings in Groningen experience movements due to a wide variety of causes. Traffic and construction work also cause building movement.

Appendix A - Spectral Hazard Maps

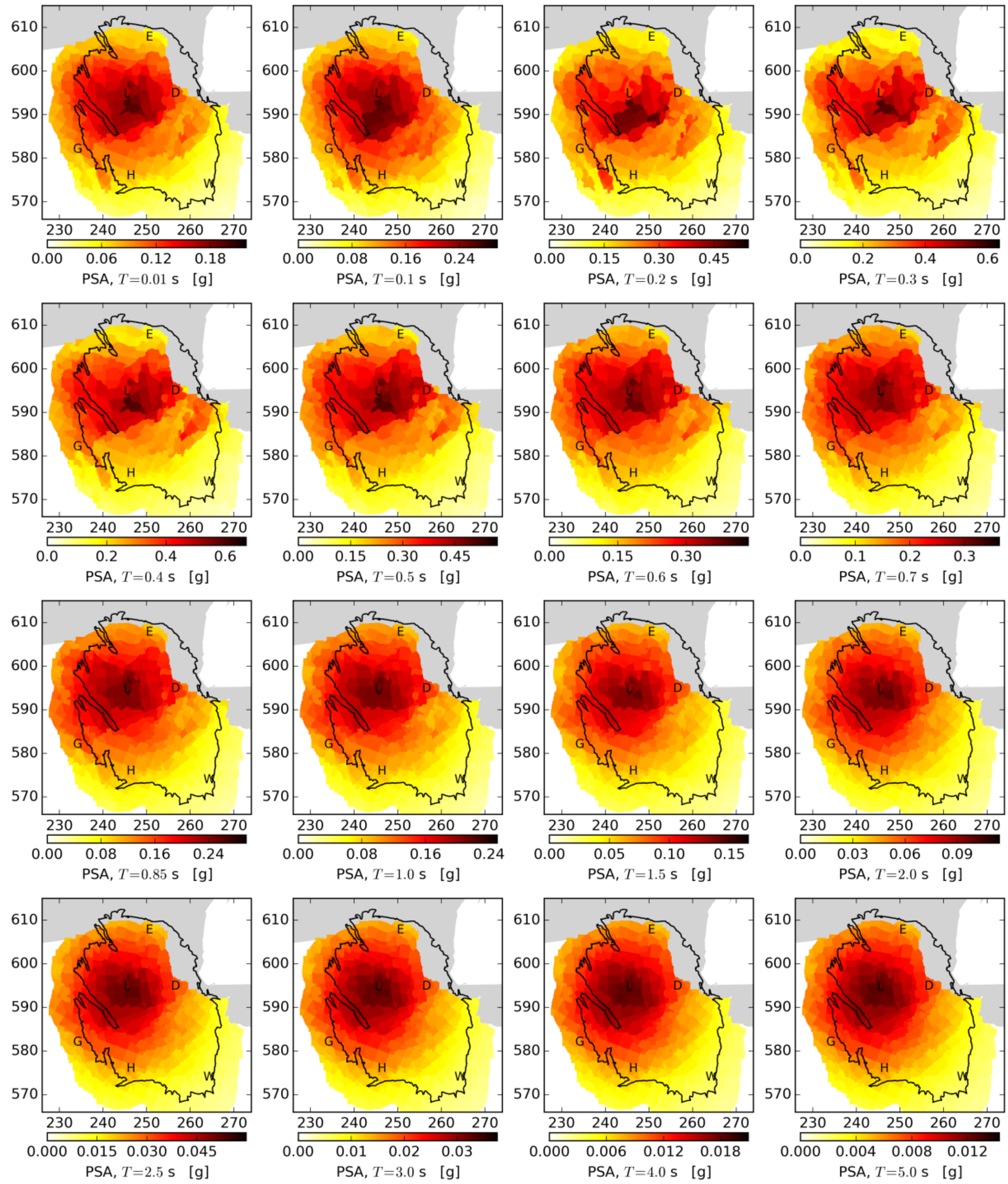


Figure A.1 *Mean spectral hazard maps with an average 0.2% annual chance of exceedance (1 in 475 years) from 2016 to 2017 given the V2 linear compaction model and the 27 bcm production plan. Mean hazard was computed according to the 9 branches of the logic tree representing epsitemic uncertainty in the seismological and ground motion models.*

