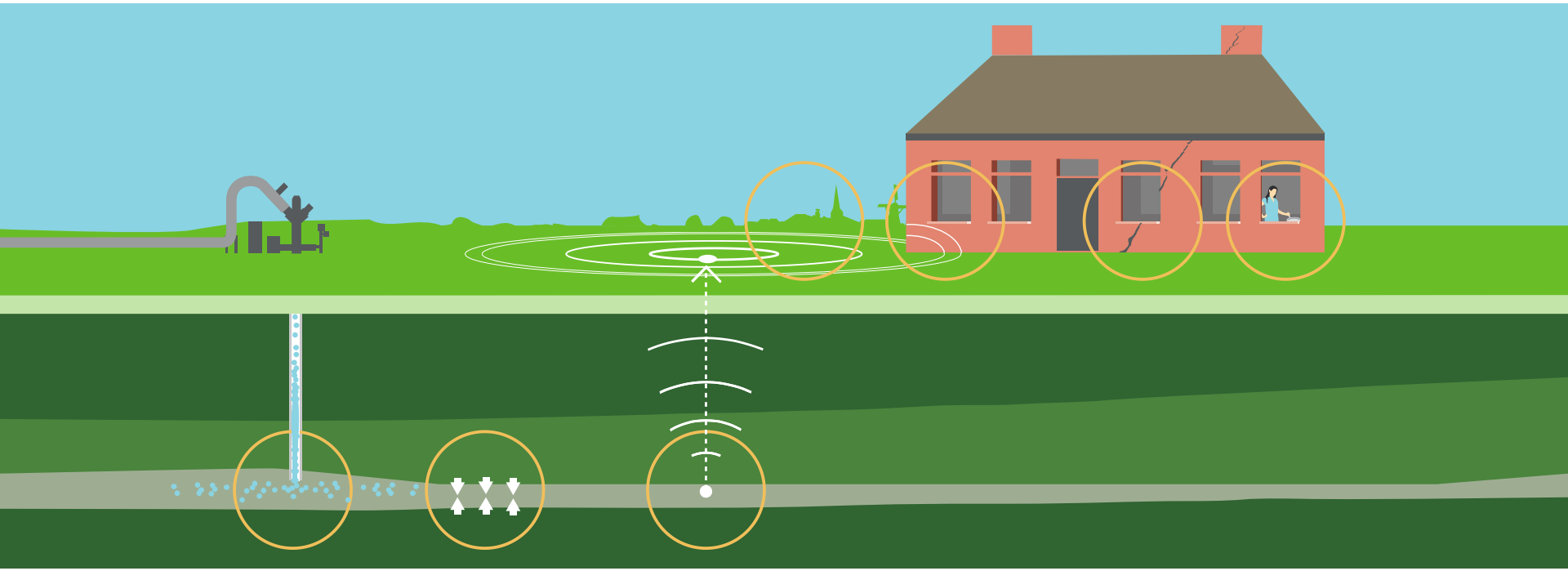
NAM

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



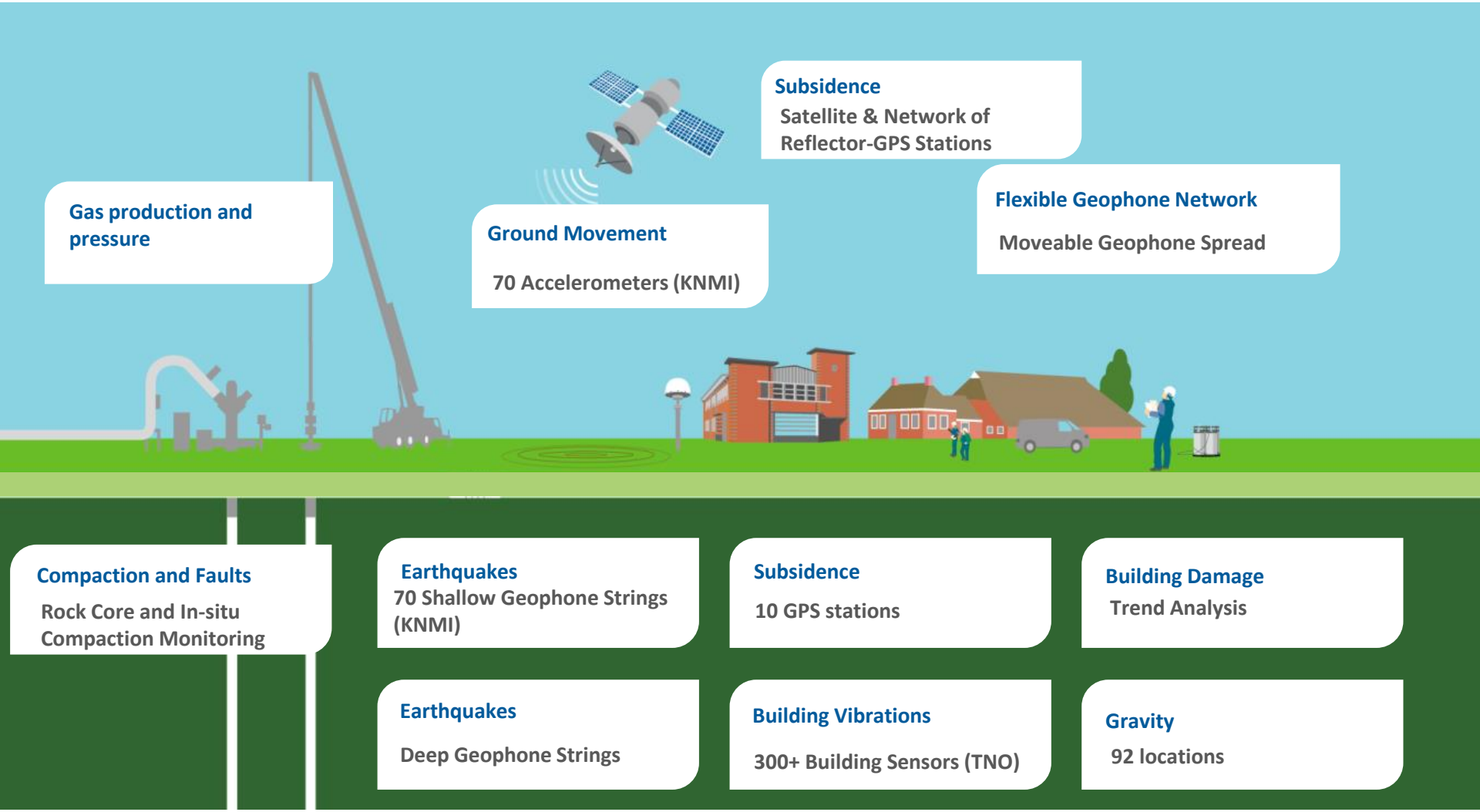
GAS PRODUCTION 1 → COMPACTION 2 → SEISMOLOGIC MODEL 3 → GROUND MOTION PREDICTION 4 → EXPOSURE 5 → BUILDING STRENGTH 6 → RISK/SAFETY 7

