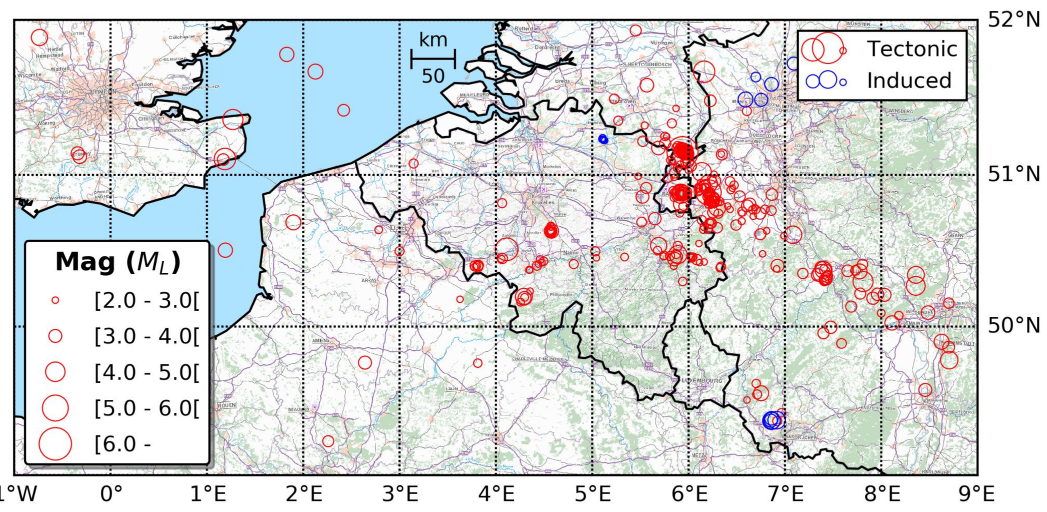
The BELSHAKE database of earthquake ground motion in Belgium

Kris Vanneste & Mahsa Onvani
Royal Observatory of Belgium

Introduction

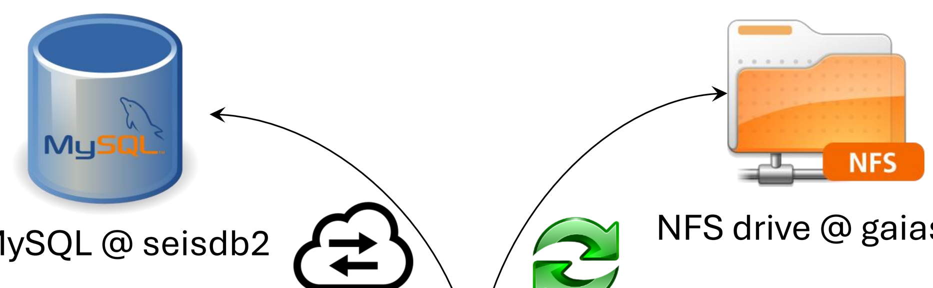
The BELSHAKE database is a new ground-motion database compiled in the frame of a project funded by the Belgian Science Policy Office. It currently contains ~7500 digital records from 333 natural and induced earthquakes with ML≥2 in and around Belgium since 1985, recorded with broadband, accelerometric, and short-period sensors operated by the Royal Observatory of Belgium (ROB).



Database structure

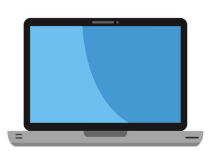
SQL Database (metadata)

Waveform archive



MySQL @ seisdb2

- Event metadata
- Station metadata
- Event-station metadata
- Waveform metadata
- Intensity measures
- Magnitude solutions
- …



