Assessment of Building Damage based on Production Scenario “Basispad Kabinet” for the Groningen field

Addendum to:

Induced Seismicity in Groningen
Assessment of Hazard,
Building Damage and Risk
(November 2017)

June 2018

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Contents

Summary

In the Hazard, Building Damage and Risk Assessment of November 2017 (Ref. 5), the seismic risk for a 24 Bcm/year production scenario was presented. In a letter to Parliament (Ref. 7) the Minister of Economic Affairs and Climate Policy presented a new production scenario, “Basispad Kabinet”, which shows a reduction in production from the Groningen field, ultimately leading to cessation of production by 2030.

The required deliverables from the Hazard and Risk Assessment were specified in the Expectation Letter (Verwachtingenbrief) (Ref. 8) which the Minister of Economic Affairs and Climate Policy sent to NAM on 2nd May 2018. In this Expectation Letter, in addition to the Hazard and Risk Assessment report also an Operational Strategy for gas-year 2018/2019 was requested, which contains the operational implementation of the production strategy for the Groningen System (Ref. 15). The Hazard and Risk Assessment based on the production scenario “Basispad Kabinet” is document in Reference 14.

In this report, the building damage associated with production scenario “Tijdspad Kabinet” has been assessed. With declining production, the hazard and building damage will also decline. The report shows the F/N curves for building damage state DS1 based on calibration with observed damage from historical earthquakes, and for building damage states DS2 and DS3 based on laboratory experiments carried out in EUcentre in Pavia and LNEC in Lisbon.

Both the Hazard and Risk Assessment (Ref. 14) and the building damage assessment in this document are based on the methodology described in the Hazard, Building Damage and Risk Assessment of November 2017 (Ref. 5),

1 Introduction

Winningsplan 2016

In April 2016, NAM submitted the Groningen Winningsplan 2016 (Ref. 1) to the Minister of Economic Affairs and Climate Policy. This Winningsplan was accompanied by a Technical Addendum (Ref. 2) providing further background to the hazard, building damage and risk assessments used in the Winningsplan. The Mining Law requires that winningsplannen are approved by the Minister of Economic Affairs and Climate Policy. This approval was granted in the Instemmingsbesluit Winningsplan Groningenveld, issued on 30th September 2016 (Ref. 3).

Hazard and Risk Assessment November 2017

In response to the specific obligation in the Instemmingsbesluit, NAM prepared the report “Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017” (Ref. 5), which was submitted to the Minister of Economic Affairs and Climate Policy and to SodM on 1st November 2017. This report describes the full hazard, building damage and risk assessment for induced seismicity in Groningen, starting from the production of gas (the cause) to the effects on people and buildings, based on an initial average annual production level of 24 Bcm/year.

Basispad Kabinet (29/3/2018)

The letter of the Minister of Economic Affairs and Climate Policy sent to Parliament (Kamerbrief) on 29th March 2018 (Ref. 7) announced the ambition of the cabinet to reduce the production from the Groningen field as soon as possible, leading to complete cessation of production before 2030. It contained a scenario of annual production volumes for the period 2018-2031, which was labelled “Basispad Kabinet”.

Expectation Letter (2/5/2018)

An Expectation Letter (Verwachtingenbrief) was sent to NAM on 2nd May 2018 (Ref. 8 and 14) by the Minister of Economic Affairs and Climate Policy, requesting NAM to perform a hazard and risk assessment for the “Basispad Kabinet” scenario, to indicate the impact of the strong reduction of production on safety risk and the number of buildings that do not comply with the Meijdam-Norm (Ref. 9 to 11). On 6th June 2018, the Minister of Economic Affairs sent a letter to Parliament informing on the progress of the measures to end production from the Groningen field (Ref.12). In this letter, a number of additional measures to reduce Groningen gas demand are referenced that were not yet incorporated in the “Basispad Kabinet” as presented on 29th March 2018. The risk impact of a scenario based on the maturation of these additional measures was not assessed, but would directionally reduce the risk further as compared to the estimates provided in the present report.

Seismic Risk Assessment for Production Scenario “Basispad Kabinet” for the Groningen field (15/6/2018)

The Hazard and Risk Assessment for the production scenario “Basispad Kabinet” was shared with the Minister of Economic Affairs and Climate Policy and SodM on Friday 15th June 2018 (Ref. 14).

As a result of the declining production of scenario “Tijdpad Kabinet”, the number of earthquakes (with magnitude M_L>1.5) and the hazard will also decline. Currently, the mean seismic event rate is about 18 earthquakes per year in the period 2018 – 2020. This will reduce to less than 5 earthquakes after 2027. This reduction is also reflected in the hazard. The largest mean PGA in the hazard map is currently about 0.16 g. This will decline to 0.11 g (the largest PGA observed to date) by 2028.

The Local Personal Risk (LPR) was probabilistically assessed for each building in the Groningen area and for each year in the period 2018- 2027. During 2019, there is not a single building that does not meet the 10^{-4}/year temporary Safety Norm level, but approximately 1,500 buildings do not conform to the 10^{-5}/year Safety Norm level for earthquake risk. This norm was set by the Minister of Economic Affairs and Climate Policy on advice of the Committee Meijdam (Ref. 9 to 11). However, this number decreases with time to less than 100 buildings by 2024. For reference, in the Hazard, Building Damage and Risk Assessment of November 2017 (Ref. 5), which was based on a 24 Bcm/year production scenario, this number of buildings increased from 2,545 in 2019 to 3,228 in 2023. Maps show (Ref. 14) that by 2024, buildings exceeding the 10^{-5}/year Meijdam Norm are located North-West of Loppersum.

Raad van State and Ministerial Decision “Winningsplan 2016”

In November 2017, the Raad van State overturned the Ministerial Instemmingsbesluit for Winningsplan 2016. A new decision by the Minister is required by November 2018. However, the prevailing production scenario has changed since April 2016 (when Winningsplan 2016 was submitted) from 24 Bcm/year scenario to an accelerated decrease and cessation of production. Furthermore, the method for hazard and risk assessment has been further developed and the exposure database of buildings further updated.