Building Damage

HAZARD

RISK

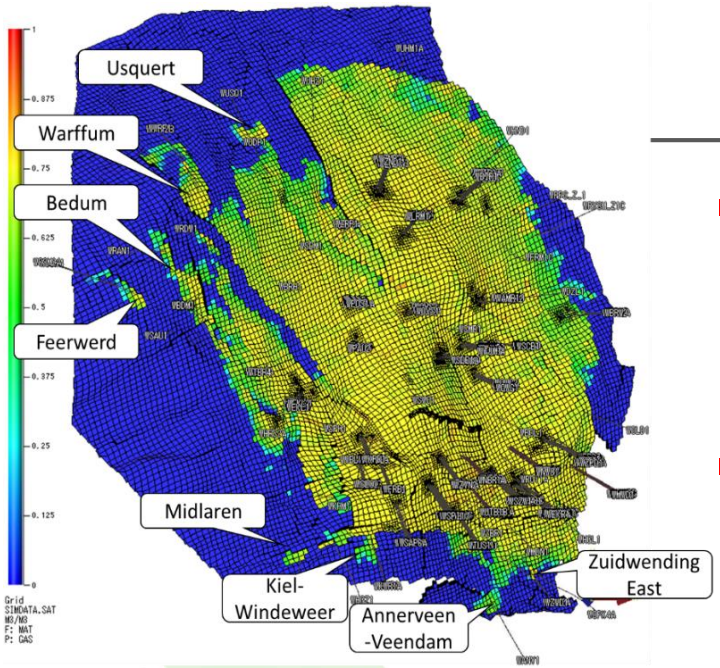
Field Measurements and Monitoring

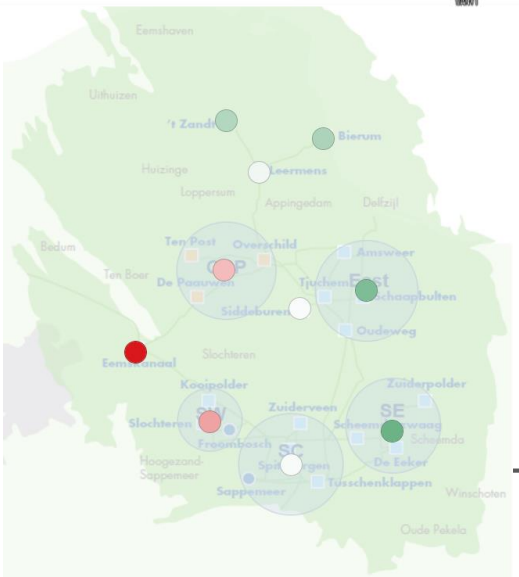


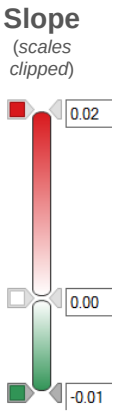
Introduction
Hazard and Risk Assessment

- 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

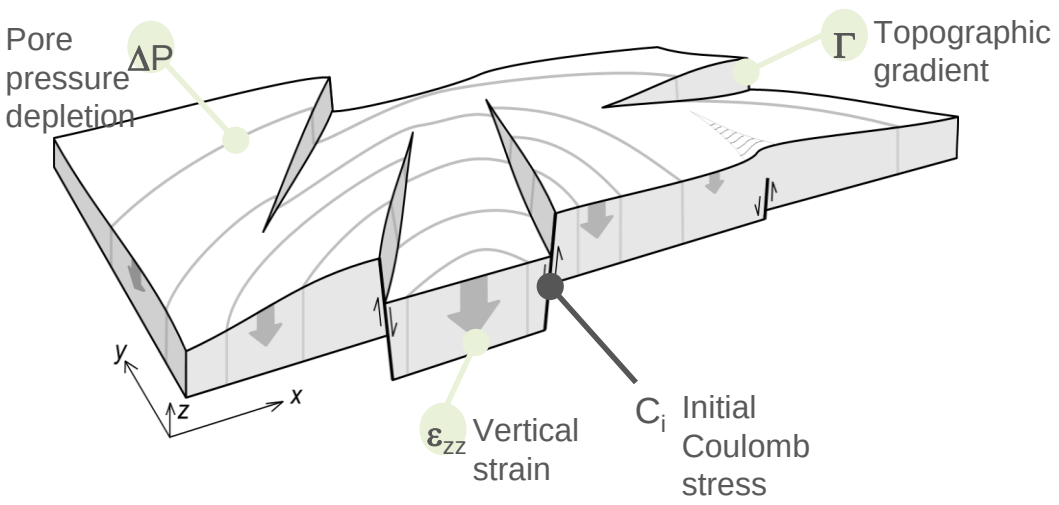


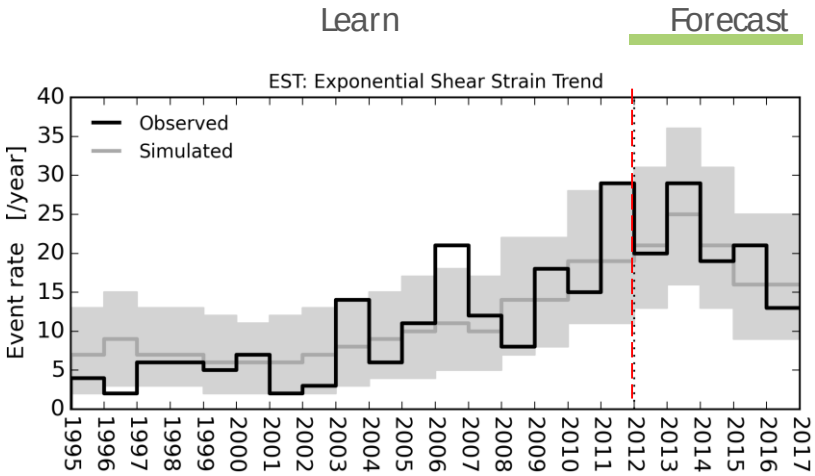




- Detailed mapping of faults in the reservoir. This forms the basis of geomechanical studies into fault behaviour (e.g. University Utrecht).
- Reservoir Model has been history matched using down-hole pressure, converted closed-in THP, water-encroachment (PNL) and subsidence. Evaluated model performance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

