NAM

Presentation: Seismic Hazard and Risk Assessment in Groningen

Symposium on seismicity induced by gas production from the Groningen Field

NAM

Date 1st February 2018

Editors Jan van Elk & Dirk Doornhof

General Introduction

The December 2017 edition of the Netherlands Journal of Geosciences is a special issue dedicated to induced seismicity in the Groningen Gas field, The Netherlands. The 22 papers in this special issue give an overview of the status at the end of 2016 (Ref. 1). These papers are available as open access and can be downloaded using the following link:

https://www.cambridge.org/core/journals/netherlands-journal-of-geosciences/latest-issue

On 1st February 2018, a symposium was organised on seismicity induced by gas production from the Groningen Field by KNGMG (Koninklijk Nederlands Geologisch Mijnbouwkundig Genootschap), PGK (Petroleum Geologische Kring), SPE (Society of Petroleum Engineering, Dutch Section) and KIVI (Koninklijk Instituut Van Ingenieurs). This slide pack was presented at this symposium, Hazard and Risk assessment studies, Groningen Field, by Jan van Elk (NAM).

References

1. Winningsplan Groningen 2016, Nederlandse Aardolie Maatschappij BV, 1st April 2016.

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Title	**Presentation: Seismic Hazard and Risk Assessment in Groningen** **Symposium on seismicity induced by gas production from the Groningen Field**		**Date**	February 2018
			Initiator	NAM
Autor(s)	**Jan van Elk and Dirk Doornhof**	**Editors**	Jan van Elk and Dirk Doornhof	
Organisation	NAM	**Organisation**	NAM	
Place in the Study and Data Acquisition Plan	Study Theme: Hazard Assessment Comment: The December 2017 edition of the Netherlands Journal of Geosciences is a special issue dedicated to induced seismicity in the Groningen Gas field, The Netherlands. The 22 papers in this special issue give an overview of the status at the end of 2016 (Ref. 1). These papers are available as open access and can be downloaded using the following link: https://www.cambridge.org/core/journals/netherlands-journal-of-geosciences/latest-issue On 1st February 2018, a symposium was organised on seismicity induced by gas production from the Groningen Field by KNGMG (Koninklijk Nederlands Geologisch Mijnbouwkundig Genootschap), PGK (Petroleum Geologische Kring), SPE (Society of Petroleum Engineering, Dutch Section) and KIVI (Koninklijk Instituut Van Ingenieurs). This slide pack was presented at this symposium, Hazard and Risk assessment studies, Groningen Field, by Jan van Elk, NAM.			
Directliy linked research				
Used data				
Associated organisation	NAM			
Assurance				

The Science behind the Groningen Gas Field

Symposium on seismicity induced by gas production from the Groningen Field

When: **Thursday 1 February 2018**
Where: **TUDelft, Faculty of Civil Engineering and Geosciences (CITG), Hall A**

Program

12:00 hrs	**Registration and lunch**
12:45 hrs	Opening and Welcome – Lucia van Geuns, KNGMG
13:00 hrs	The Groningen gas field and the Dutch society – Ruud Cino, Min. EZK
13:20 hrs	Geology of the Groningen Field – Rien Herber, RUG
13:50 hrs	Measuring seismicity in the Groningen Field - Bernard Dost, KNMI
14: 20 hrs	Regulation and monitoring in Groningen – Annemarie Muntendam-Bos, SodM
14:50 hrs	**Break**
15:20 hrs	Hazard and Risk assessment studies, Groningen Field – Jan van Elk, NAM
15:50 hrs	Induced seismicity in the Groningen Field – Further studies – Jan Dirk Jansen, TUDelft
16:20 hrs	Spoken column - Manuel Sintubin , KULeuven
16:30 hrs	Panel discussion: "Science meets Society – How to communicate complex issues?" a.o. Karin van Thienen-Visser (TNO), Berend Scheffers (EBN), Ipo Ritsema (Deltares/KEM)
17:30	**Drinks & networking**

Participation fee:

Members:	Euro 20 (SPE, KIVI, KNGMG, PGK)
Non-members:	Euro 50
Students:	Euro 10

Pre-registration **obligatory** via www.pgknet.nl/Groningen2018
Please note that there are limited seats available, 'first come first serve'

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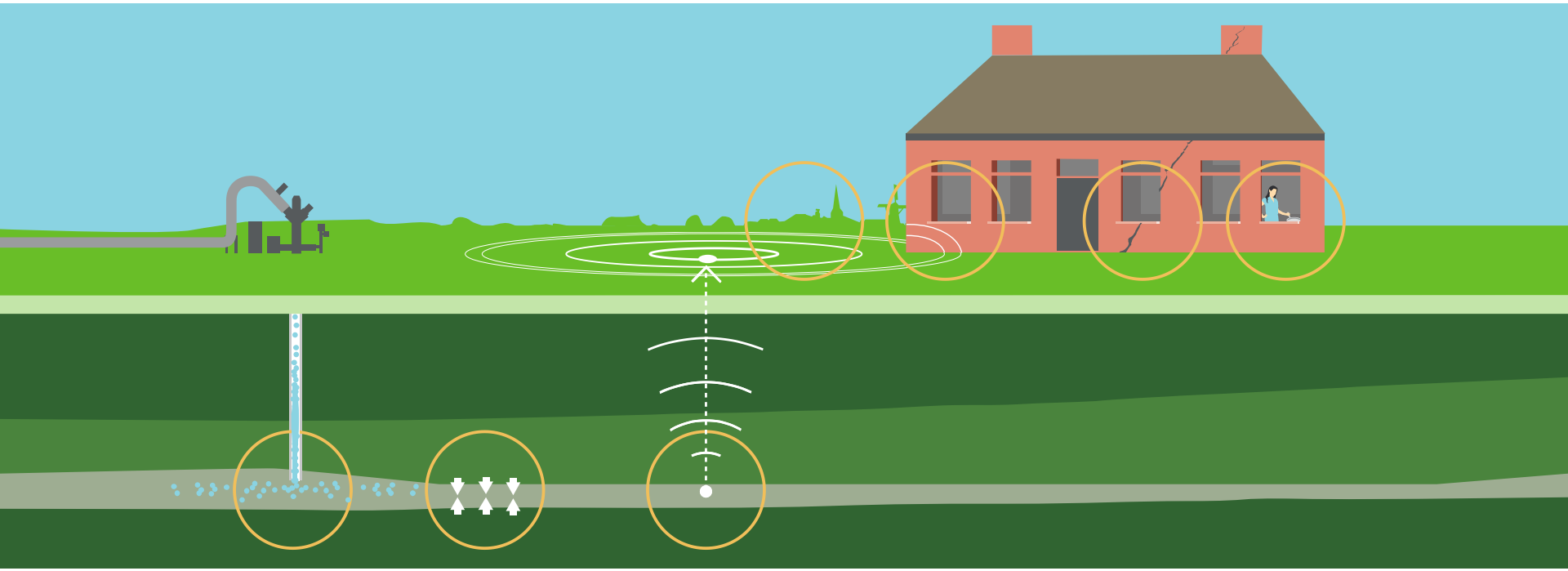
Seismic Hazard and Risk Assessment in Groningen