A description of the current methodology for hazard, building damage and risk assessment (version 5) is provided in reference 5. An update of this Hazard and Risk Assessment for the latest production scenario “Tijdspad Kabinet” is available in reference 14 and send to the Minister as per the Verwachtingenbrief (Ref. 8). However, updates of the assessment of subsidence and building damage based on the production scenario “Tijdspad Kabinet” were not yet available to the Minister. This document provides the assessment of building damage based on production scenario “Tijdspad Kabinet”. A separate document will be prepared for subsidence. With these two additional documents, all components of the Winningsplan Groningen, as in Mijnbouwbesluit article 24 a – s, are also available for production scenario “Tijdspad Kabinet”.

2 Building Damage Forecasting

2.1 Introduction

The report “Methodology Prognosis of Building Damage and Study and Data Acquisition Plan for Building Damage” (Ref. 16), issued February 2017, describes the studies program into building damage and the methodology for forecasting building damage. The building damage assessment of November 2017 (Ref. 5) contains an introduction into the classification of damage states and into the Monte Carlo method used for forecasting building damage and fatality risk.

This current report presents the forecast of building damage from DS1 to DS3 based on production scenario “Basispad Kabinet”. The higher damage states DS4 and DS5 are relevant for risk and have been addressed in the hazard and risk assessment for “Basispad Kabinet” (Ref. 14). For the assessment of DS1 building damage, empirical methods based on analysis of historical damage data are used. The assessment of DS2 and DS3 building damage is based on analytical methods supported by laboratory experiments carried out in Eucentre and LNEC (Ref. 16).

2.2 Forecast of DS1 based on Observed Damage from Historical Earthquakes

Introduction

The approach to forecast DS1 based on observed damage from historical earthquakes is described in section 8 of the report “Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017” (Ref. 5, pages 168-173). An update of that work has been prepared to incorporate the latest information/knowledge available in the following areas:

- New empirical GMPE
- A reduction in production from the Groningen field

Empirical GMPE for Peak Ground Velocity from Small-Magnitude Earthquakes

The empirical model for the prediction of peak ground velocity (PGV) used in November 2017 covered a magnitude range from M_L 2.5 to 3.6. However, to apply the model to smaller earthquakes, requires an extrapolation outside the strict range of applicability of the equations. To address this issue, a new PGV model has been derived, based on the same dataset of Groningen ground-motion recordings, that is applicable to a wider range of magnitudes M_L 1.8-3.6 (Ref. 18). This new model is used in the present report.

Earthquake catalogue of events

For the forecast, a range of possible future realizations is needed that adequately represent the anticipated earthquake distribution, both in terms of magnitude and location in the field. These have been generated stochastically, using the hazard tool for the “Basispad Kabinet” based on the temperature demand scenario. This is the same scenario as used for the full hazard and risk assessment. In the Monte Carlo simulation process, repeated random sampling of a set of input distributions is used to create a probabilistic distribution output. So-called ‘synthetic earthquake catalogues’ (i.e. event locations and magnitudes for the period 2018-2027) are generated from the input probability distributions of total seismic moment, number of events and event epicentres. This forecast uses events between $M_L = 1.8$ and 4.0.

Results

Figure 2.1 shows results of the DS1 damage forecast in the form of an annual F/N curve for the Groningen field area, one per year, for the whole Groningen area, shown for the period 2018-2027.

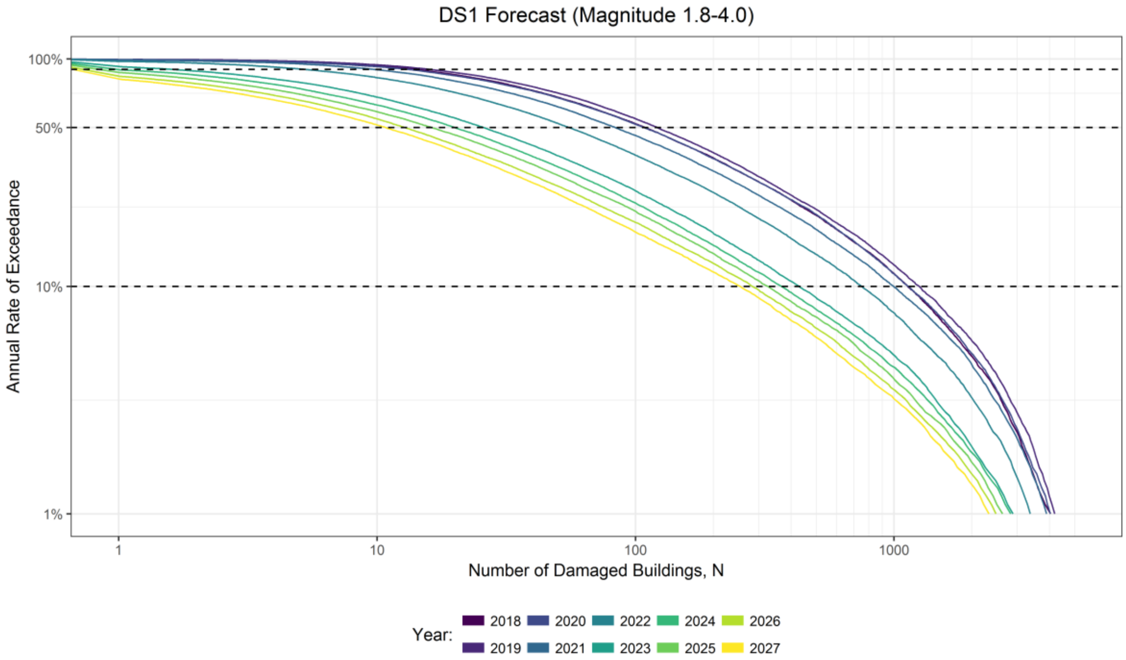


Figure 2.1 DS1 Forecast per year for period 2018-2027 based on the mean from the logic tree.

The median forecast (P50 or 50%) is indicated together with the 80% confidence interval (10% to 90%). Each building in the exposure area was assigned with a relevant typology. It was assumed that any resulting building damage is repaired after the event and before the next one (instant repair). The figure shows that in 2018 a fifty percent chance that more than 110 buildings will be damaged with aesthetic damage (DS1) (due to all earthquakes in that year smaller than M_L=4). In 2023 there is a fifty percent chance that more than 50 buildings will be damaged with aesthetic damage. Figure 2.2 shows the Mean and P50 for the DS1 damage forecast per year for the period 2018-2027. Due to the skewed distribution of building damage the mean number of damaged buildings is considerably higher than the P50.