Seismogenic Model



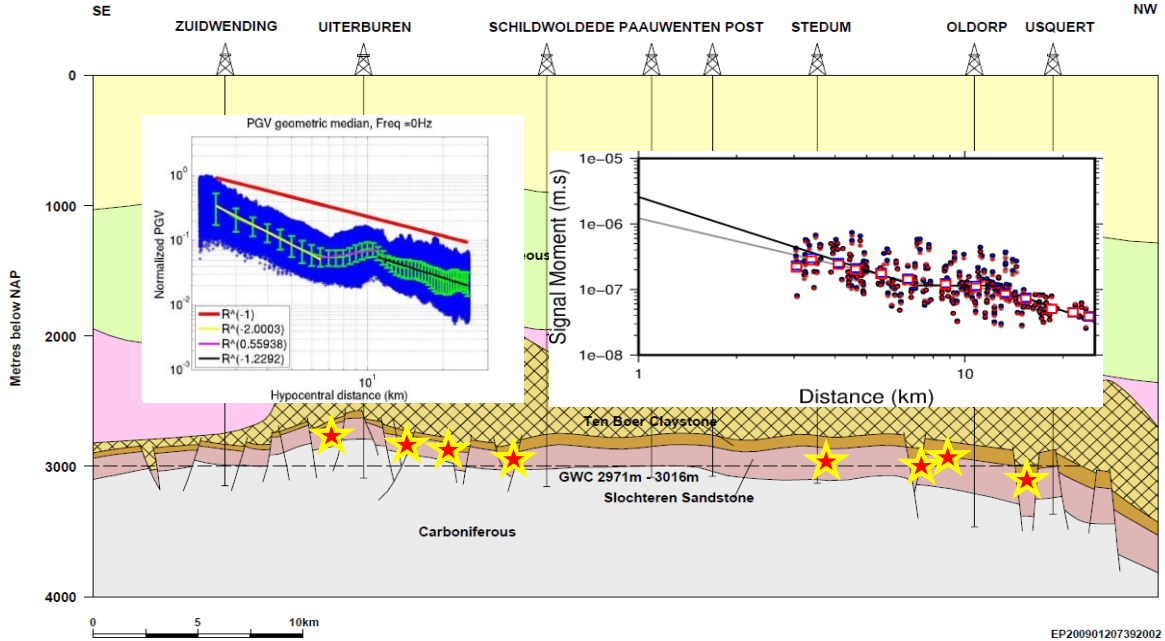


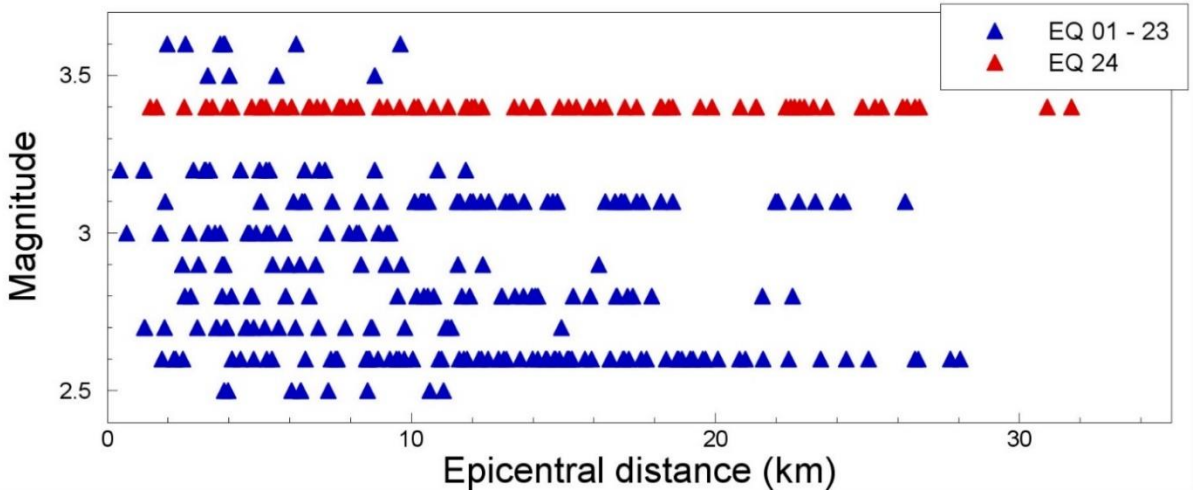
- Physics-based seismogenic models of increasing complexity have been evaluated using prospective testing.
- Theory of extreme threshold failures within a heterogeneous poro-elastic thin-sheet forecasts Groningen induced seismicity.
- Exponential shear strain trend with ETAS aftershocks.

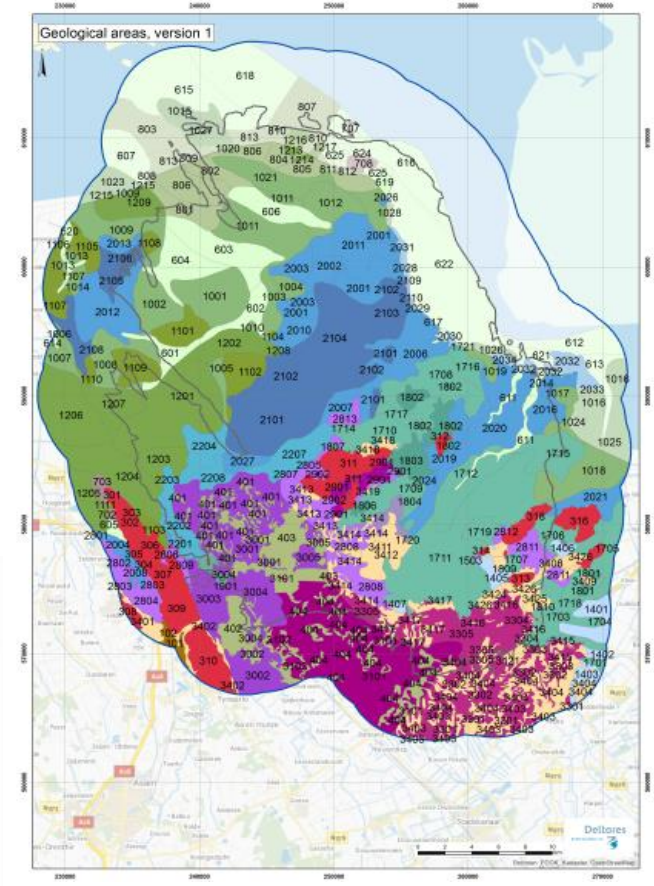
Ground Motion

- 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.