Symposium on seismicity induced by gas production from the Groningen Field

Jan van Elk & Dirk Doornhof - 1st February 2018

Earthquake studies cover 7 themes



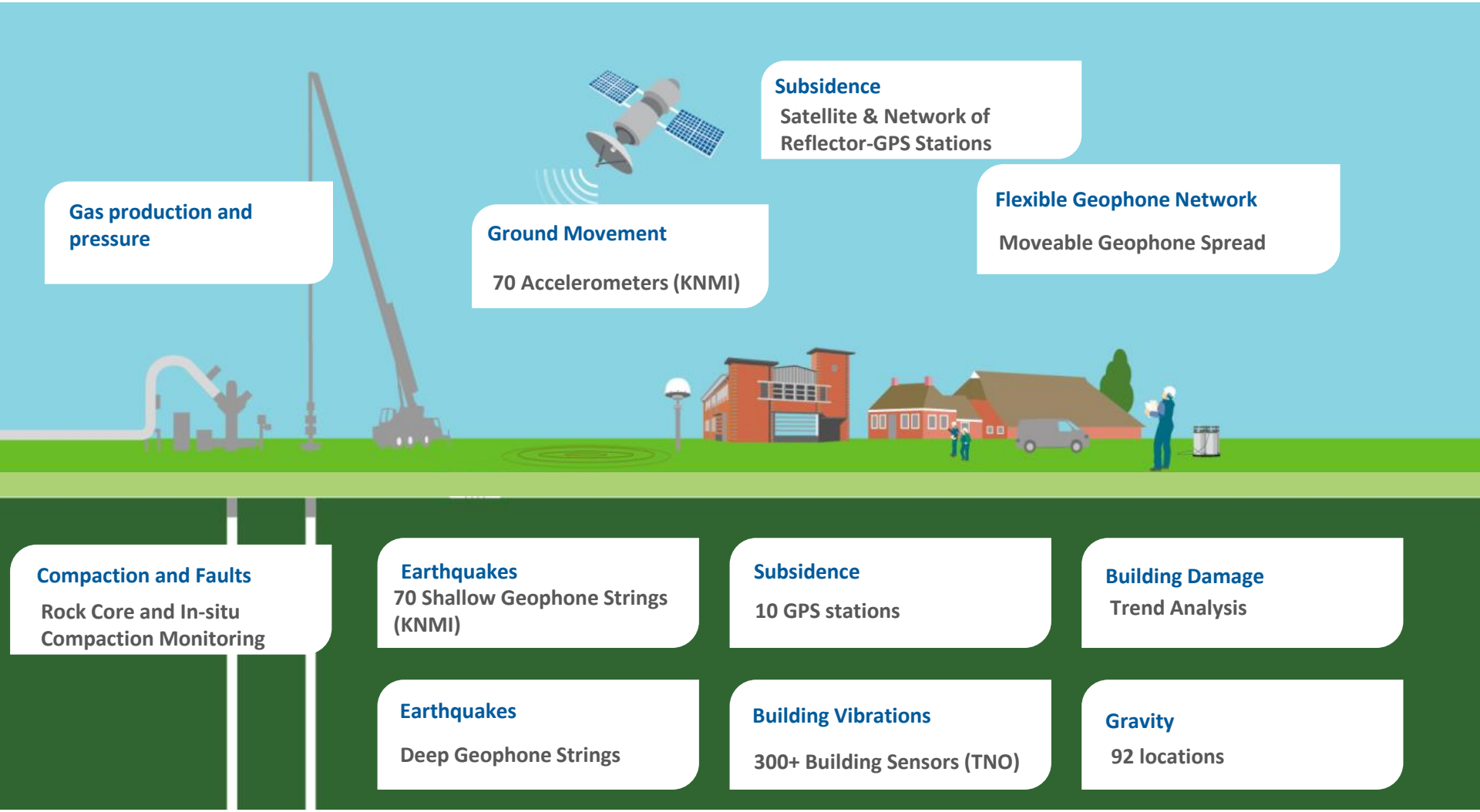
GAS PRODUCTION 1 → COMPACTION 2 → SEISMOLOGIC MODEL 3 → GROUND MOTION PREDICTION 4 → EXPOSURE 5 → BUILDING STRENGTH 6 → RISK/SAFETY 7