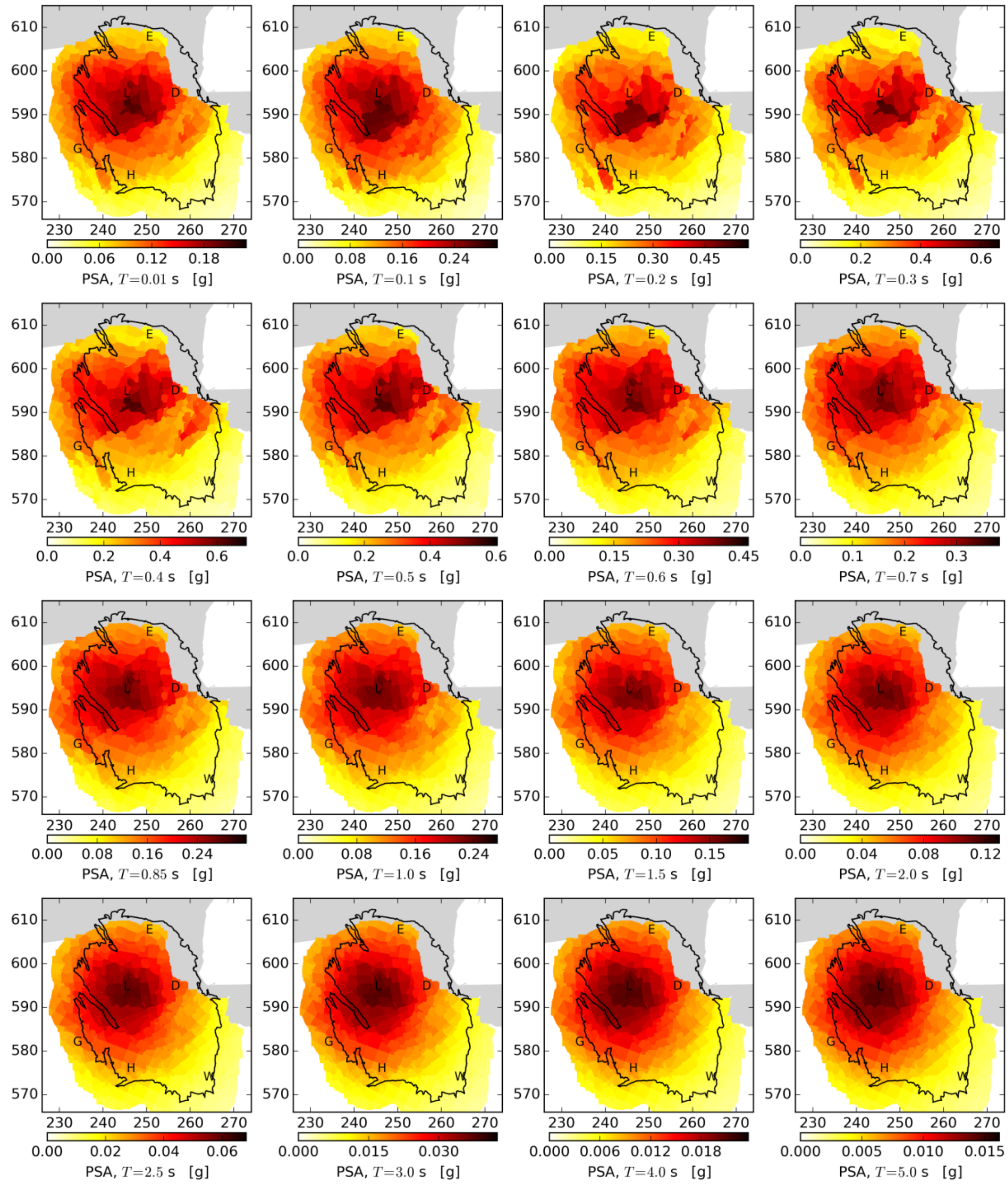


Figure A.2 *As figure A.1, except for the 5-year period 2016-2021.*

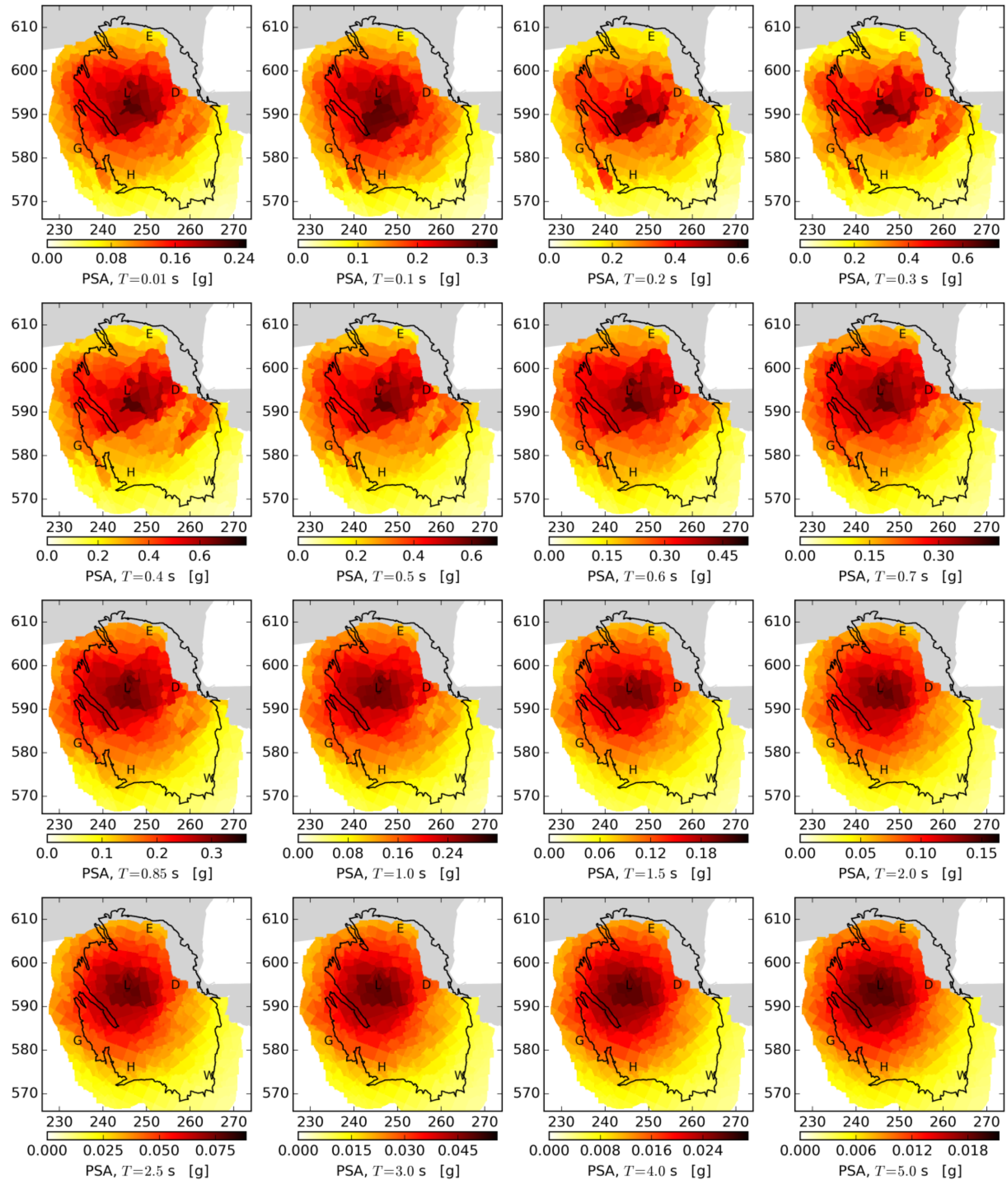


Figure A.3 *As figure A.1, except for the 5-year period 2016-2021.*

Appendix B - Seismic Event Rate and Annual Total Seismic Moment (2016 – 2035)

The development of the Seismic Event rate has also been assessed for a longer period up to 2035.

