# Combining active and passive noise surveys for site effect analyses of the BE Belgian Seismic Network, serving for relative site condition estimates across Belgium


ROYAL OBSERVATORY OF BELGIUM
SEISMOLOGY GRAVIMETRY

mzeckra@uni-koeln.de
Koen.vannoten@seismology.be

*Martin Zeckra[1], Koen Van Noten[2]*, Thomas Lecocq, Raphael De Plaen* and Giovanni Rapagnani*

* Presenting authors



belspo

AGU23 WIDE. OPEN. SCIENCE.
San Francisco, CA & Online Everywhere
11-15 December 2023

S43J-0443
14 December 2023 - 14:10 - 18:30


## Context

EPOS-BE EUROPEAN PLATE OBSERVING SYSTEM BELGIUM

The Belgian seismic network (FDSN code "BE"), currently consists of 36 seismometers and 16 accelerometers that have been strategically installed throughout the country. Operated by the Royal Observatory of Belgium, these seismometers are located at the surface, in man-made galleries, as well as in shallow and deep boreholes. In the framework of providing our station data to EPOS, i.e. EPOS-BE, we performed a **site characterization** study using SmartSolo Seismic Nodes.

Orfeus

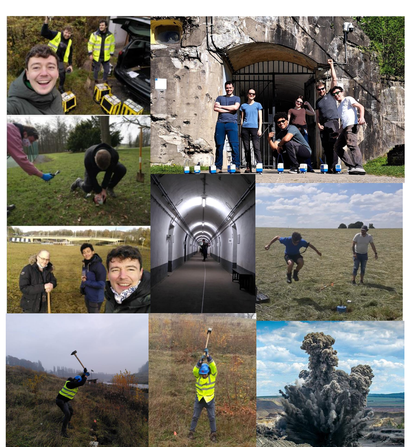
## Instruments

All we can use! But mostly SmartSolo IGU16HR-3C 3 component geophones, Electrical Resistivity Tomography, dGPS & walky talkies ;-).

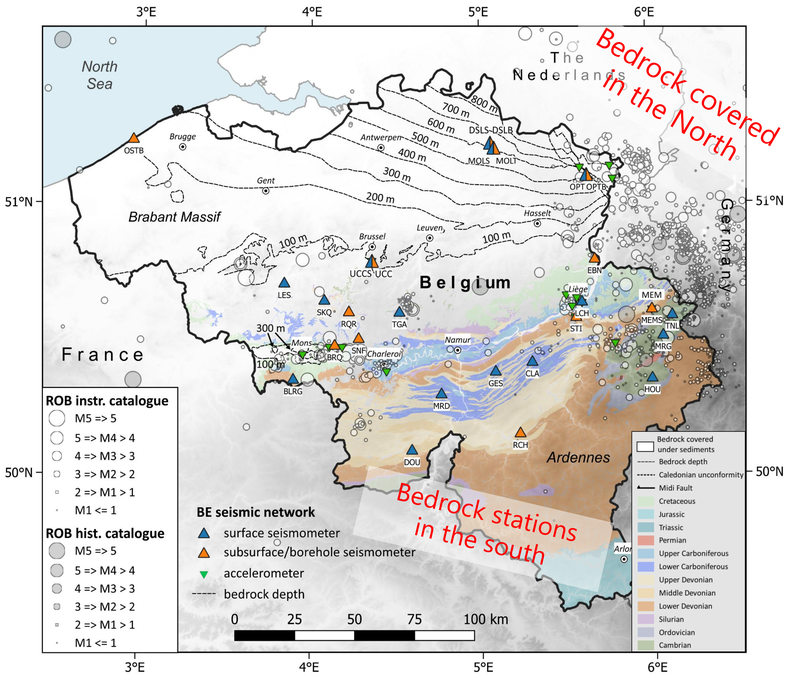

## Methods

Passive ambient noise **arrays** using **FK** and **MSPAC** array techniques involving up to 34 SmartSolo geophonesμ

Sites with limited survey space or absent dispersion curves, active sources in terms of **MASW** and **refraction seismics** from hammer shots or array cross-correlations from stone quarry explosions were added as further constraint or additional input data for the joint inversion.