Building Damage

HAZARD

RISK

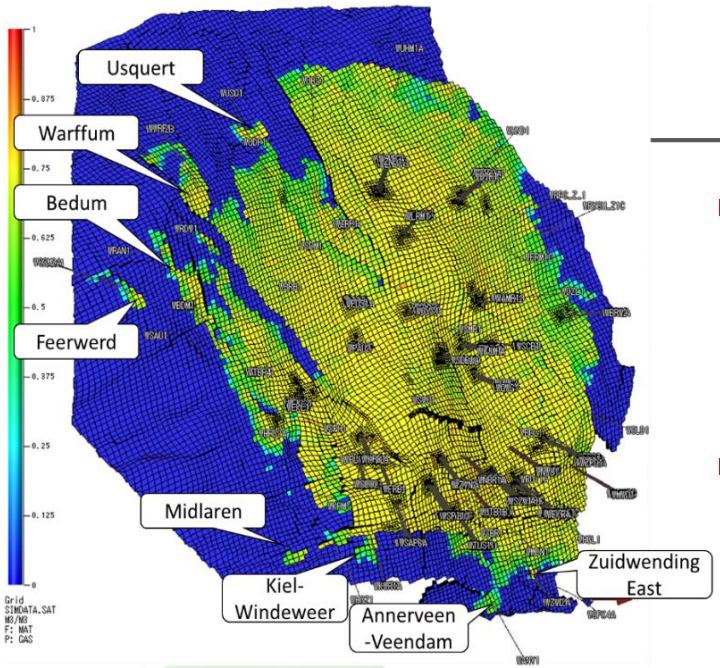
Field Measurements and Monitoring

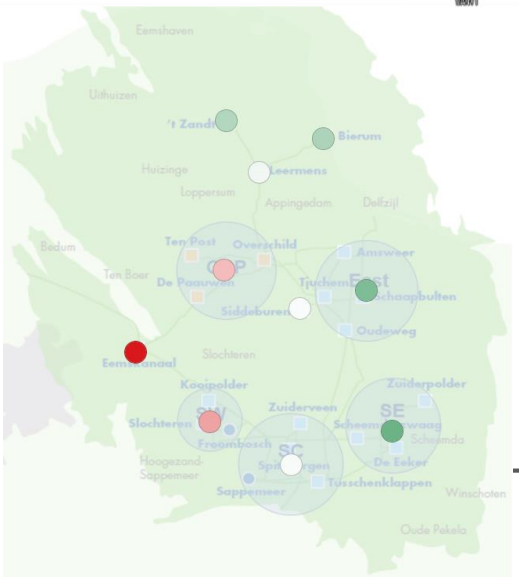


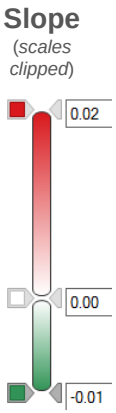
Introduction
Hazard and Risk Assessment

- The hazard- and risk assessment spans from cause (gas production) to effect (accidents, harm and building damage).
- The uncertainties in each step of the assessment are identified, estimated and consistently incorporated in the assessment.
- A traditional Probabilistic Seismic Hazard and Risk Framework is used (based on Cornell, 1968).
- Implementation is based on Monte Carlo Method (C- and Python Code)
- NAM has sought the assistance and advice of external experts from academia and knowledge institutes for each expertise area. Rigorous assurance processes are in place.
- Key is the collection of data in Groningen to prepare a hazard and risk assessment specific to the Groningen situation.

Gas Production

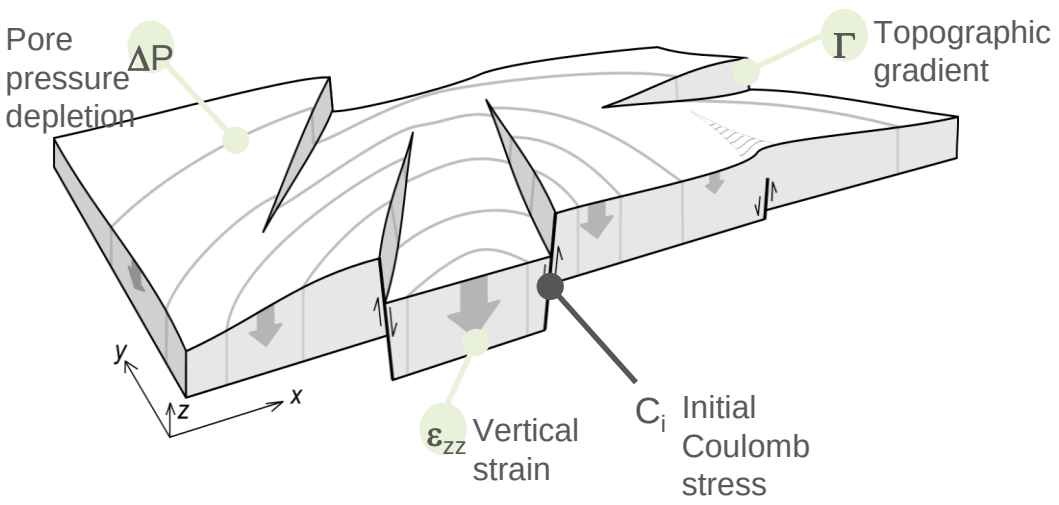


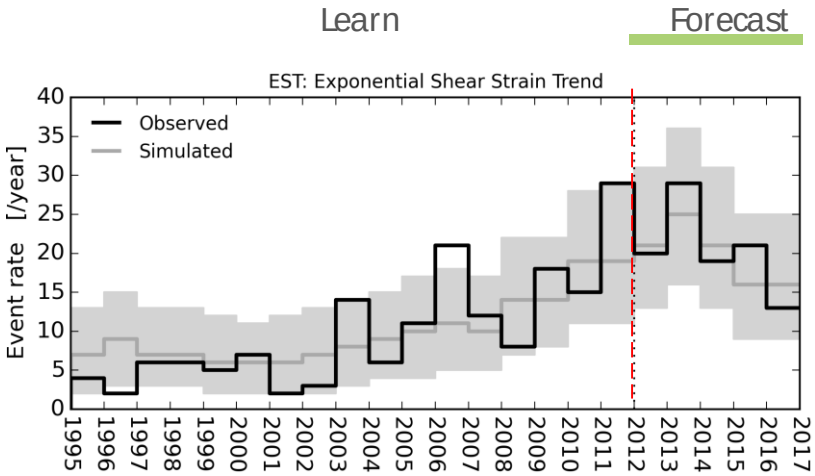




- Detailed mapping of faults in the reservoir. This forms the basis of geomechanical studies into fault behaviour (e.g. University Utrecht).
- Reservoir Model has been history matched using down-hole pressure, converted closed-in THP, water-encroachment (PNL) and subsidence. Evaluated model performance against gravity survey data.
- Optimisation of the distribution of the gas production from the field to reduce seismicity.