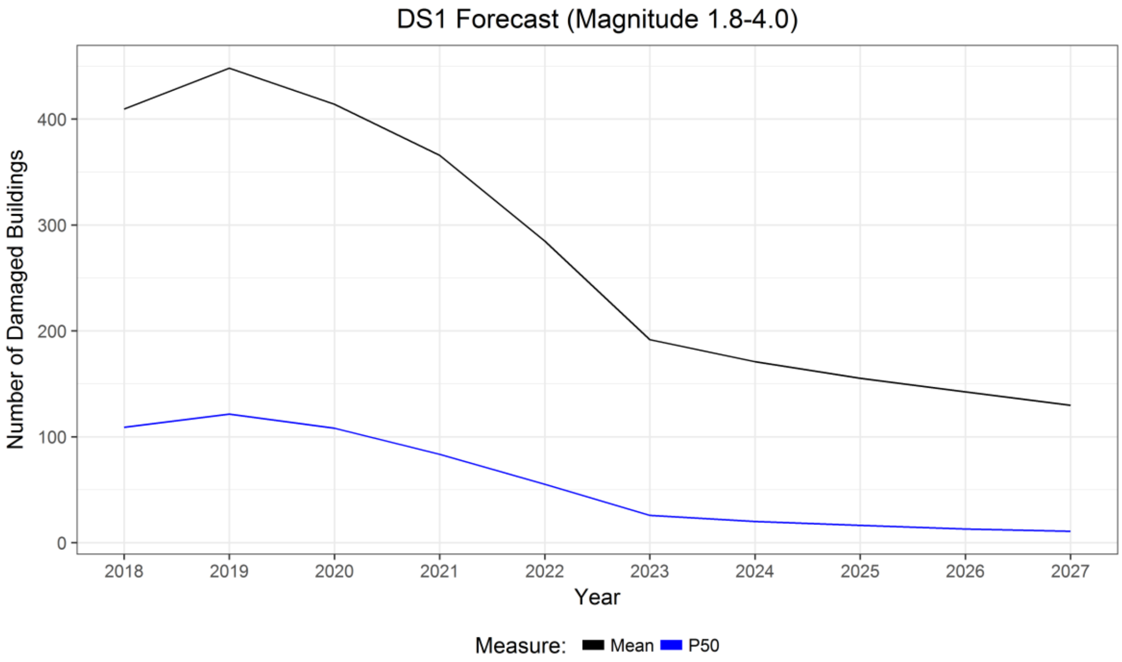
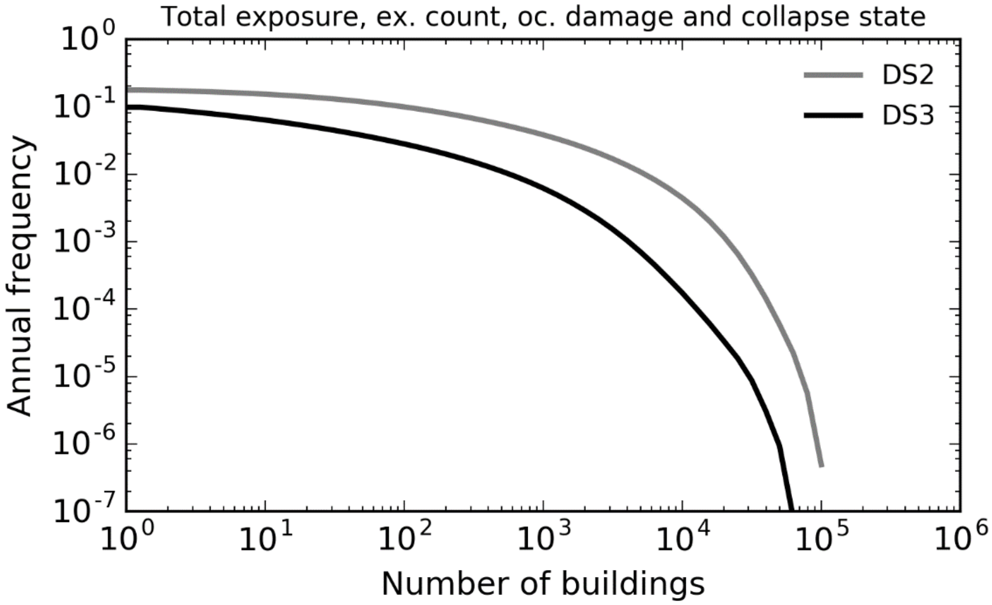


Figure 2.2 *Mean and P50 DS1 Forecast per year for period 2018-2027 (mean from the logic tree).*

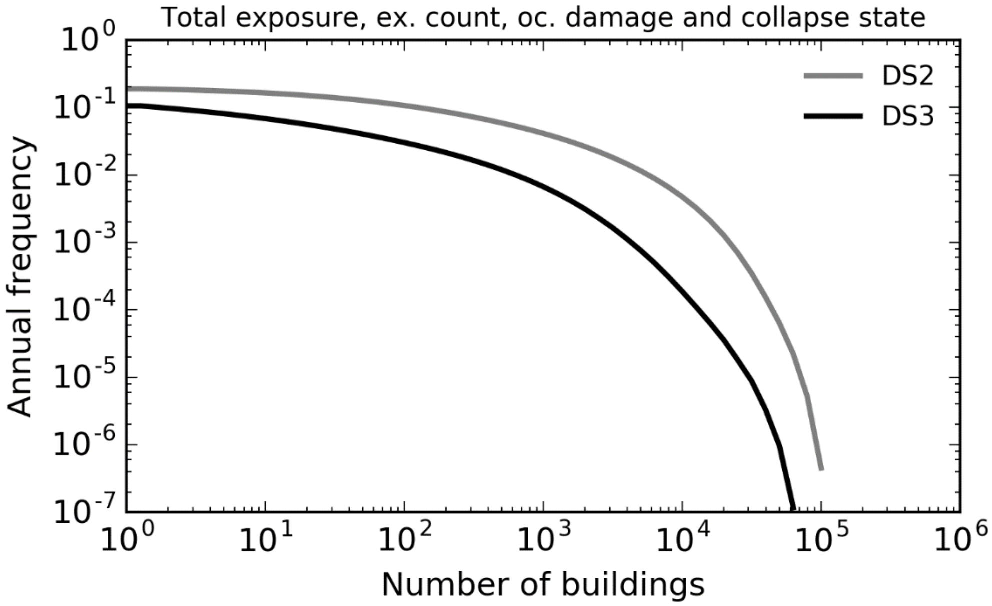
2.3 Forecast of DS 2 and DS3 based on Analytical Modelling and Experimental Tests

Fragility functions for DS2 and DS3 have been developed for each structural system identified in the exposure model using the extensive analytical modelling and experimental test campaign described in (Ref. 16). F/N curves have been calculated with the Monte Carlo risk engine which show the annual frequency of exceedance (F) of different numbers of groups of buildings (N) which simultaneously reach DS2 or DS3. Figure 2.3 shows the F/N curve for the whole field for each of the years in the period 2018 to 2027. The F/N curves for three consecutive 5-year periods (2018 to 2022, 2023 to 2027 and 2028 to 2032) are shown in figure 2.4.