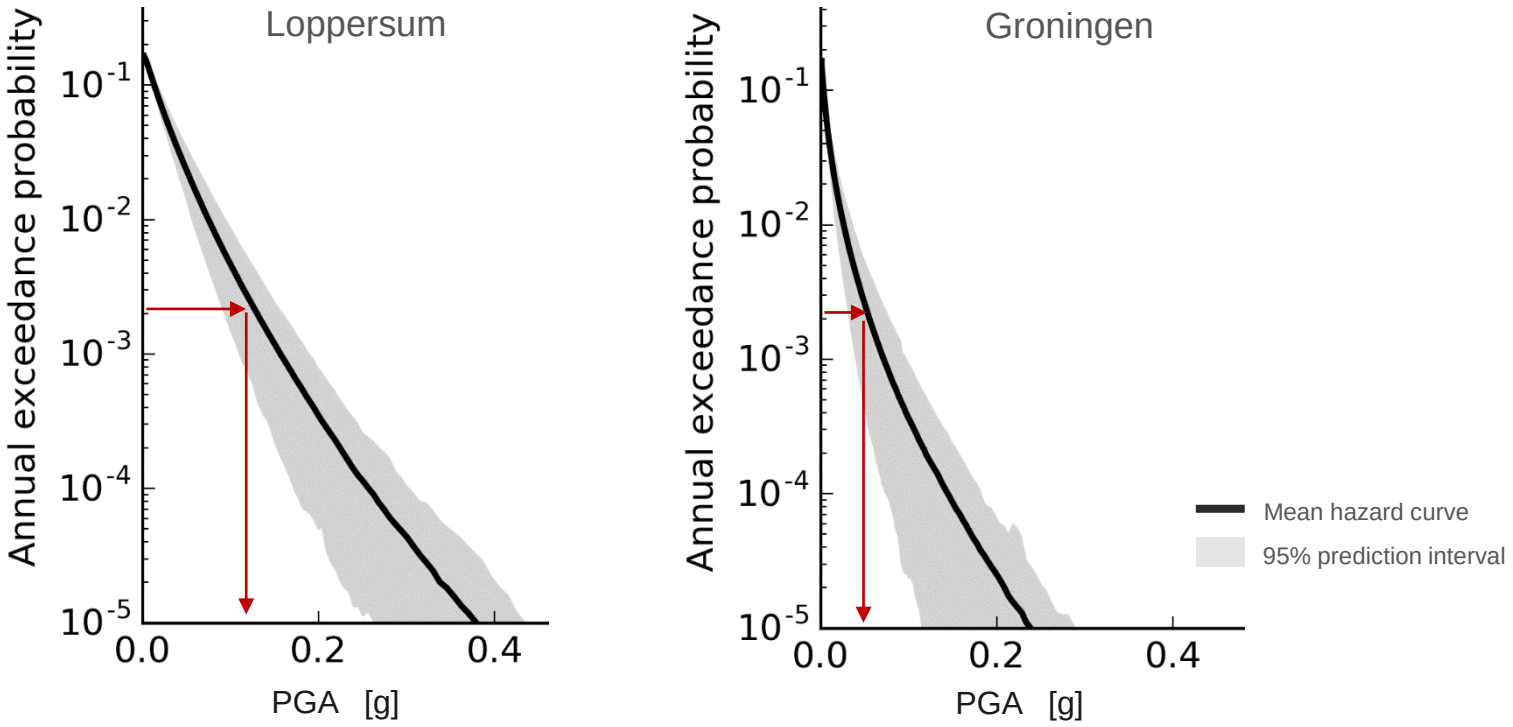
Ground Motion





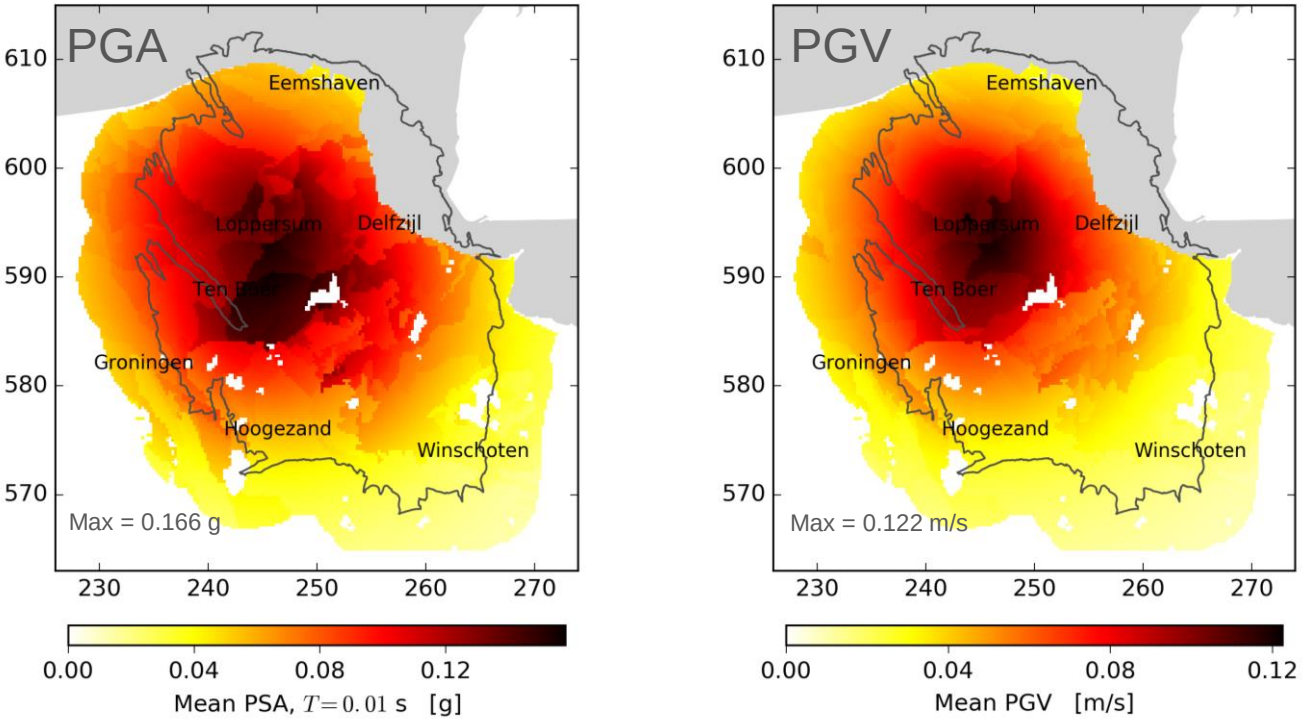


Seismic Hazard Curves