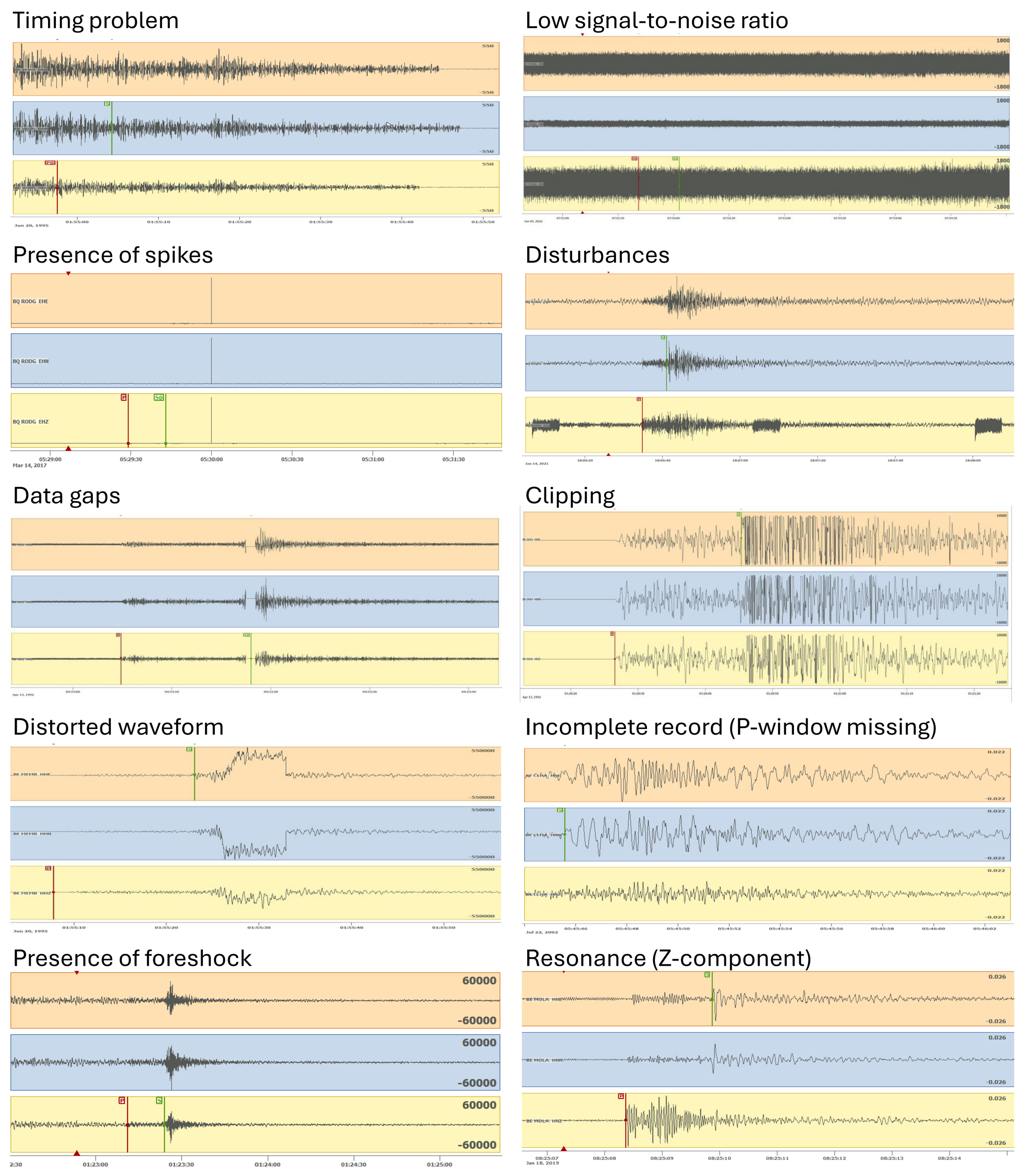
NFS drive @ gaiastore

ASDF files:

- 1 file for each event/station
- Raw data + intermediate processing steps, stored as different waveform "tags"
- Instrument response
- Fourier spectra for different windows (P, S, signal, full)