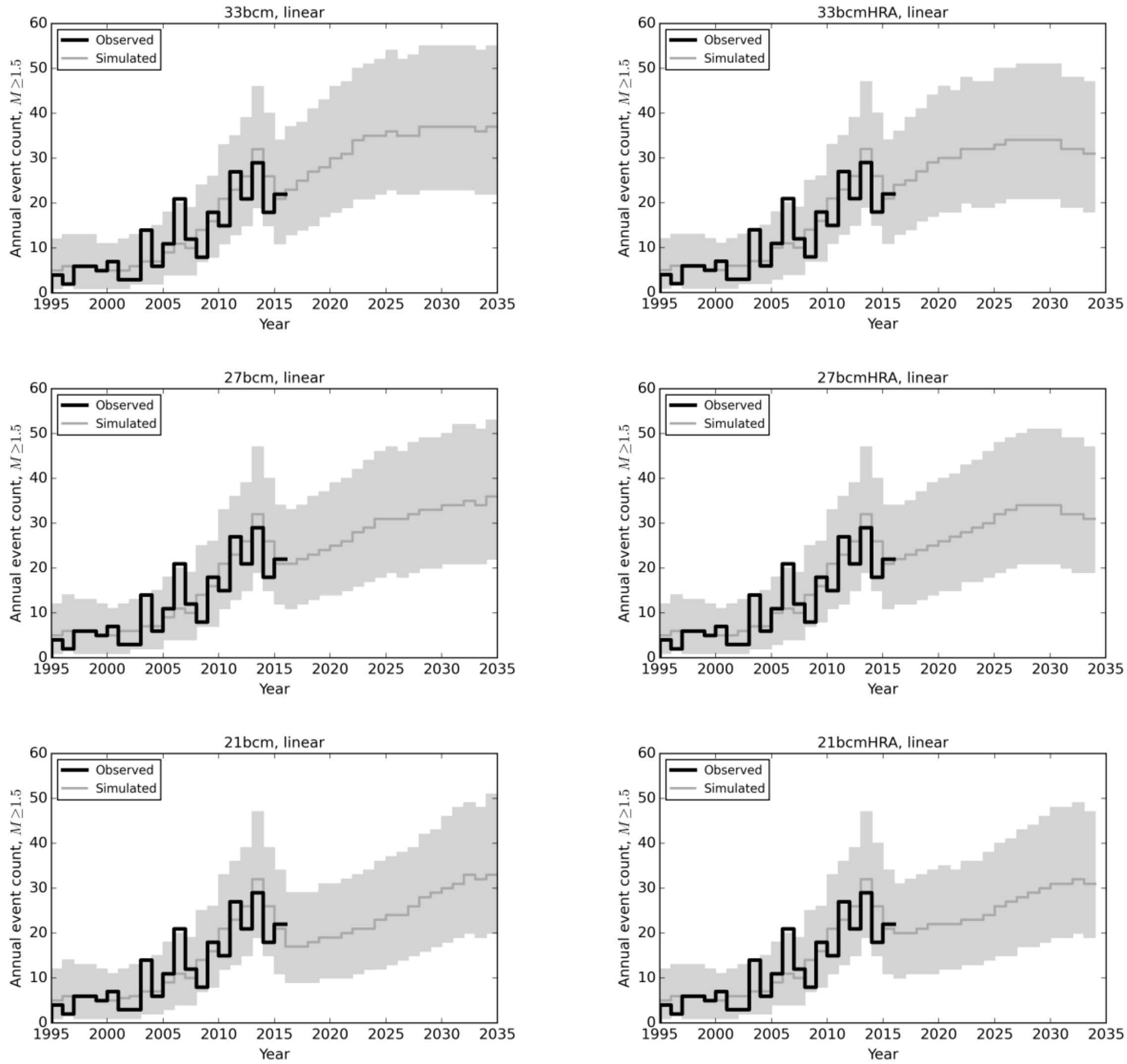


Figure B.1 *The annual number of M ≥ 1:5 according to the seismological model with aftershocks for the different production scenarios for the period up to 2035. Simulated results are based on 10,000 independent simulations; grey lines and regions denote the expected annual event count and its 95% confidence interval respectively. These simulations are based a Monte Carlo sampling of the distribution of estimated parameter values and includes aftershocks. A linear compaction model is used. Note that uncertainty in the compaction forecast increases with time, this uncertainty is not included in these seismological forecasts. Left the optimised production offtake distribution is used, while on the right the distribution imposed early 2015 is used (also basis for interim update HRA Nov. 2015).*

The difference in seismic event rate (fig. B.1)and annual total seismic moment (fig. B.2) between the three production scenarios is limited. The development of the events rate slowed down for the lower production rate scenarios and the plateau delayed.