Seismogenic Model



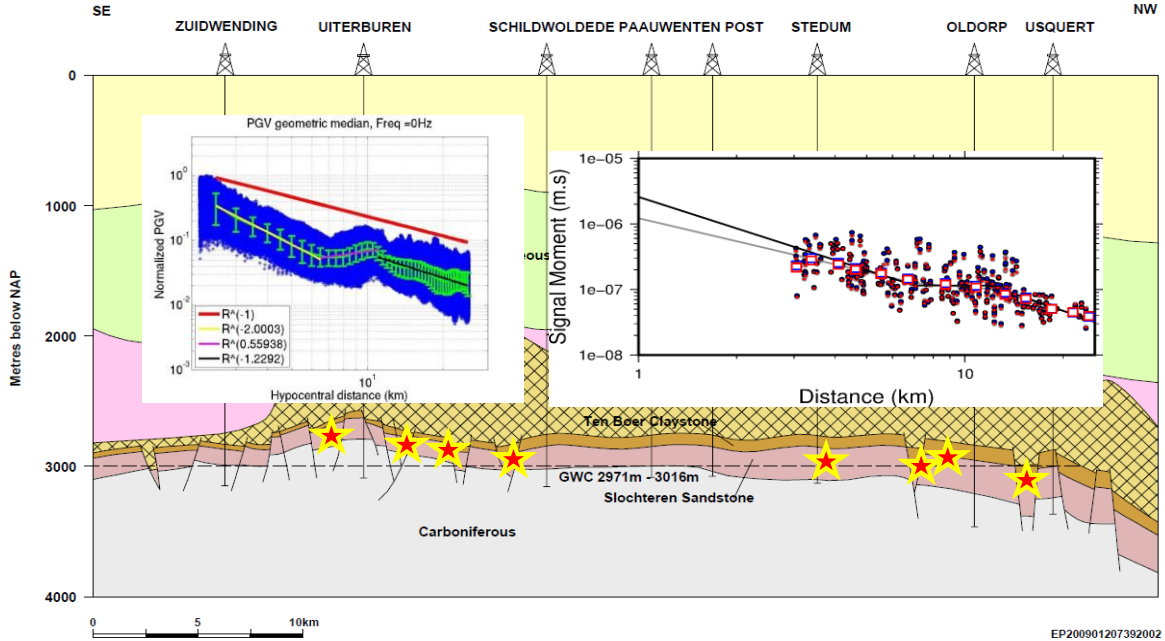


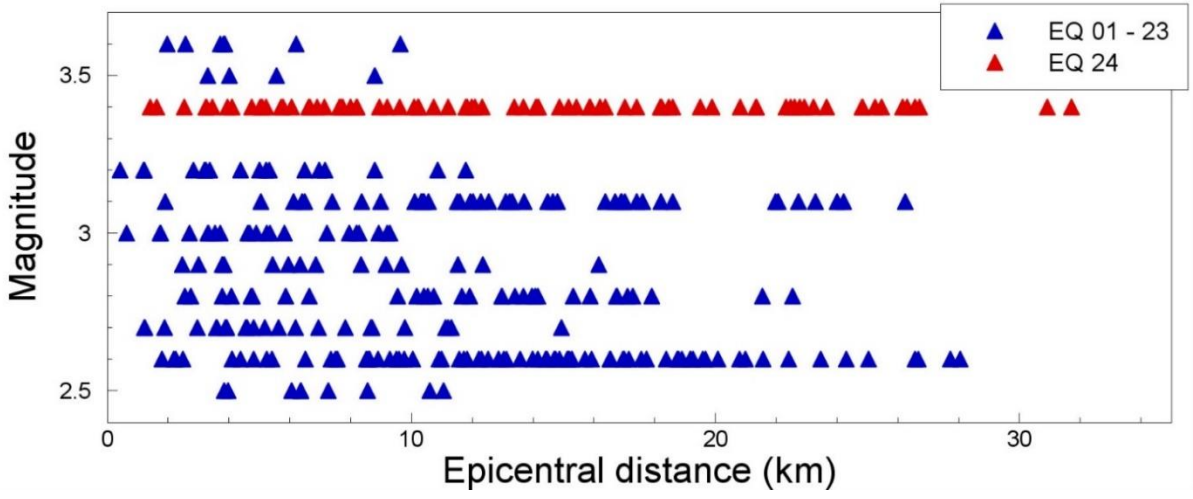
- Physics-based seismogenic models of increasing complexity have been evaluated using prospective testing.
- Theory of extreme threshold failures within a heterogeneous poro-elastic thin-sheet forecasts Groningen induced seismicity.
- Exponential shear strain trend with ETAS aftershocks.

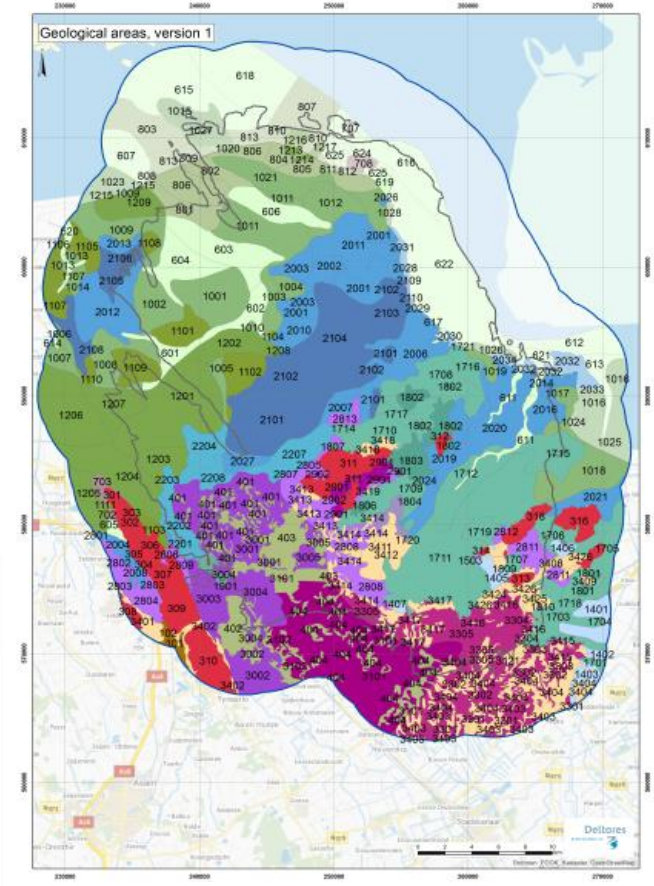
Ground Motion

- Model to predict distributions—medians plus sigmas—of Sa(T), PGV and duration (DS5-75) as needed for risk assessments.
- Applicable from ML 2.5 to largest Mmax, accounting for finite rupture dimensions of larger events and epistemic uncertainty associated with extrapolation from small-magnitude recordings.
- Model the variation of near-surface profiles across the field and the non-linear response of soft soil deposits.
- Model to reflect the unique velocity structure above the gas reservoir.
- Model to reflect source characteristics of Groningen earthquakes—and potential for larger stress drops for bigger event.