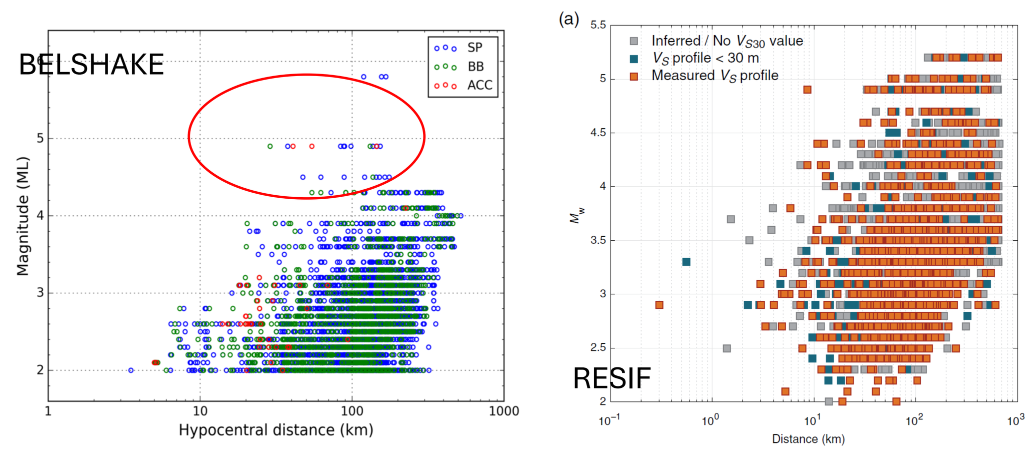
Quality control

All waveforms were visually inspected for various problems. These were either fixed or flagged in the database. The latter allows to assess the quality of every record, component and window.



Magnitude-distance coverage

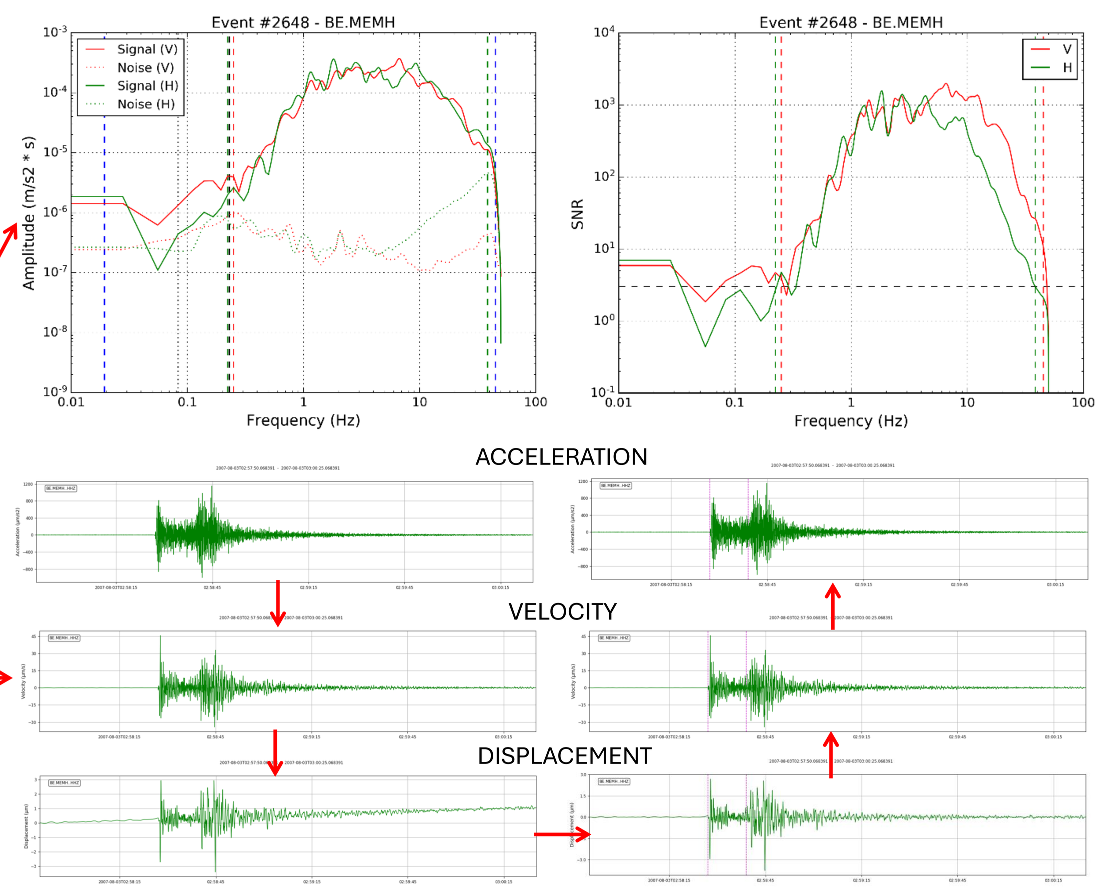
The magnitude coverage is pretty good up to M=4, but clearly less than the French RESIF database (Traversa et al., 2020) for the range M=4.0 – 5.5. There are only few records for the largest event (1992 Roermond earthquake) but we are looking for additional waveform data from other networks.