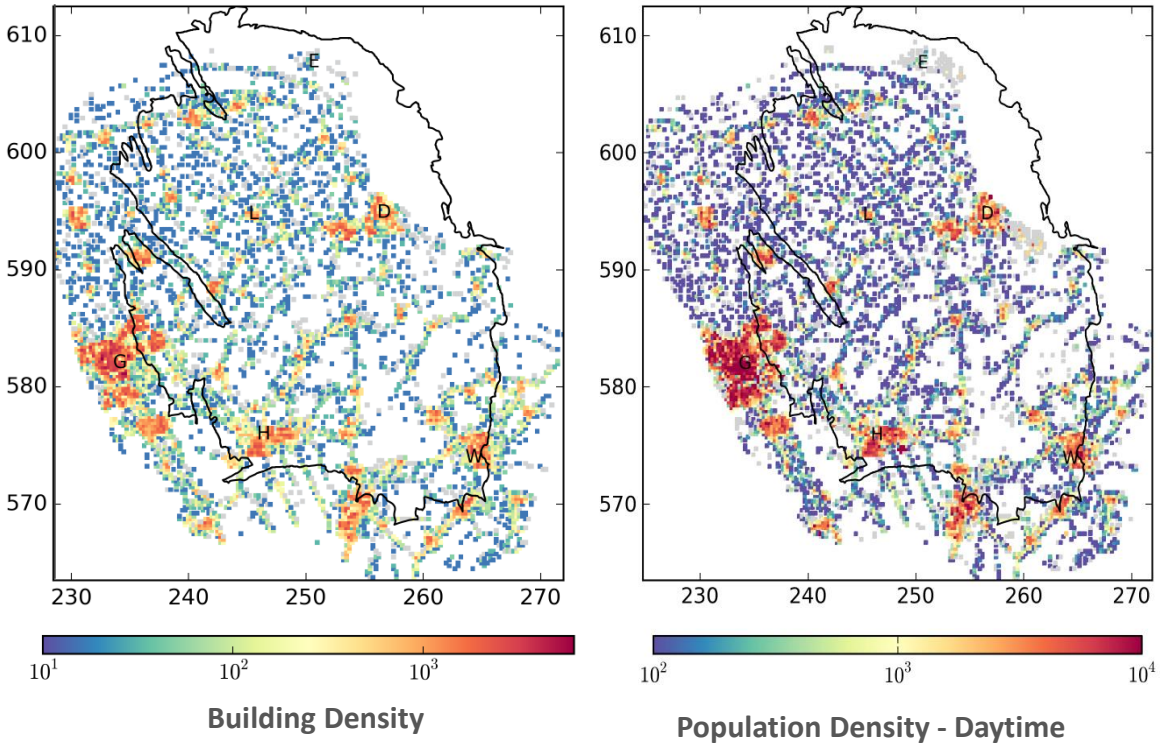


Seismic Hazard Maps

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.