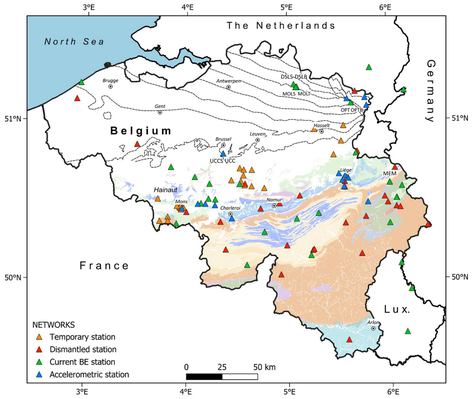


## The Belgian seismic network

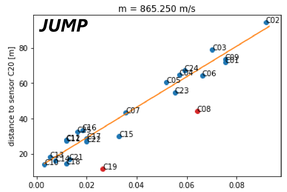


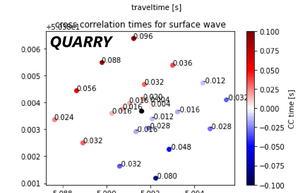

## Geology is key for site characterisation

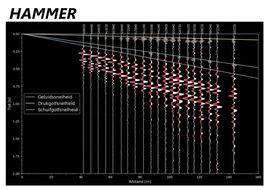
Based on the full site characterisation of 9 sites, subsurface site conditions are defined as proxies and then linked to geological conditions of former and less-used stations. Through this, we present for the first time a site-characteristic database **of 125 seismic stations**, ever installed, across the Belgian territory

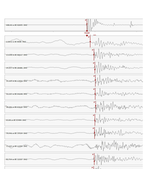


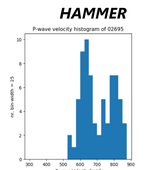

- ❑ Current network (45)
- ❑ Dismantled stations (29)
- ❑ Temporary networks (34)
- ❑ Accelerometric network (16)



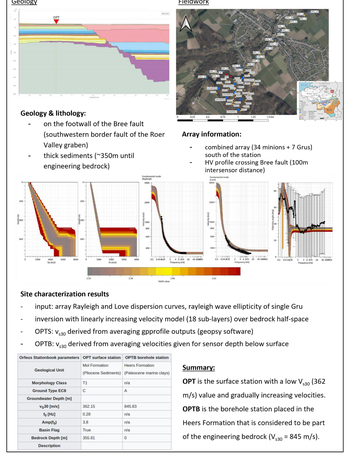






### OPT(B) – Opitter




**Geology & lithology:**
- on the footwall of the Bree fault (southwestern border fault of the Roer Valley graben)
- thick sediments (~350m until engineering bedrock)

**Array information:**
- combined array (34 minions + 7 Grus) south of the station
- HV profile crossing Bree fault (100m intersensor distance)

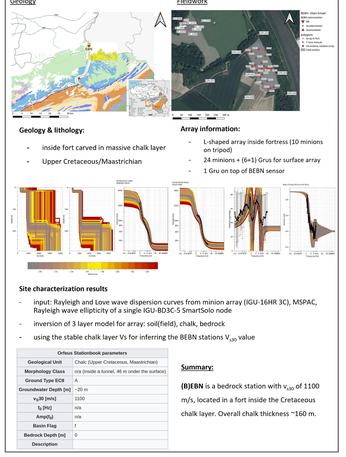


**Site characterization results**
- input: array Rayleigh and Love dispersion curves, rayleigh wave ellipticity of single Gru
- inversion with linearly increasing velocity model (18 sub-layers) over bedrock half-space
- OPTS: $v_{s30}$ derived from averaging ggprofile outputs (geopsy software)
- OPTB: $v_{s30}$ derived from averaging velocities given for sensor depth below surface