Waveform processing

Based on literature review of the processing schemes applied in existing ground-motion databases (RESIF, ITACA, PEER NGA-East, ESM), we designed a processing flow which we implemented in python and applied in a semi-automated way to all waveform data with reliable response information in the BELSHAKE archive. All processing parameters are stored in a separate table in the database and the main intermediate processing steps are stored with a particular tag in the ASDF files.

Step	Processing	ASDF waveform tag
0	**Raw** data (optional trimming, timeshift, …)	00raw
[1]	**Manual correction** (baseline correction, spike removal, …)	[01corr]
2	**Window definition** (combination of Goulet method for P-, S- and coda windows, and Perron method for noise window(s))	
3	**Demeaning / detrending (linear)**	
4	**Tapering** (using fixed lengths instead of taper rates)	
5	**Restitution to native ground-motion type** (velocity or acceleration)	02rest
[6]	**Differentiation** (freq. domain) **to acceleration**	
7	Compute **signal/noise FAS** to determine SNR and fmin/fmax	
8	**Tapering**	
9	**Zero-phase bandpass filtering with zero padding**	
10	**Re-establish initial time scale** (trimming)	03filt
11a	**Integration** (time domain) **to velocity and displacement**, and fit 6th-order polynomial with 0th and 1st coefficients constrained to 0; subtract fit from displacement	04dis
11b	Subtract 1st derivative of polynomial fit from velocity	04vel
11c	Subtract 2nd derivative of polynomial fit from acceleration in step 10	04acc
12	**Windowing, tapering and zero-padding** to length of P- or S-window (whichever is longest)	05acc_noise, 05acc_p, 05acc_s, 05acc_coda, 05acc_signal, 05acc_full



Intensity measures

After uniform processing of all reliable waveforms, we computed various intensity measures for different window-component combinations:

Windows:

- P
- S
- Signal (P + S)
- Full (P + S + coda)

Components:

- Physical: Z, E, N
- Rotated: T
- Virtual: GM, RotD50, RotD100

Category	Code	Intensity measure	Formula	Unit
Peak ground motion	PGA	Peak Ground Acceleration	$max(\|a(t)\|)$	cm/s^2
	PGV	Peak Ground Velocity	$max(\|v(t)\|)$	cm/s
	PGD	Peak Ground Displacement	$max(\|d(t)\|)$	cm
Response spectra	PSA	Acceleration response spectrum	0.01 – 4 s / 0.25 – 100 Hz, 5% damping	cm/s^2
	PSV	Pseudo-spectral velocity	$PSA * (2\pi f)^{-1}$	cm/s
	SD	Spectral displacement	$PSA * (2\pi f)^{-2}$	cm
Integrals over time series	RMSa	Root-Mean-Square Acceleration	$\sqrt{{}^{1}/_{T_d} \int a(t)^2\,dt}$	cm/s^2
	AI	Arias Intensity	$(\pi/2g)\int^{T_d} a(t)^2\,dt$	m/s
	CAV	Cumulative Absolute Velocity	$\int \|a(t)\|\,dt$	$g.s$
	sCAV	Standardized CAV	CAV of 1-s windows where PGA ≥ 0.025 g	$g.s$
	bCAV	Bracketed CAV	CAV of portion of $a(t)$ ≥ 0.05 g	$g.s$
Integrals over part of response spectrum	HI	Housner Intensity	$\int_{T=0.1}^{2.5} PSV(T)\,dT$	cm
	ASI	Acceleration Spectral Intensity	$\int_{T=0.1}^{0.5} PSA(T)\,dT$	cm/s
Average over part of response spectrum	EPA	Effective Peak Acceleration	$\overline{PSA[0.1 \le T \le 0.5]}/2.5$	cm/s^2
	EPV	Effective Peak Velocity	$\overline{PSV[0.7 \le T \le 2]}/2.5$	cm/s
	EPD	Effective Peak Displacement	$\overline{SD[2.5 \le T \le 4.0]}/2.5$	cm
Duration	D5_75	Significant (Arias) duration	T corresponding to buildup from 5% to 75% of cumulative AI	s
	D5_95	Significant (Arias) duration	T corresponding to buildup from 5% to 95% of cumulative AI	s
	Db5PcG	Bracketed duration	T of portion between first and last occurrence of $a(t)$ ≥ 0.05 g	s