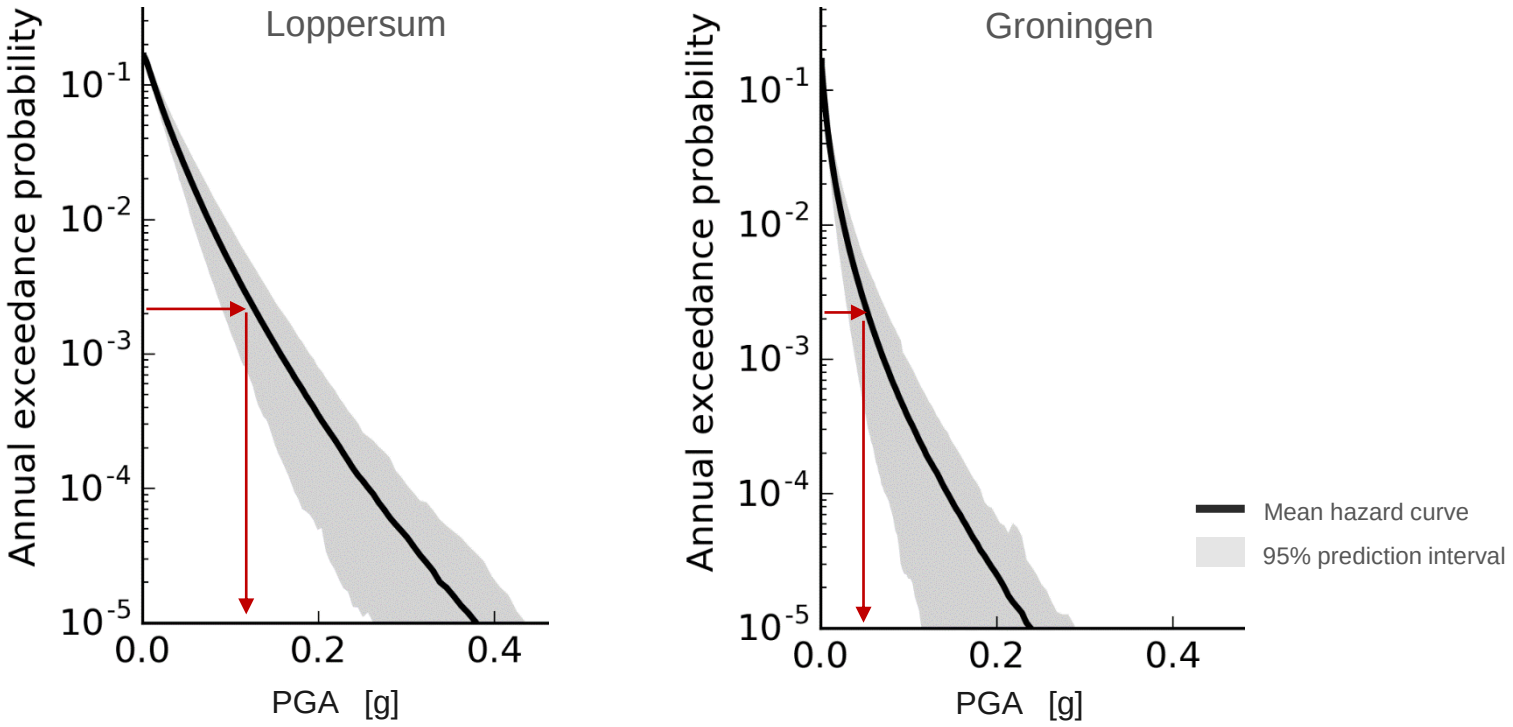
Ground Motion





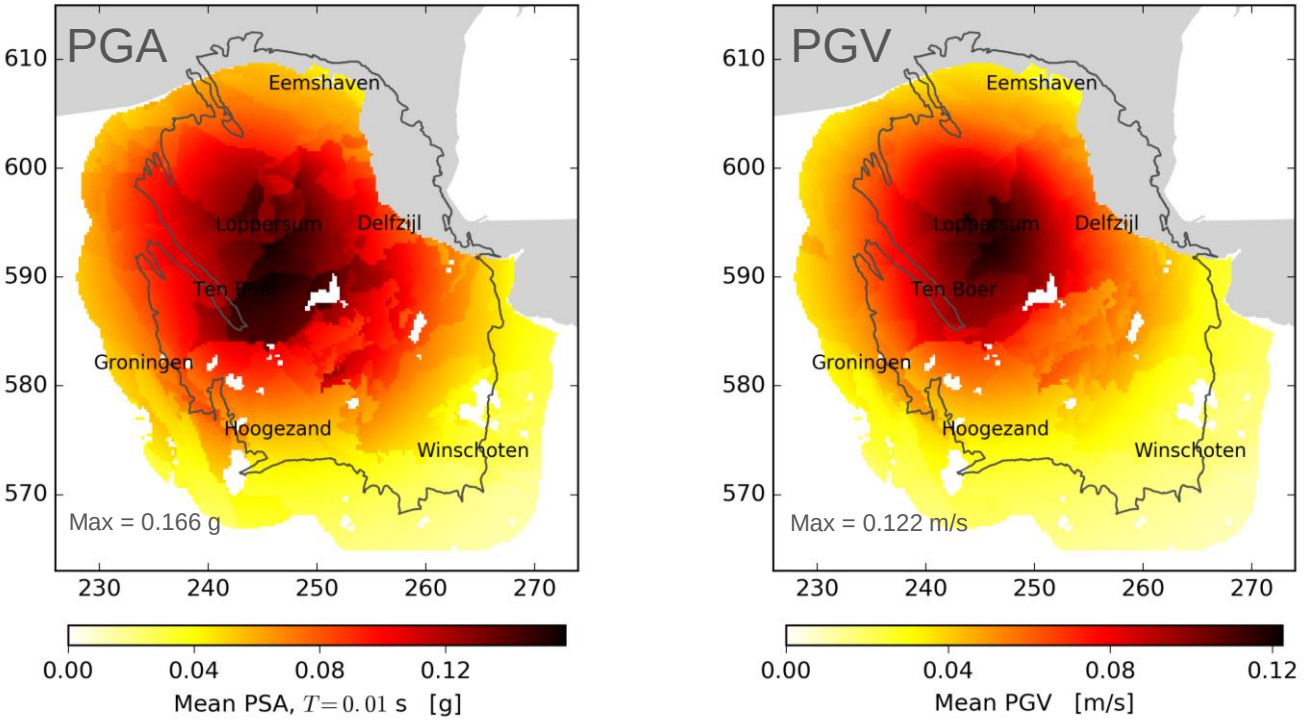


Seismic Hazard Curves

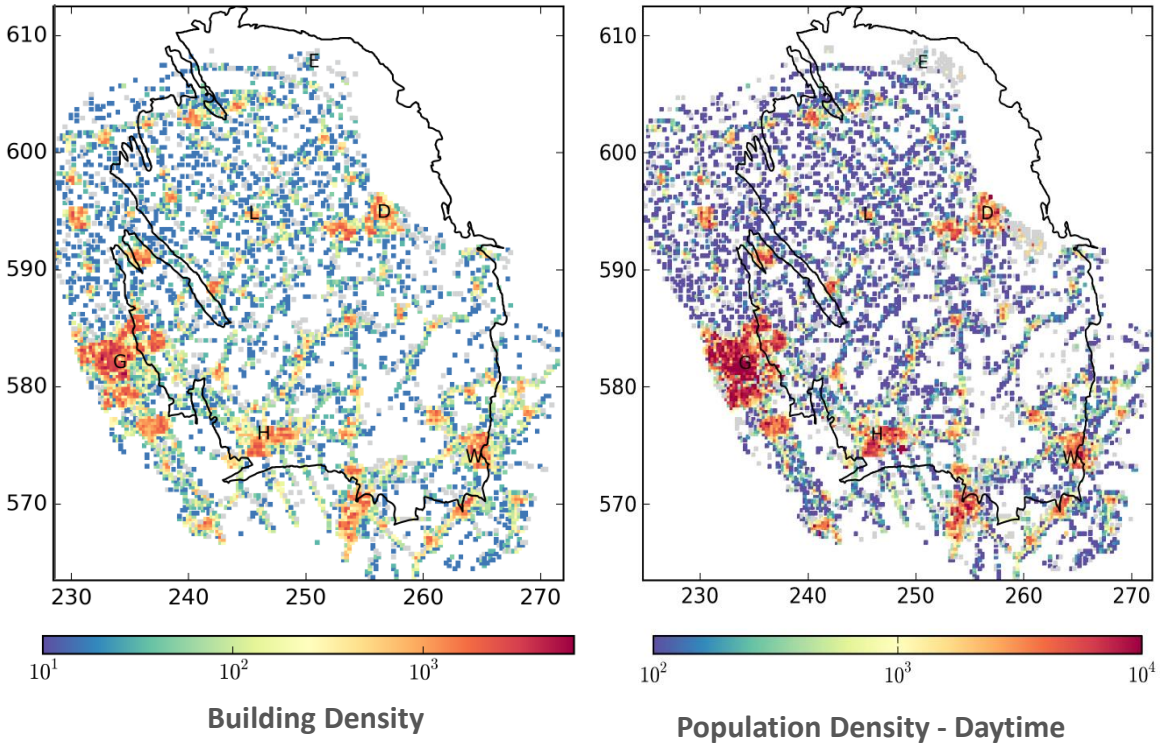


Seismic Hazard Maps

Assessment period: 1-1-2017 to 1-1-2022
Production scenario: 24 bcm/year
Exceedance probability: 0.21%/year (Poisson return periods 475 year)



Exposure in Groningen



- THE GEM (Global Earthquake Model) Taxonomy of Structural Systems is used to classify the buildings in Groningen into building typologies.

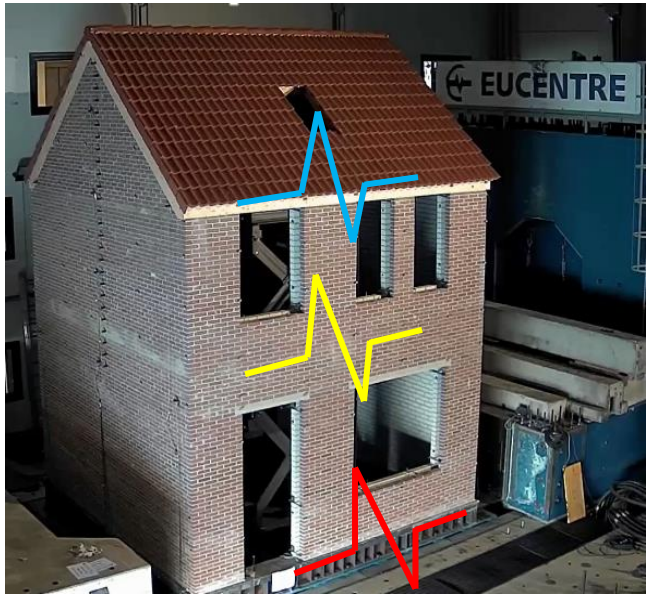
Building Response to Earthquakes

In-situ material characterisation	**13 URM houses** **2 RC buildings**
Lab material characterisation	≈ 200 test specimens (taken from actual houses)
Components testing	7 URM walls in-plane 8 RC precast connections (2-way) 3 URM walls OOP one-way 5 URM walls OOP two-way (damage)
Full-structure testing	2 URM houses (shake-table) 1 URM houses (damage, collapse) 2 URM structures (push-over) 1 roof + gables (damage, collapse) 1 roof (cyclic, collapse) 2 RC structures (cyclic, damage) 1 RC structures (shake-table)