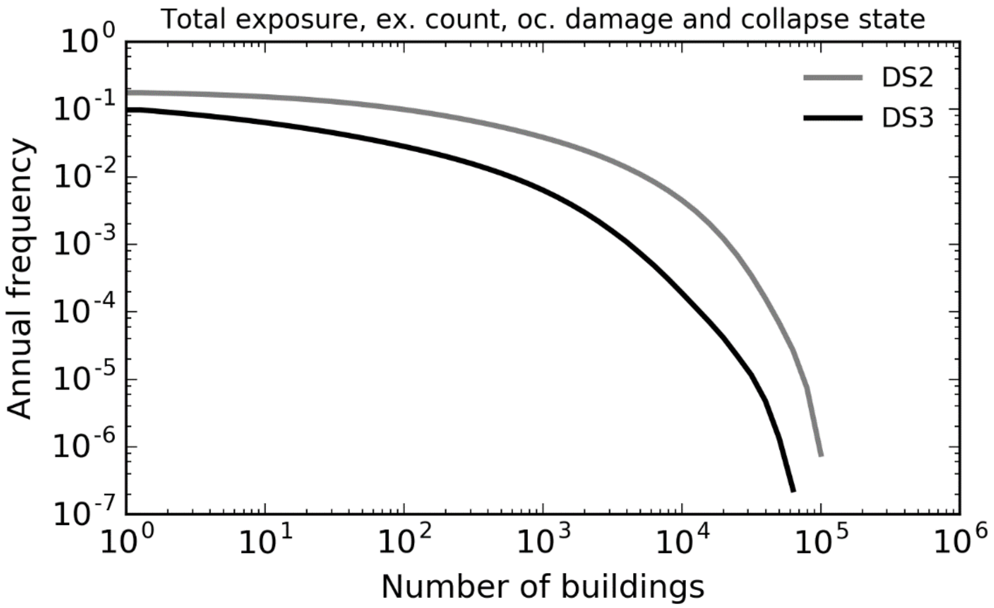
Figure 2.3 shows that in 2018, the annual frequency of exceedance of having anywhere 100 buildings simultaneously damaged to DS2 in a given earthquake is around 15%; in other words, the return period of having more than 100 buildings damaged to DS2 is around 7 years. This return period increases to around 20 years for a group of 1,000 buildings with DS2 damage. The return periods for DS3 are considerably higher.


Total exposure, ex. count, oc. damage and collapse state
Annual frequency
Number of buildings
DS2
DS3
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^0
10^1
10^2
10^3
10^4
10^5
10^6

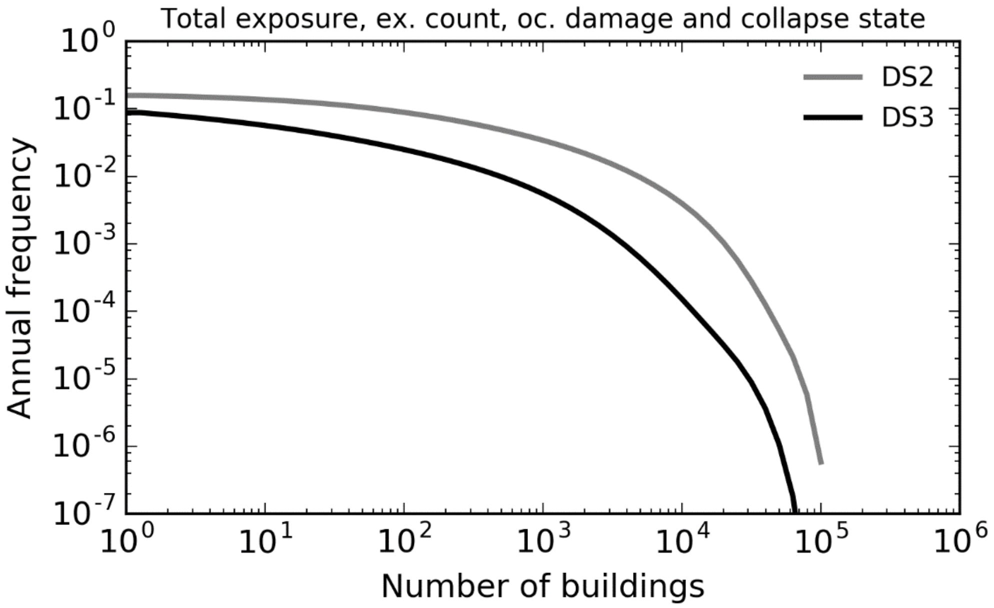
2018


Total exposure, ex. count, oc. damage and collapse state
Annual frequency
Number of buildings
DS2
DS3
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^0
10^1
10^2
10^3
10^4
10^5
10^6