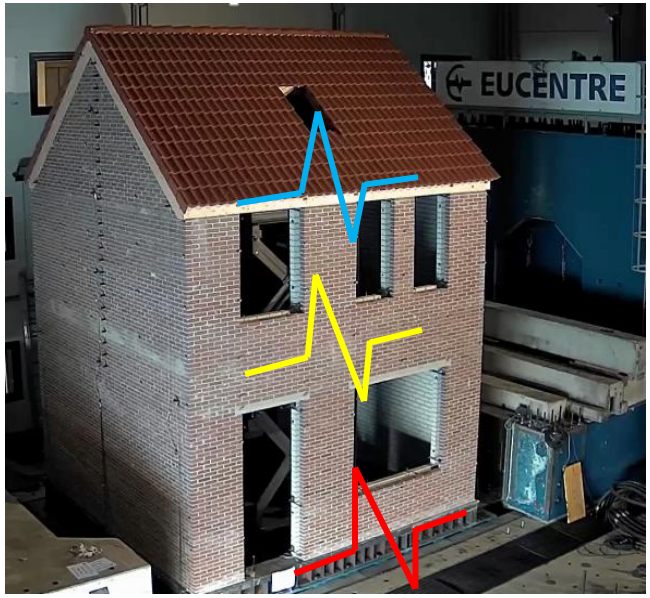
Building Response to Earthquakes

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

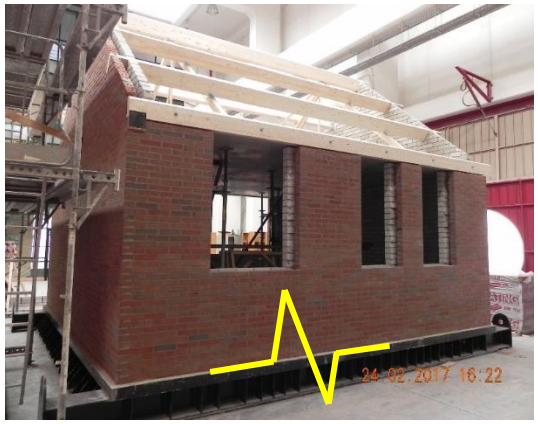
Building Response to Earthquakes

Eucentre, Italy



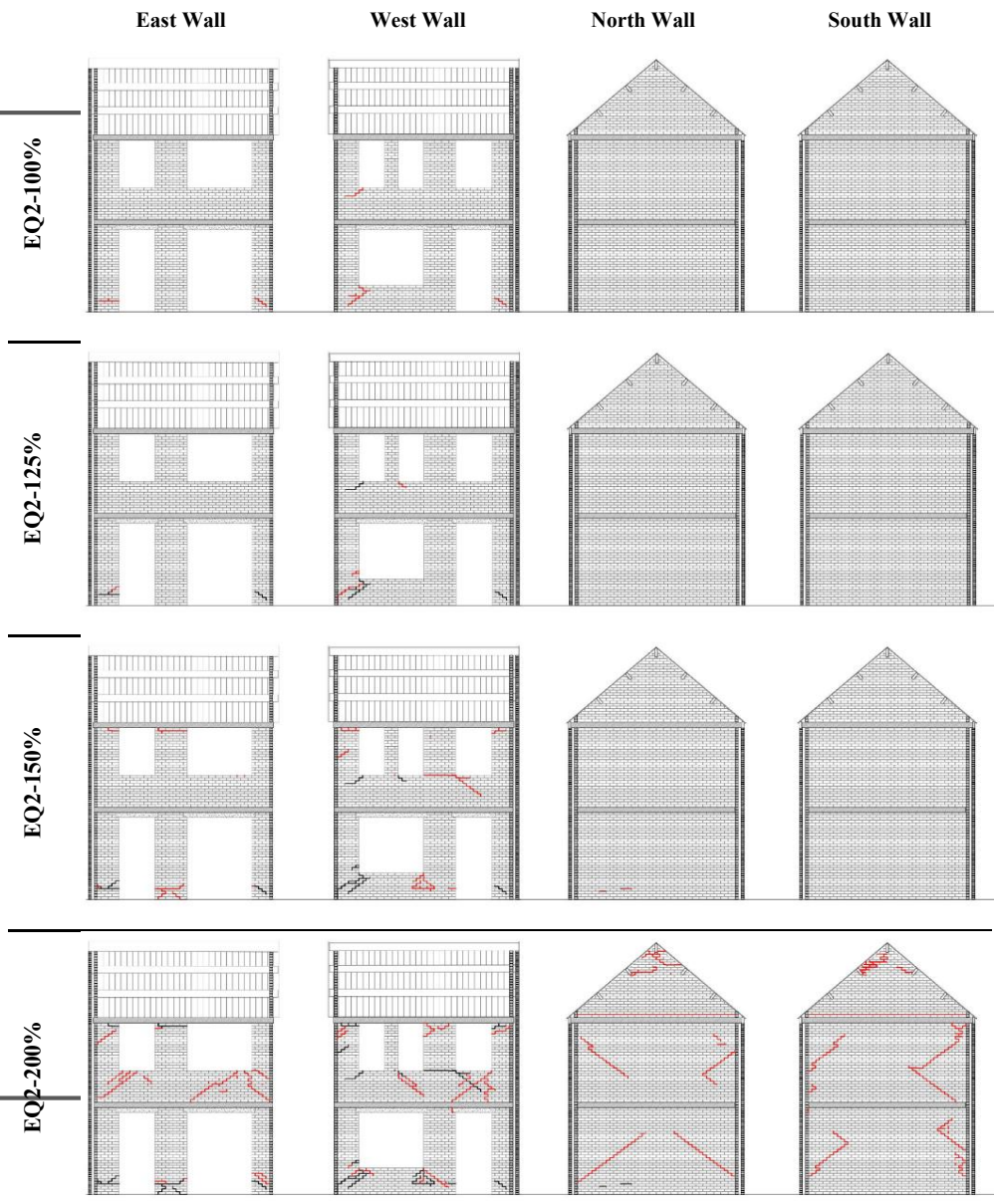
Floor Accelerogram input at LNEC

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	-