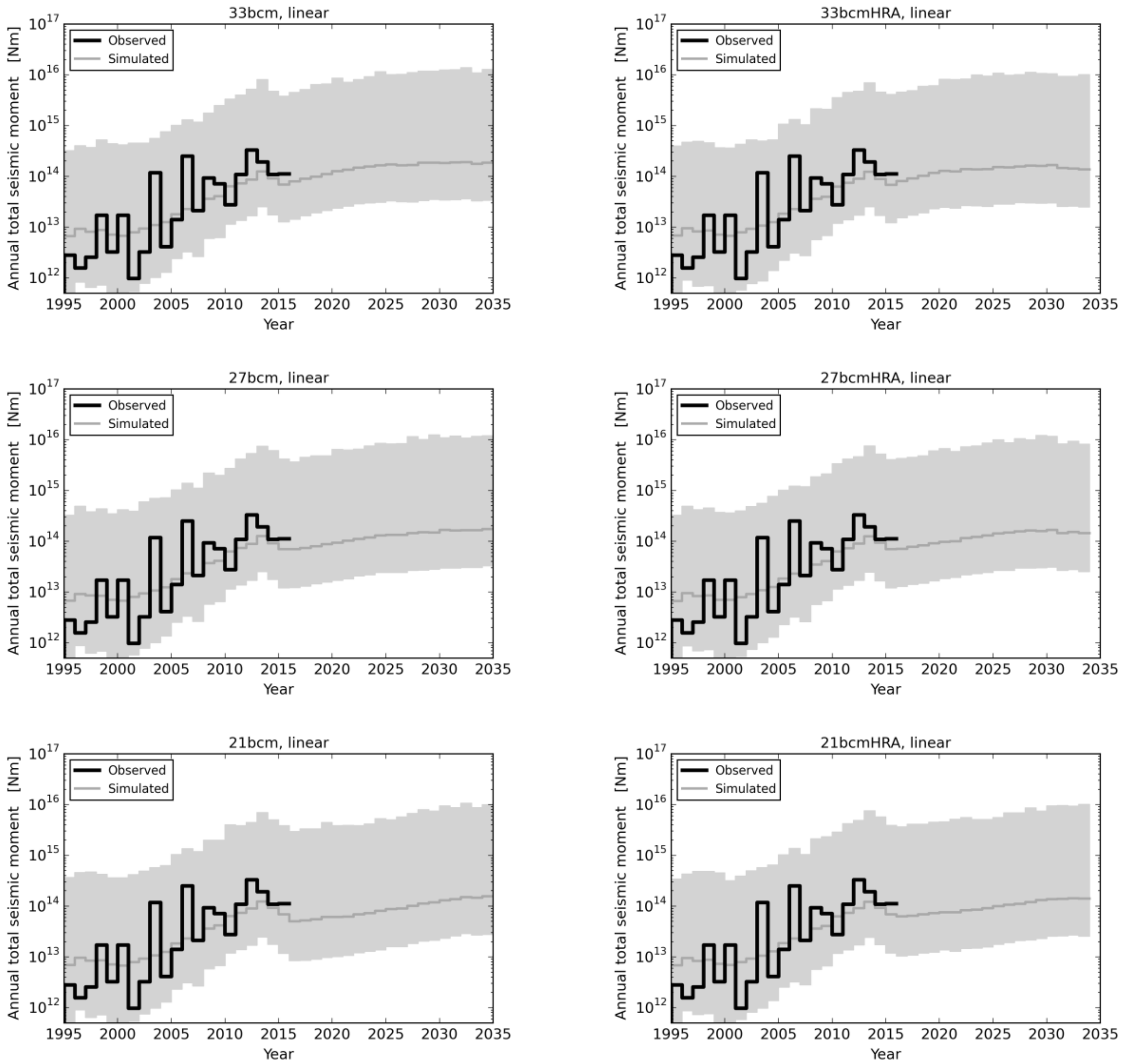