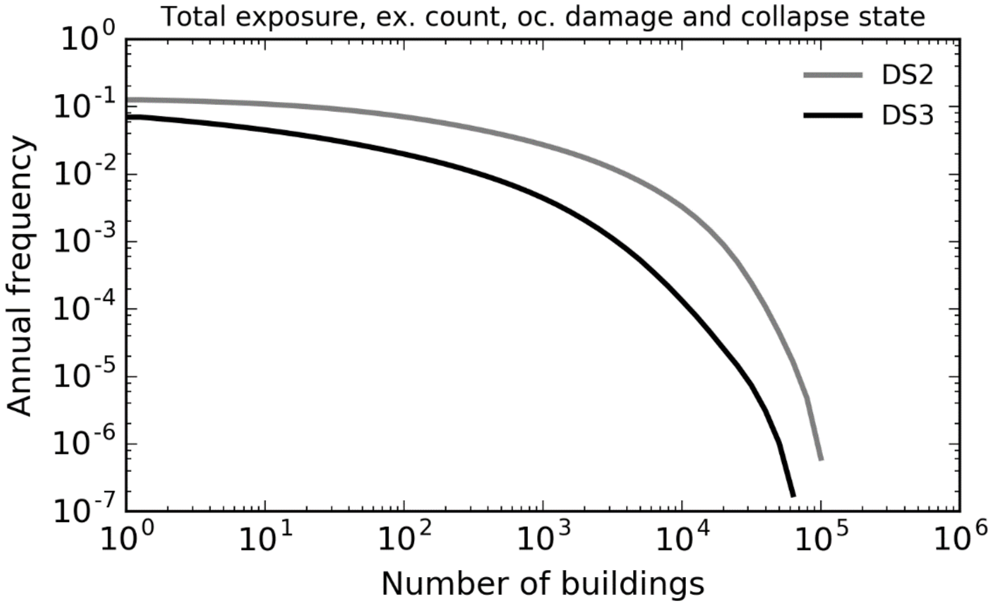
2019


Total exposure, ex. count, oc. damage and collapse state
Annual frequency
Number of buildings
DS2
DS3
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^0
10^1
10^2
10^3
10^4
10^5
10^6

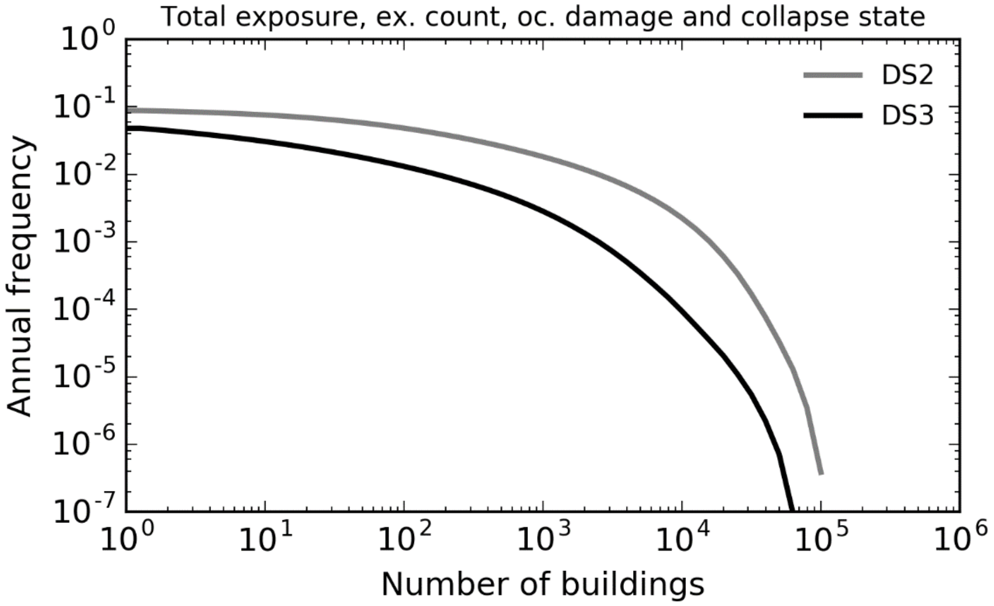
2020


Total exposure, ex. count, oc. damage and collapse state
Annual frequency
Number of buildings
DS2
DS3
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^0
10^1
10^2
10^3
10^4
10^5
10^6

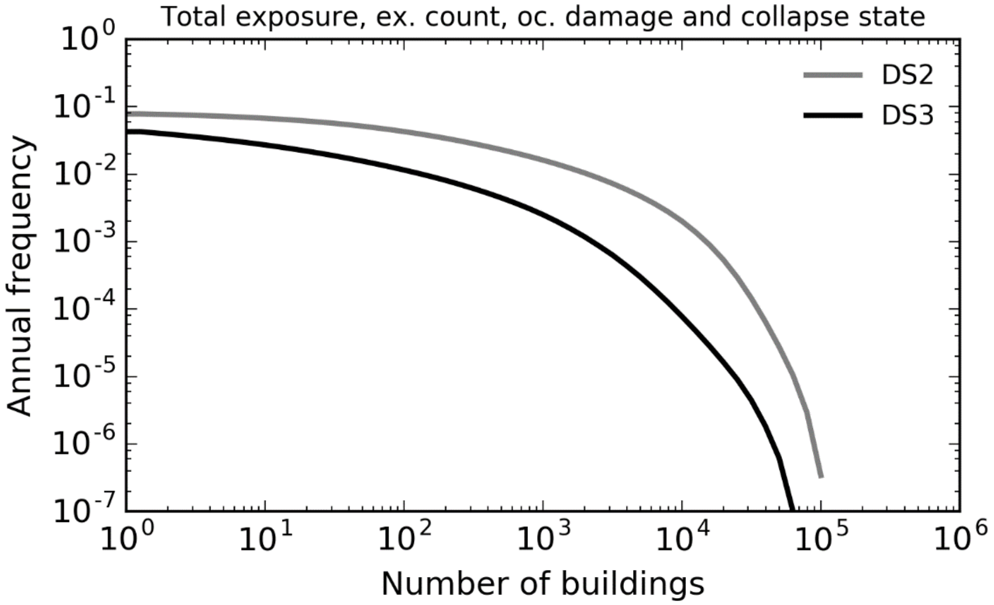
2021


Total exposure, ex. count, oc. damage and collapse state
Annual frequency
Number of buildings
DS2
DS3
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^0
10^1
10^2
10^3
10^4
10^5
10^6