GMPE fitting and residual analysis

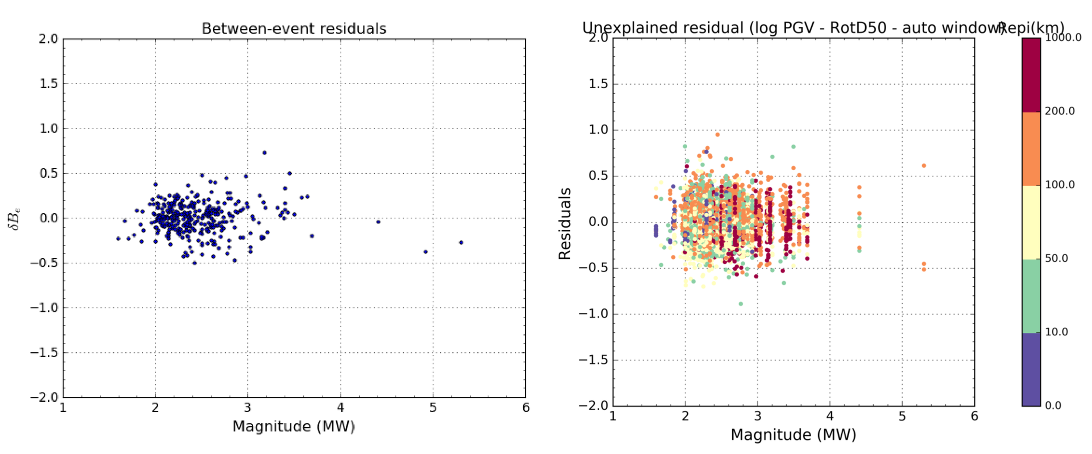
To analyze the residuals, we fit an ad-hoc GMPE to the data using mixed-effects regression, similar to Traversa et al. (2020):

$$\log_{10} IM = \left(c_1 + c_2(M - M_{ref})\right)\log_{10}\left(\frac{\sqrt{R^2 + h^2}}{R_{ref}}\right) - c_3\left(\sqrt{+R^2 + h^2} - R_{ref}\right) + b_1(M - M_{ref}) + \delta B_e + \delta S2S_s + \epsilon$$

This allows separating the residuals into:

- δB_e: between-event residual
- $\delta S2S_s$: station-to-station residual
- ε: unexplained or event- and station-corrected residual

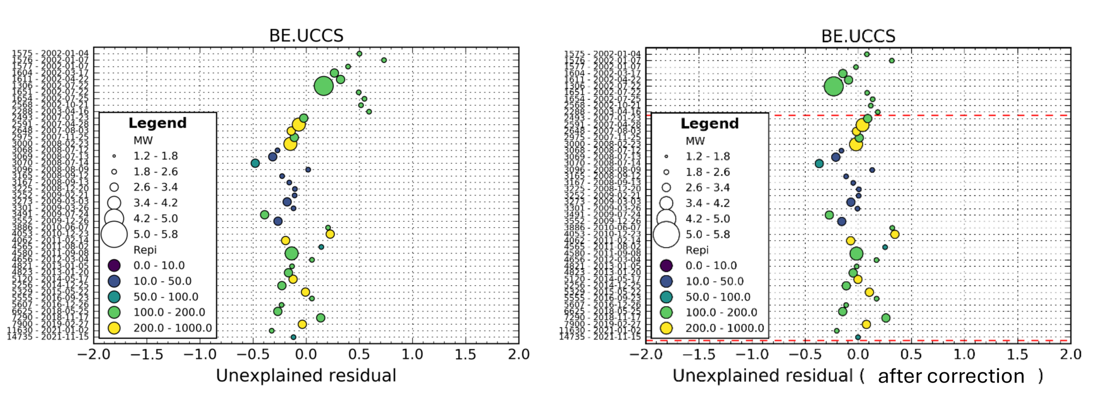
The obtained residuals mostly vary within a narrow range (-0.5 to 0.5) and show no discernible trend with distance or magnitude. The between-event residuals show only 1 potential outlier. This may point to incorrect magnitude or location or to unique source characteristics (e.g., anomalous stress drop).



We also analyze the evolution with time of the unexplained residual for each station. Consistent anomalies over a prolonged period may point to:

- problems with the instrument response
- changes in station emplacement (e.g., surface → borehole)

Thus, we could identify a number of problems, which were solved by correcting the instrument response (or flagging it as unreliable if correction was not possible) and by using different station location codes for different emplacements.