| Orfeus Stationbook parameters | OPT surface station | OPTB borehole station |
|---|---|---|
| Geological Unit | Mol Formation (Pliocene Sediments) | Heers Formation (Pleistocene marine clays) |
| Morphology Class | T1 | n/a |
| Ground Type EC8 | C | A |
| Groundwater Depth [m] | | |
| $v_s30$ [m/s] | 362.15 | 845.83 |
| $f_0$ [Hz] | 0.29 | n/a |
| Amp($f_0$) | 3.8 | n/a |
| Basin Flag | True | n/a |
| Bedrock Depth [m] | 355.91 | 0 |
| Description | | |

**Summary:**
**OPT** is the surface station with a low $V_{s30}$ (362 m/s) value and gradually increasing velocities.
**OPTB** is the borehole station placed in the Heers Formation that is considered to be part of the engineering bedrock ($V_{s30}$ = 845 m/s).

### (B)EBN – Eben-Emael




**Geology & lithology:**
- inside fort carved in massive chalk layer
- Upper Cretaceous/Maastrichian

**Array information:**
- L-shaped array inside fortress (10 minions on tripod)
- 24 minions + (6+1) Grus for surface array
- 1 Gru on top of BEBN sensor

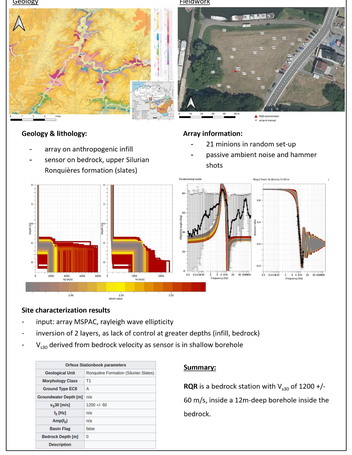


**Site characterization results**
- input: Rayleigh and Love wave dispersion curves from minion array (IGU-16HR 3C), MSPAC, Rayleigh wave ellipticity of a single IGU-BD3C-5 SmartSolo node
- inversion of 3 layer model for array: soil(field), chalk, bedrock
- using the stable chalk layer Vs for inferring the BEBN stations $V_{s30}$ value

| Orfeus Stationbook parameters | |
|---|---|
| Geological Unit | Chalk (Upper Cretaceous, Maastrichian) |
| Morphology Class | n/a (Inside a tunnel, 46 m under the surface) |
| Ground Type EC8 | A |
| Groundwater Depth [m] | ~20 m |
| $v_s30$ [m/s] | 1200 |
| $f_0$ [Hz] | n/a |
| Amp($f_0$) | n/a |
| Basin Flag | f |
| Bedrock Depth [m] | 0 |
| Description | |

**Summary:**
**(B)EBN** is a bedrock station with $v_{s30}$ of 1100 m/s, located in a fort inside the Cretaceous chalk layer. Overall chalk thickness ~160 m.

### RQR – Ronquières




**Geology & lithology:**
- array on anthropogenic infill
- sensor on bedrock, upper Silurian Ronquières formation (slates)

**Array information:**
- 21 minions in random set-up
- passive ambient noise and hammer shots

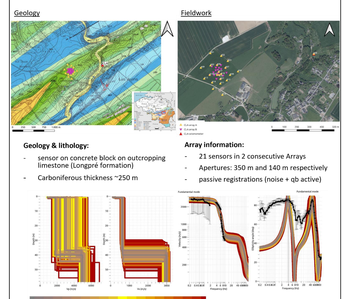


**Site characterization results**
- input: array MSPAC, rayleigh wave ellipticity
- inversion of 2 layers, as lack of control at greater depths (infill, bedrock)
- $V_{s30}$ derived from bedrock velocity as sensor is in shallow borehole

| Orfeus Stationbook parameters | |
|---|---|
| Geological Unit | Ronquière Formation (Silurian Slates) |
| Morphology Class | T1 |
| Ground Type EC8 | A |
| Groundwater Depth [m] | n/a |
| $v_s30$ [m/s] | 1200 +/- 60 |
| $f_0$ [Hz] | n/a |
| Amp($f_0$) | n/a |
| Basin Flag | false |
| Bedrock Depth [m] | 0 |
| Description | |