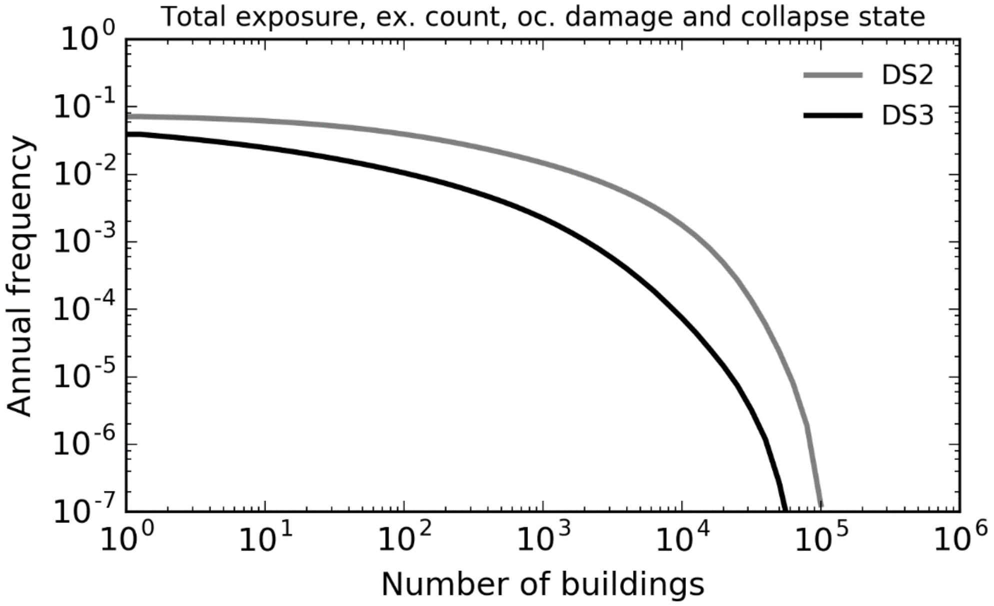
2022


Total exposure, ex. count, oc. damage and collapse state
Annual frequency
Number of buildings
DS2
DS3
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^0
10^1
10^2
10^3
10^4
10^5
10^6

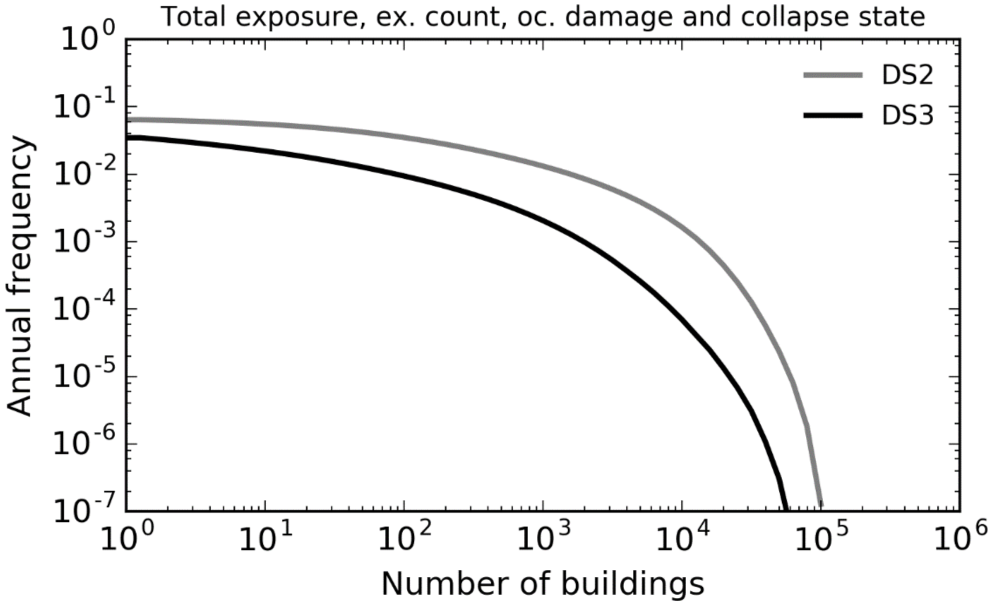
2023


Total exposure, ex. count, oc. damage and collapse state
DS2
DS3
Annual frequency
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Number of buildings
10^0
10^1
10^2
10^3
10^4
10^5
10^6

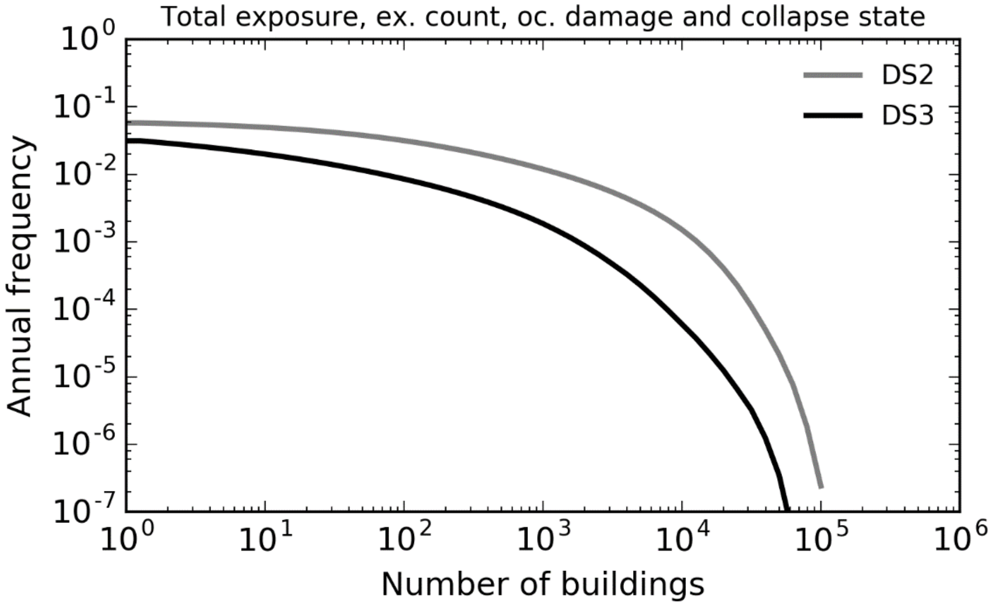
2024


Total exposure, ex. count, oc. damage and collapse state
DS2
DS3
Annual frequency
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Number of buildings
10^0
10^1
10^2
10^3
10^4
10^5
10^6