- Seismic building response study program consists of:
  - In-situ testing
  - Building material testing in laboratory
  - Testing of small assemblages
  - Testing of walls
  - Testing of full Building Structures
- Partners in the program are:
  - Eucentre (Italy) and LNEC (Portugal)
  - ARUP
  - TU Delft and TU Eindhoven
  - MOSAYK
- Experiments are designed to improve and calibrate the modelling of Building Response
- Rigorous pre- and post-diction approach

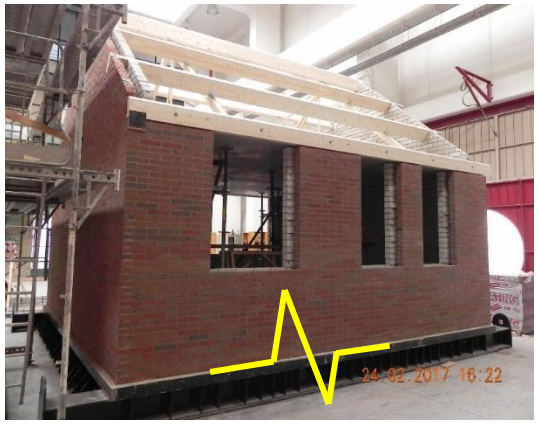
Building Response to Earthquakes

Eucentre, Italy



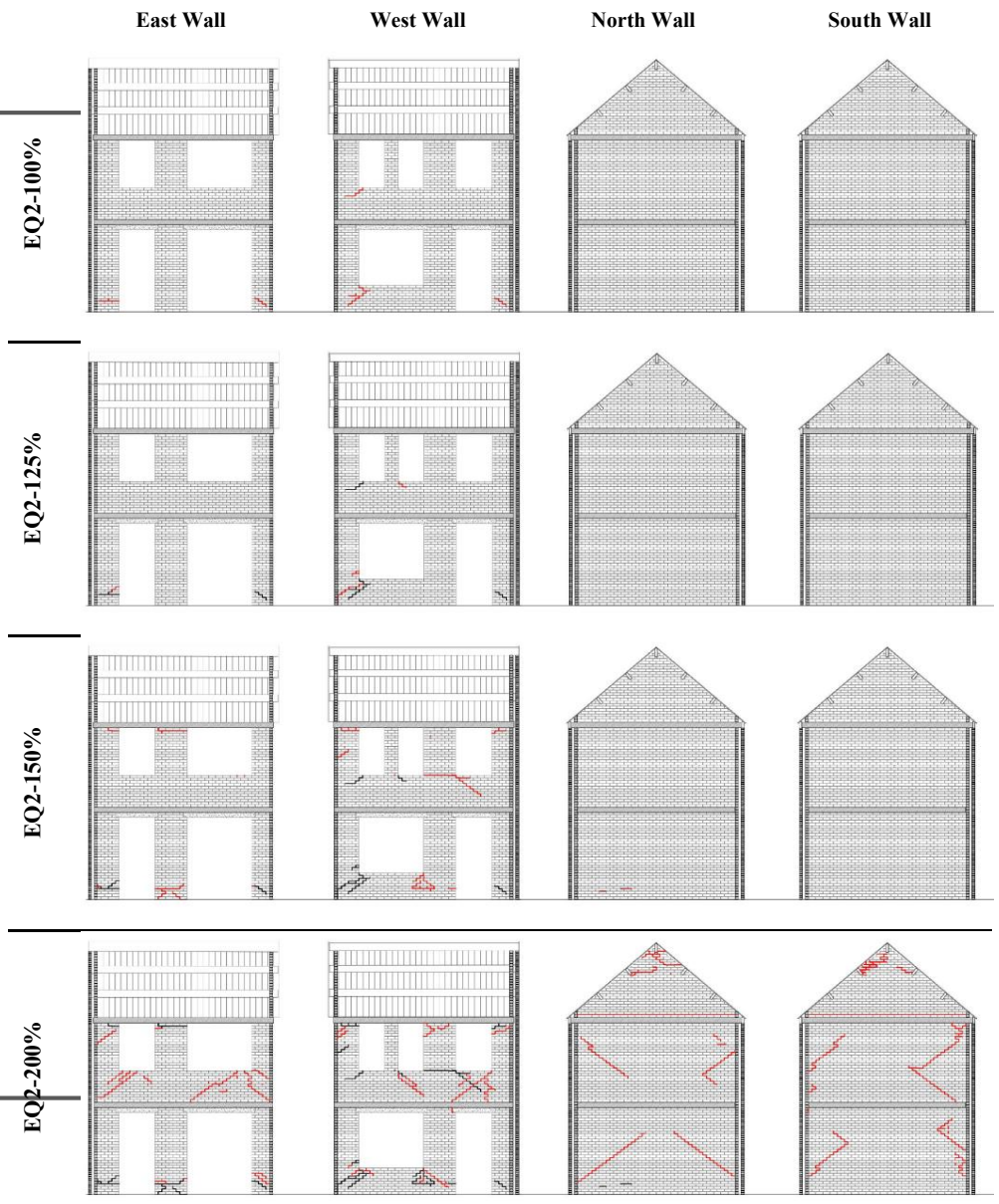
Floor Accelerogram input at LNEC

LNEC, Portugal



Building Response to Earthquakes

Test #	Test Input	Test Name	Nominal *PGA* [g]	Recorded *PGA* [g]
1	RNDM	RNDM-01	0.050	-
2	EQ1	EQ1-25%	0.024	0.024
3	RNDM	RNDM-03	0.050	-
4	EQ1	EQ1-50%	0.049	0.050
5	RNDM	RNDM-05	0.050	-
6	EQ1	EQ1-50%-C	0.048	0.050
7	EQ1	EQ1-100%	0.096	0.099
8	RNDM	RNDM-08	0.050	-
9	EQ1	EQ1-150%	0.144	0.137
10	RNDM	RNDM-10	0.050	-
11	EQ2	EQ2-30%-C	0.053	0.064
12	EQ2	EQ2-30%-C	0.053	0.059
13	EQ2	EQ2-30%-C	0.053	0.056
14	EQ2	EQ2-50%	0.079	0.087
15	RNDM	RNDM-15	0.050	-
16	EQ2	EQ2-100%	0.159	0.170
17	RNDM	RNDM_17	0.050	-
18	EQ2	EQ2-50%-C	0.079	0.114
19	EQ2	EQ2-125%	0.199	0.194
20	RNDM	RNDM-20	0.050	-
21	EQ2	EQ2-150%	0.239	0.243
22	RNDM	RNDM-22	0.050	-
23	EQ2	EQ2-200%	0.319	0.307
24	RNDM	RNDM-24	0.050	-