NAM

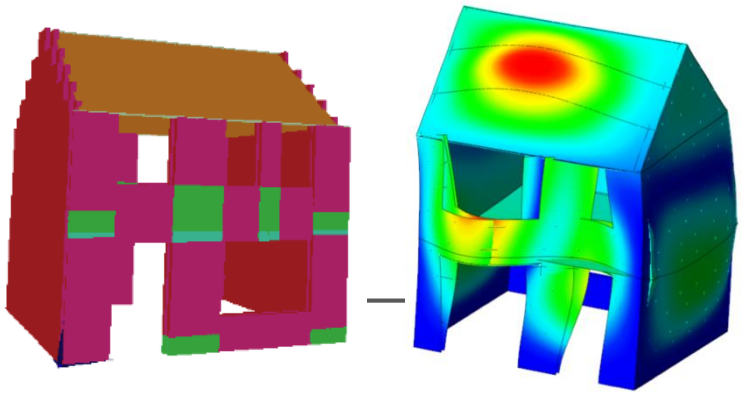
Building Response to Earthquakes

Masonry

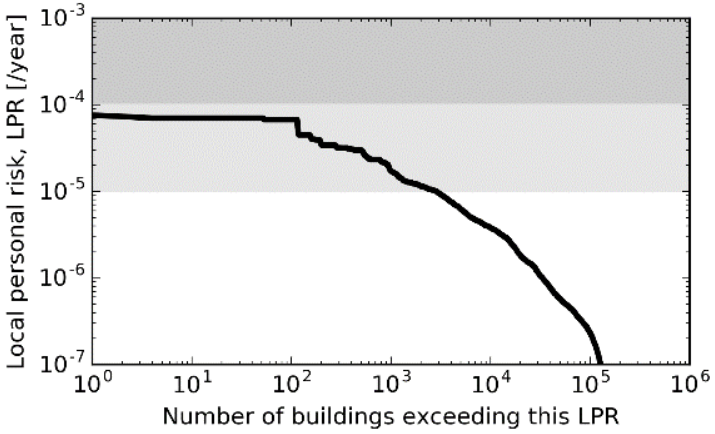
Concrete

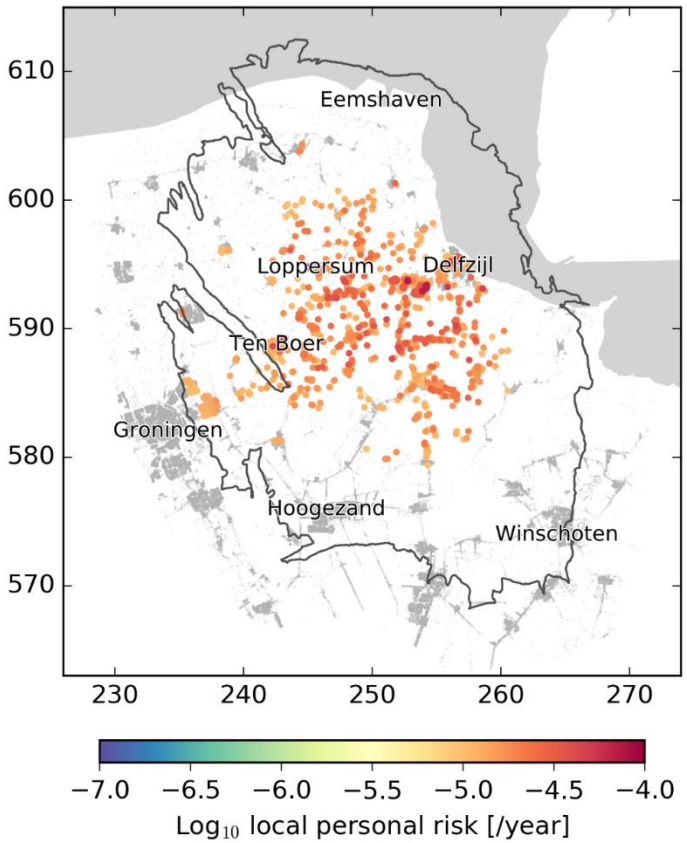
Building Response to Earthquakes

- 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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