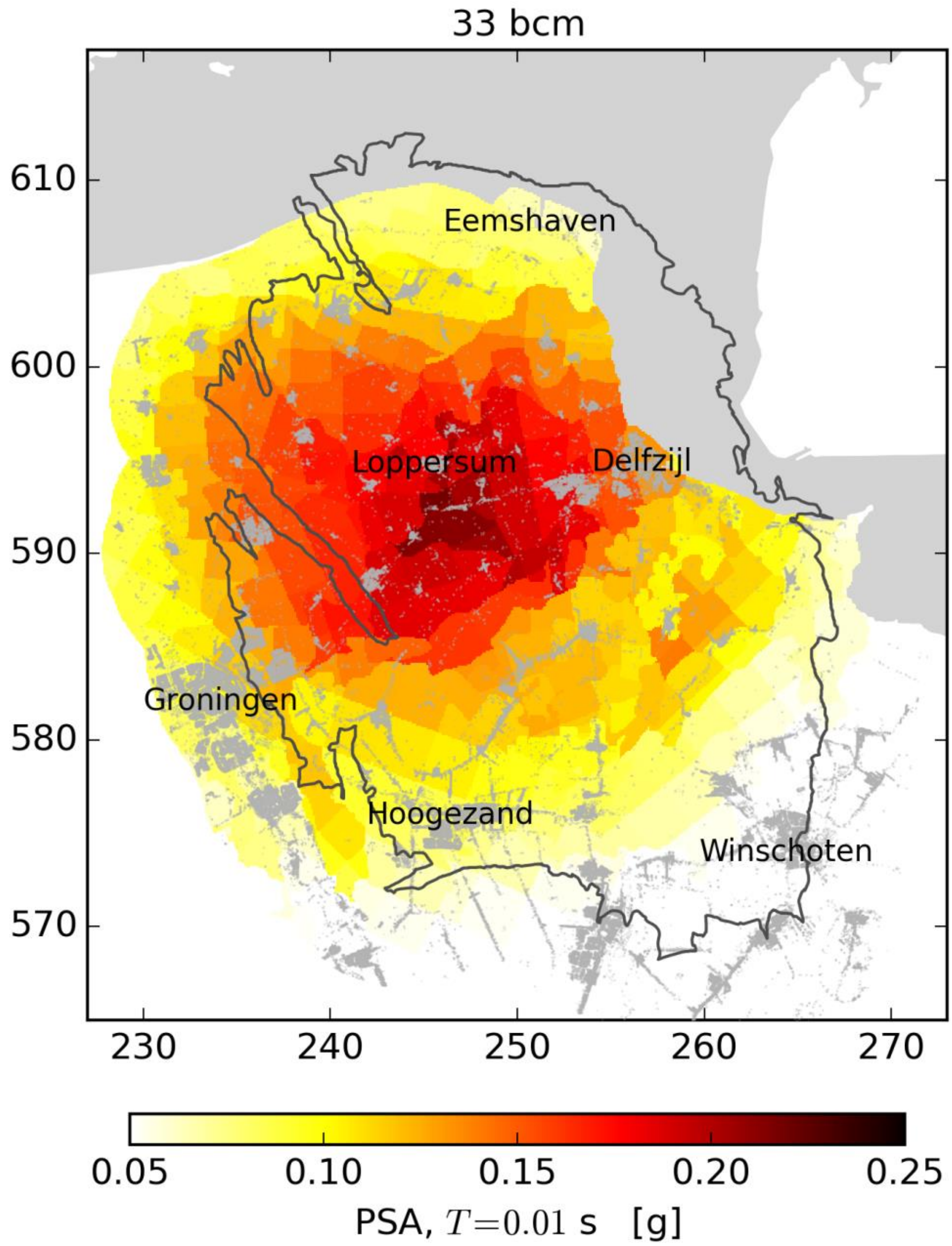