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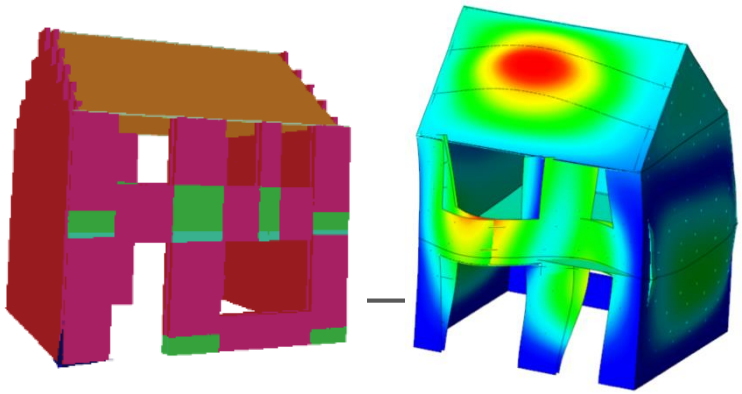
Building Response to Earthquakes

Masonry

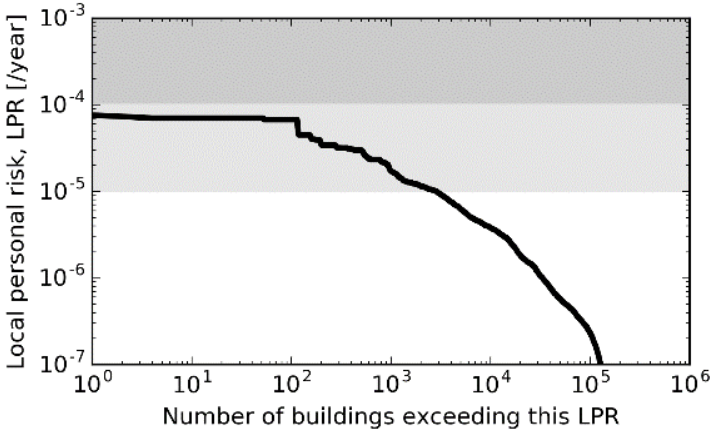
Concrete

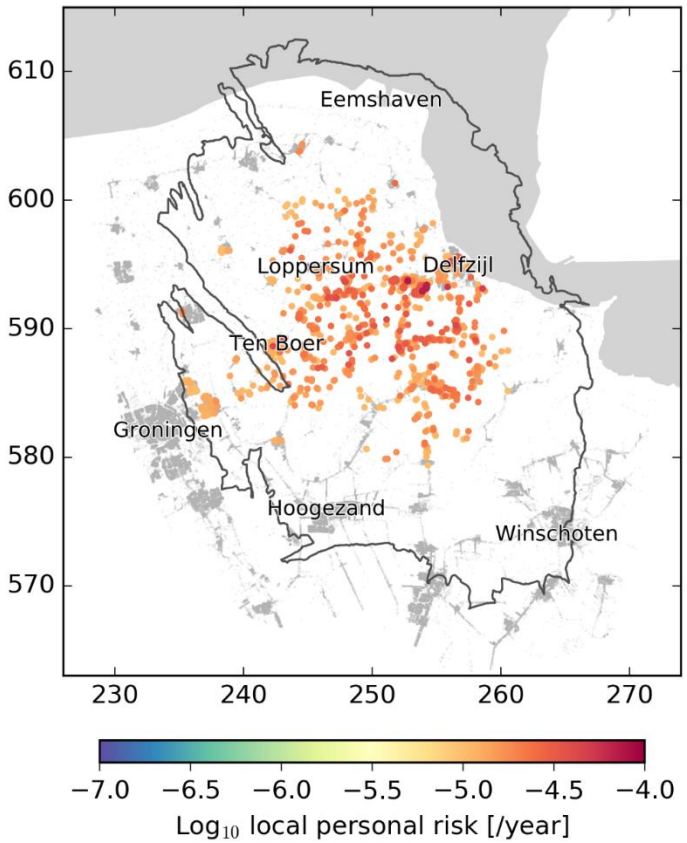
Building Response to Earthquakes

- Modelling pre-and post-diction done by:
  - ARUP using LS-Dyna
  - MOSAYK using ELS - Extreme Loading for Structures
  - TU Delft using Diana
  - EUCentre using Tremuri



Seismic Risk





- Risk Assessment allows comparison with the Meijdam-Norm for Local Personal Risk (LPR).
- No buildings are exposed to mean LPR > 10^{-4}.
- Some 2,800 houses have 10^{-5}<mean LPR<10^{-4}.
- Structural Upgrading program will need to have larger scope than the probabilistic assessment of the number of buildings exceeding the threshold LPR.

Conclusions

- All reports (130) are published at the “onderzoeksrapporten” page of www.nam.nl. Together some 89,500 downloads (as at 1st February 2018).
- More than 40 papers have been published in respected peer-reviewed journals (SCImago Journal Ranking).
- All raw data is freely available for research[1].
- Rigorous Assurance processes are in place.
- Latest update:
  - Hazard, Building Damage and Risk Assessment – November 2017 (currently 543 downloads).

1 For some data (e.g. TNO sensor data) there are privacy aspects that need to be considered when sharing the data.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