2025

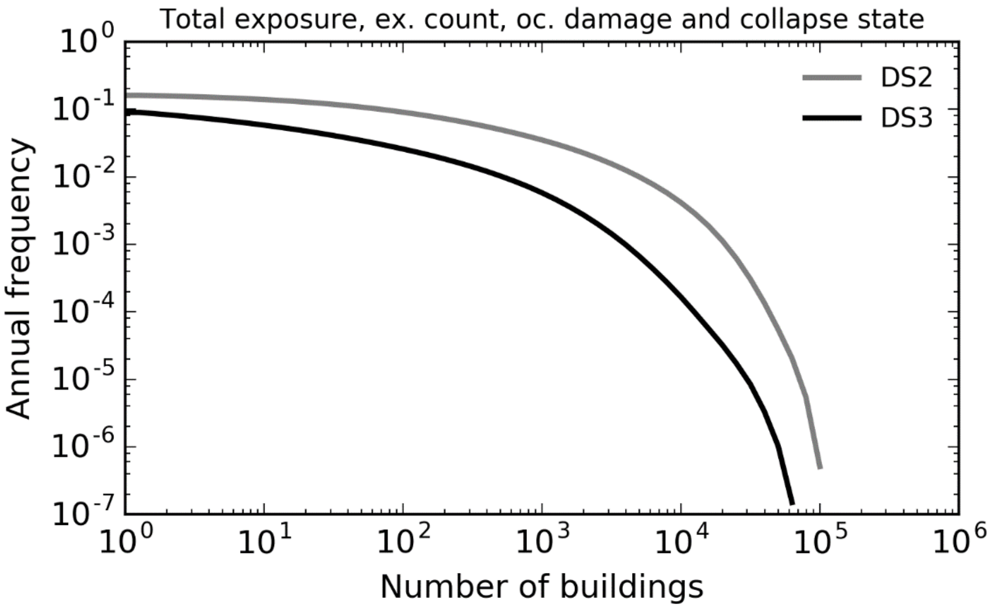


2026

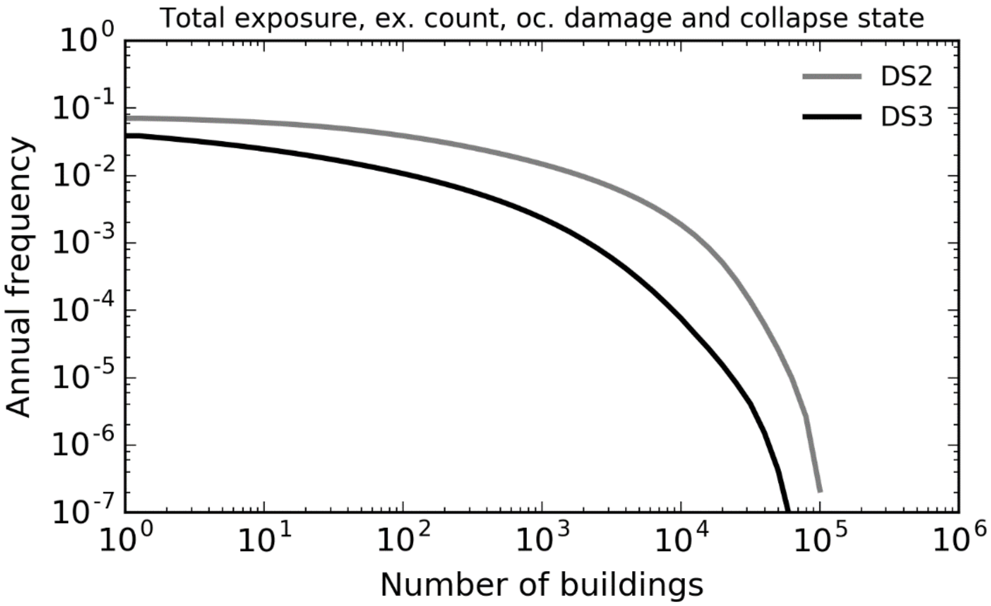


2027

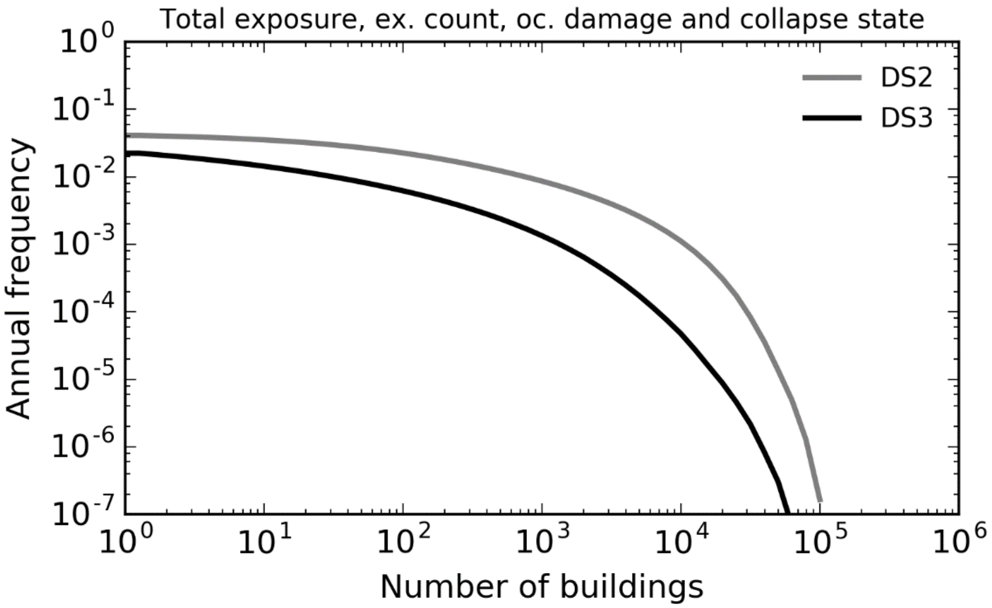
Figure 2.3 Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2018 to 2027.



2018 - 2023



2023 - 2028



2028 - 2033

Figure 2.4 Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2018 to the years 2027.