Figure B.2 As Figure B.1, except for annual total seismic moment.

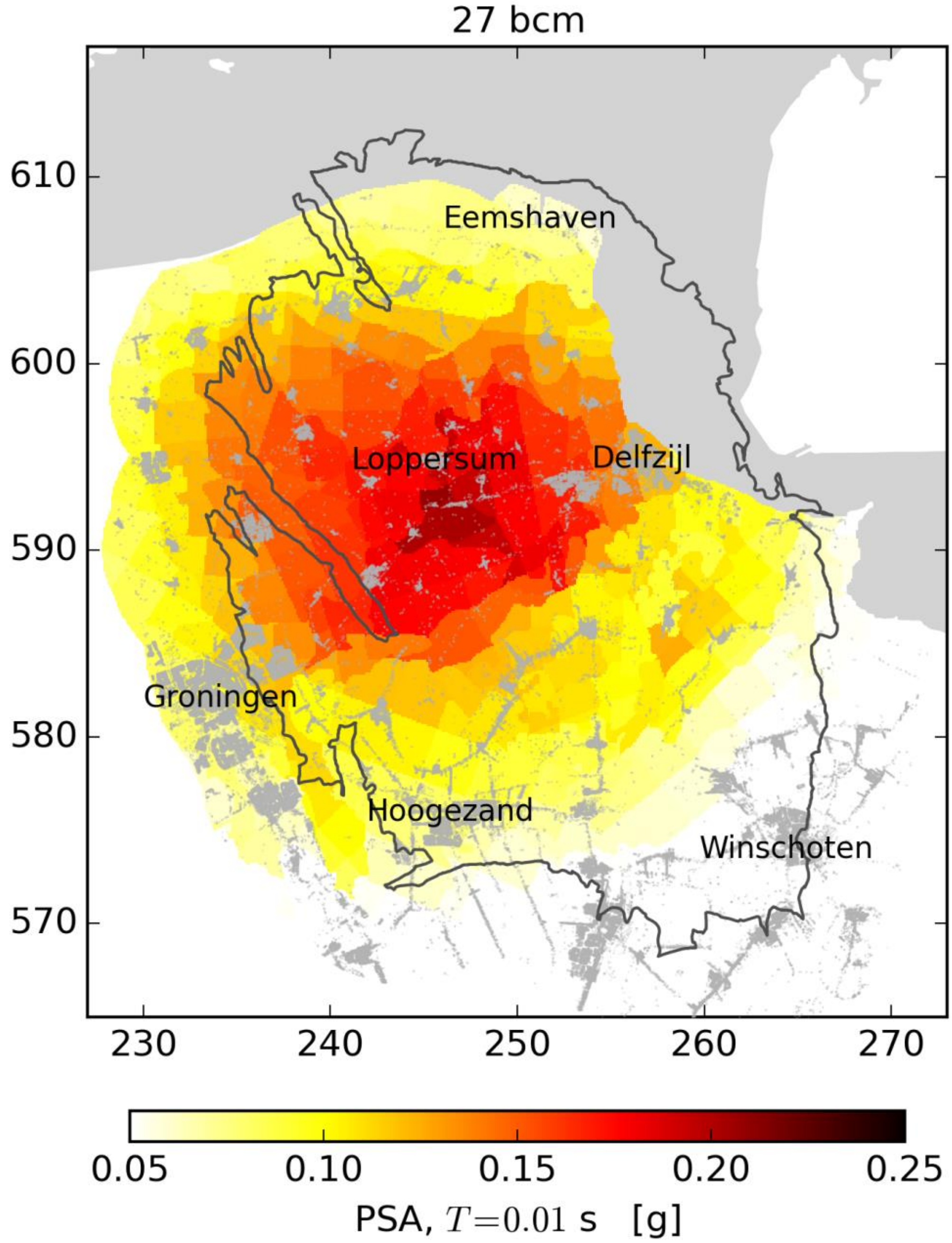
Appendix C – Hazard Maps Large Format



Assessment period: 2016-2021

Exceedance probability: 0.2%/year

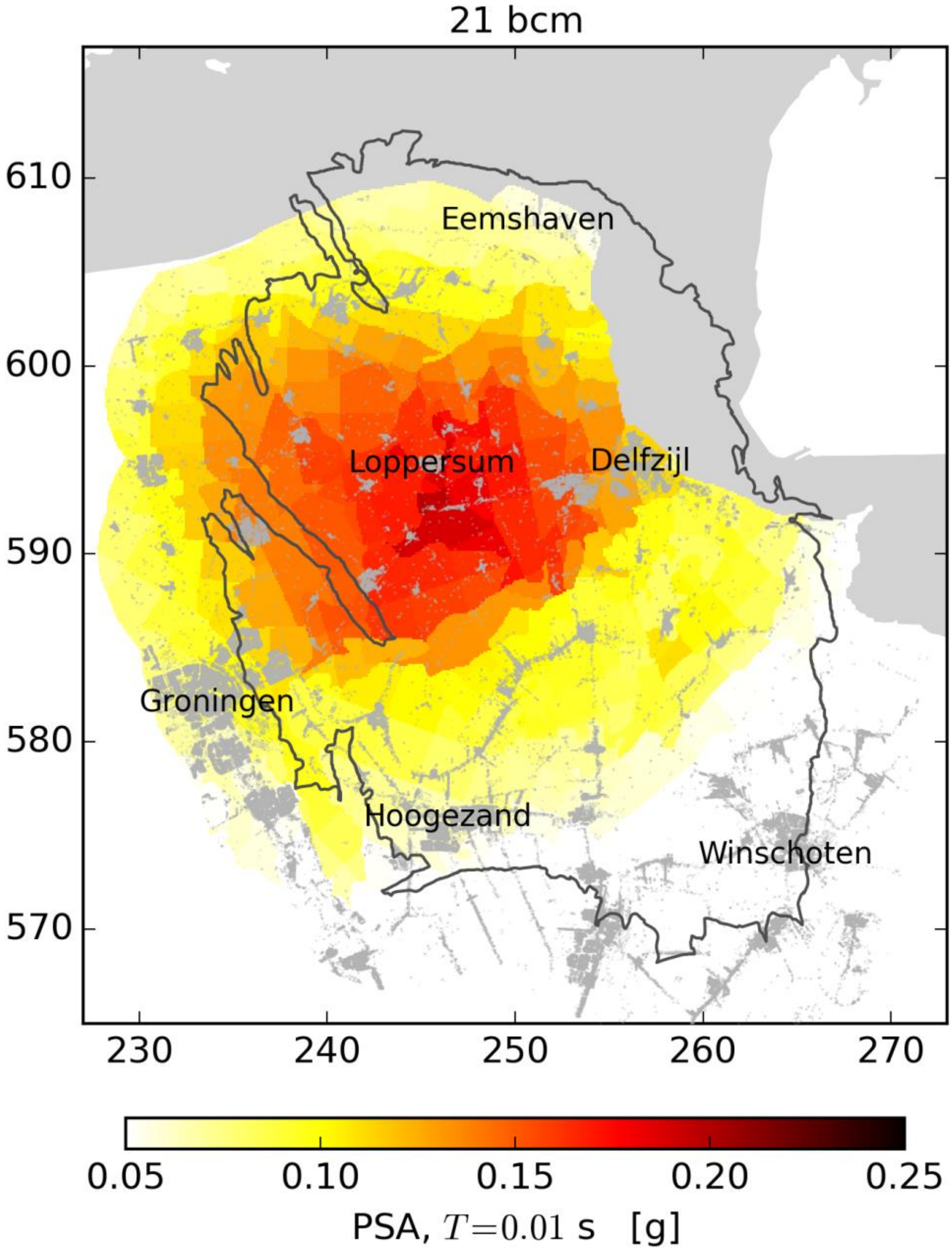
Production scenario: 33 bcm (optimized)



Assessment period: 2016-2021

Exceedance probability: 0.2%/year

Production scenario: 27 bcm (optimized)



Assessment period: 2016-2021

Exceedance probability: 0.2%/year

Production scenario: 21 bcm (optimized)

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List of abbreviations

TNO	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek, Netherlands Organisation for Applied Scientific Research
ARPR	Annual Review of Petroleum Recources
GFR2015	Groningen Field Review 2015
RMS	Root Mean Square
PVT	Fluid behaviour as a function of Pressure, Volume and Temperature
HRA	Hazard and Risk Assessment
RFT	Repeat Formation Tester
SPTG	Static Pressure and Temperature Measurement
GWC	Gas Water Contact
PNL	Pulse Neutron Log
CITHP	Closed in tubing head pressures
BU	Build-up
UR	Ultimate recovery
NorGroN	Norg-Groningen pipeline
(N.)Bcm	N.Bcm refers to a volume of a billion normal cubic meters. Normal means the volume is measured at a standard temperature (0 ºC) and pressure (1 bar).