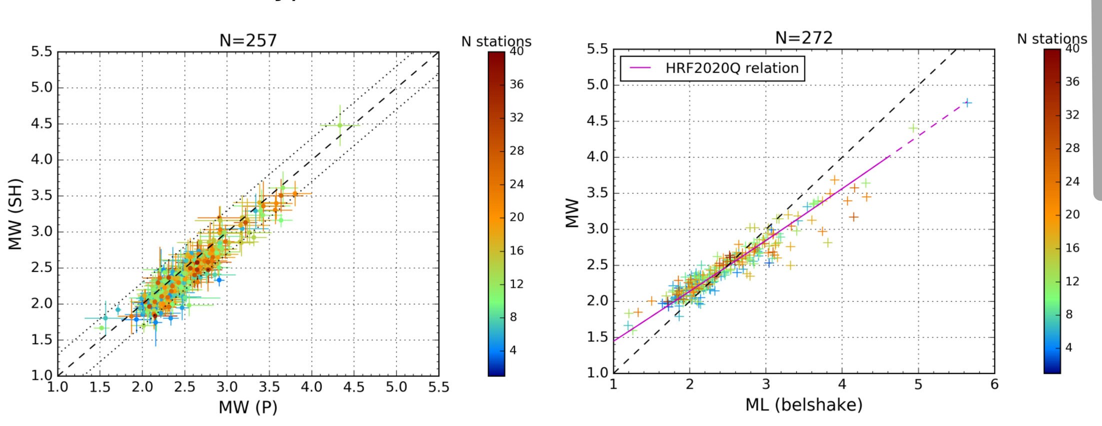


Magnitude assessment

Compilation of the BELSHAKE database also provided the opportunity to compute moment magnitudes, which are lacking for most events in the ROB catalog. This was based on spectral fitting of displacement spectra using the python package sourcespec (https://github.com/SeismicSource/sourcespec). For each event, we calculated up to 4 different solutions:

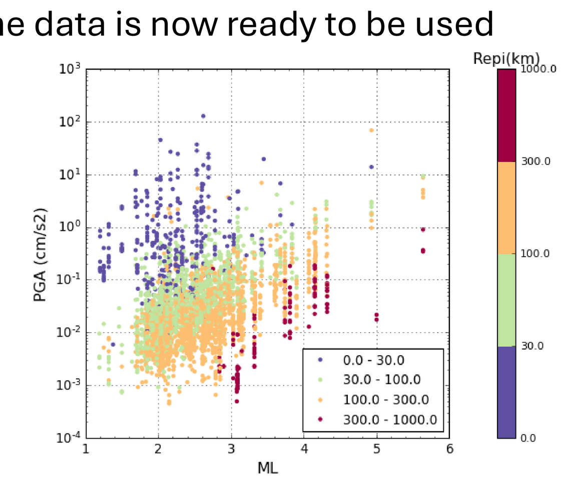
- Wave type: P-wave (Z component) and SH wave (T comp.)
- Radiation pattern: average and based on focal mechanism (if available)

The obtained results are consistent, both internally and with respect to the catalog of neighboring networks (Bensberg station, Germany).



Conclusions

- After two years, we have compiled a ground-motion database for Belgium and neighboring regions
- The waveforms have been visually inspected and quality can be assessed for each record/component/window
- Various checks have been performed to identify records with incorrect instrument response or other problems
- GMPE fitting shows that the residuals are well behaved
- Comparison of common events with the French RESIF database also shows a good agreement
- It is expected that further improvements will be made in the near future, but the data is now ready to be used



Outlook

The BELSHAKE database will allow evaluating ground-motion models or calibrate regionally adaptable models for application in Belgium and will also contribute to existing databases by increasing the coverage of low-seismicity zones and small magnitudes. In addition, the processed records will also be useful for many other applications, e.g., reassessment of local magnitudes, computation of moment magnitudes, study of crustal attenuation, etc.

Data availability

A first flatfile has been released on Zenodo. Access is currently restricted, but can be requested: https://zenodo.org/records/10669582

SCAN ME

References

Traversa, P., Maufroy, E., Hollender, F., Perron, V., Bremaud, V., Shible, H., Drouet, S., Guéguen, P., Langlais, M., Wolyniec, D., Péquegnat, C., Douste-Bacque, I., 2020. RESIF RAP and RLBP Dataset of Earthquake Ground Motion in Mainland France. Seismological Research Letters 91, 2409–2424.