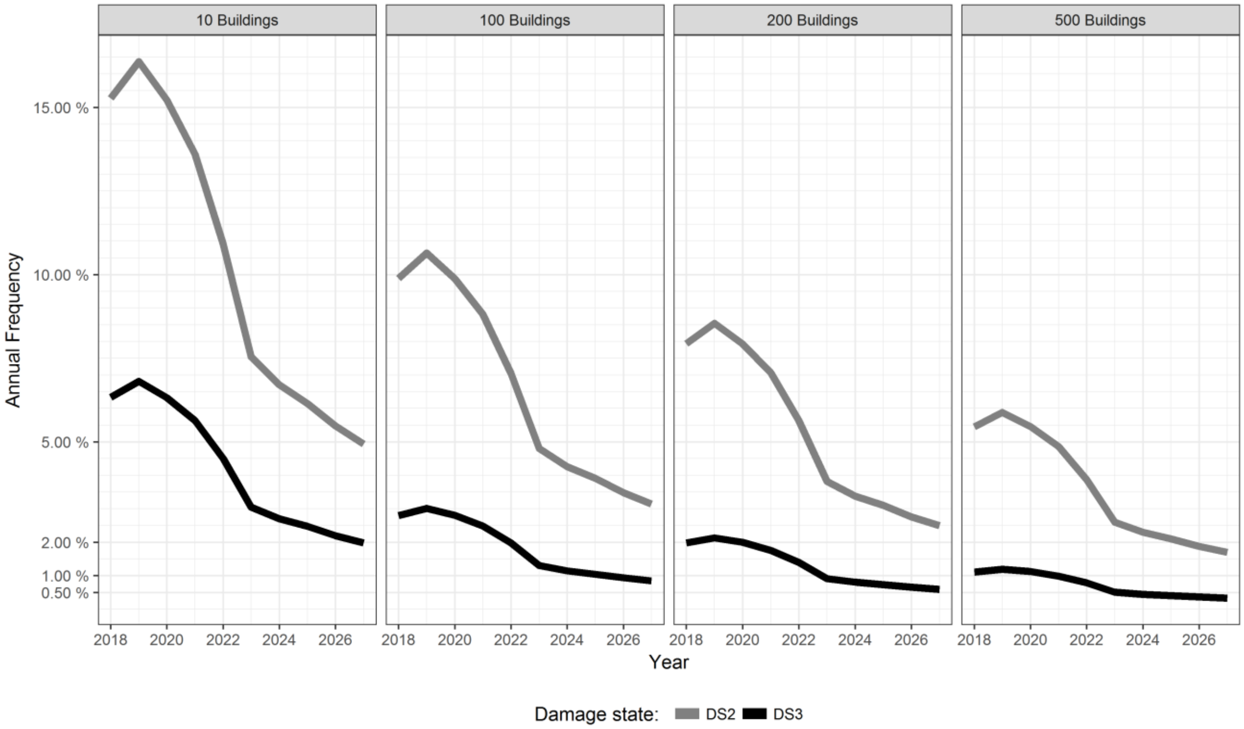
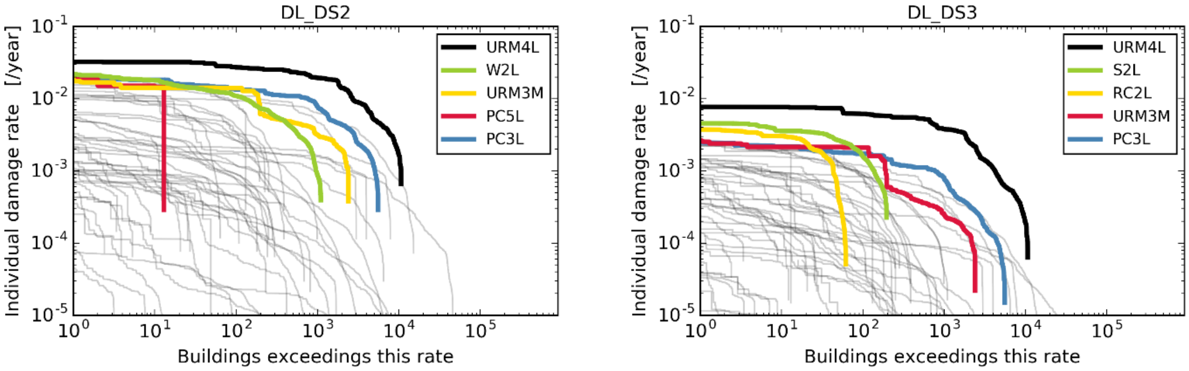


Figure 2.5 Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2018 to the years 2027.

Figure 2.5 shows the exceedance damage count for the occurrence of the given damage state (DS). For instance in 2019, the chance of 10 or more buildings reaching a DS2 damage state is about 16%. The chance that 100 buildings or more reach damage state DS3 is about 3%.

Figure 2.6 provides some insight into the structural systems that are contributing most to the damage forecasts. These plots show the numbers of buildings exceeding a given average annual damage rate for DS2 and DS3. The interesting finding from these plots is that damage is not limited to unreinforced masonry buildings (URM), but reinforced concrete buildings (RC2L, PC3L, PC4L) are also susceptible to damage.



DS2

DS3

Figure 2.6 *Numbers of buildings exceeding a given average annual damage rate for DS2 and DS3, for the “Basispad Kabinet” average weather scenario and 2018 – 2023 assessment period. Shown structural systems represent the top-five ranked according to individual damage rate.*

Conclusion

In this report, the building damage associated with production scenario “Tijdspad Kabinet” has been assessed. With declining production, the hazard and building damage will also decline. The report shows the F/N curves for building damage state DS1 based on calibration with observed damage from historical earthquakes, and for building damage states DS2 and DS3 based on laboratory experiments carried out in EUcentre in Pavia and LNEC in Lisbon.

3 References

All reports referenced in this section prepared by NAM can be downloaded from the webpage “onderzoeksrapporten” on www.nam.nl.

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17. NAM (Jeroen Uilenreef and Jan van Elk), 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, April 2016.
18. Julian J Bommer, Peter J Stafford & Michail Ntinalexis, Empirical Ground-Motion Prediction Equations for Peak Ground Velocity from Small-Magnitude Earthquakes in the Groningen Field Using Multiple Definitions of the Horizontal Component of Motion, November 2017

Appendix A – Abbreviations

EZK	Ministry of Economic Affairs and Climate Policy
GTS	Gasunie Transport Services BV
GY	Gas-year (12-months period following 1st October). This was introduced for practical reasons. The gas-year starts with the 6 coldest months of the year avoiding a winter period to be split over two one-year time periods, such as a calendar year.
H-gas	High Calorific Gas (Gas from most gas fields has a higher calorific value than gas from the Groningen gas field)
HRA	Hazard and Risk Assessment
L-Gas	Low Calorific Gas (Groningen gas has a lower calorific value than gas from many other gas fields because of its higher nitrogen content)
LPR	Local Personal Risk
MC	Monte Carlo
N_2	Nitrogen
NAM	Nederlandse Aardolie Maatschappij BV
NFA	No Further Activity
UGS	Underground Gas Storage

A more complete list if abbreviations can be found in "Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017" available from www.nam.nl.