**Summary:**
**RQR** is a bedrock station with $V_{s30}$ of 1200 +/- 60 m/s, inside a 12m-deep borehole inside the bedrock.

### CLA – Clavier




**Geology & lithology:**
- sensor on concrete block on outcropping limestone (Longpré formation)
- Carboniferous thickness ~250 m

**Array information:**
- 21 sensors in 2 consecutive Arrays
- Apertures: 350 m and 140 m respectively
- passive registrations (noise + qb active)

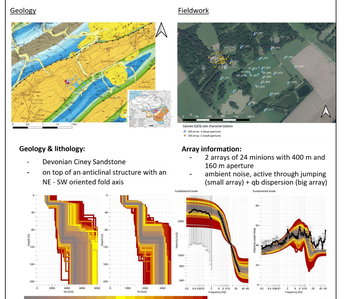


**Site characterization results**
- input: array dispersion curves, quarry blast dispersion curve
- inversion of 3 layer model for array (soil, weathered layer, bedrock)
- using the bedrock layer vs for inferring the CLA stations $V_{s30}$ value

| Orfeus Stationbook parameters | |
|---|---|
| Geological Unit | Limestone (Longpré formation) |
| Morphology Class | T2 |
| Ground Type EC8 | A (hard rock) |
| Groundwater Depth [m] | 25 - 30 m |
| $v_s30$ [m/s] | 2900 m/s |
| $f_0$ [Hz] | n/a |
| Amp($f_0$) | n/a |
| Basin Flag | False |
| Bedrock Depth [m] | 0 |
| Description | |

**Summary:**
**CLA** is a bedrock station with $v_{s30}$ of 2900 m/s, located directly on the outcropping Carboniferous bedrock, on the top of a steep slope.

### GES – Gesves




**Geology & lithology:**
- Devonian Ciney Sandstone
- on top of an anticlinal structure with an NE - SW oriented fold axis

**Array information:**
- 2 arrays of 24 minions with 400 m and 160 m aperture
- ambient noise, active through jumping (small array) + qb dispersion (big array)

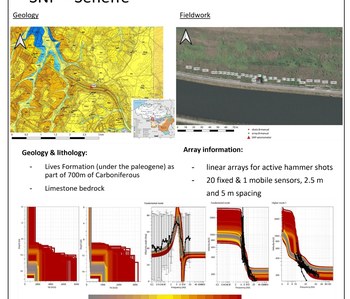


**Site characterization results**
- input: array and quarry blast dispersion curve, MSPAC, rayleigh wave ellipticity
- inversion of 3 layer model for array (soil, weathered layer, bedrock)
- $V_{s30}$ derived from averaging ggprofile outputs (geopsy software)

| Morphology Data | |
|---|---|
| Geological Unit | Sandstone (Ciney formation) |
| Morphology Class | T1 |
| Ground Type EC8 | A (hard rock) |
| Groundwater Depth [m] | ~10 |
| $v_s30$ [m/s] | 982 +/- 32 |
| $f_0$ [Hz] | ~50 |
| Amp($f_0$) | 10 |
| Basin Flag | False |
| Bedrock Depth [m] | 0.3 |
| Description | n/a |

**Summary:**
**GES** is a bedrock station with $v_{s30}$ of 982 +/- 32m/s, located in the basement of a building, maybe leading to a higher $V_{s30}$ value.

### SNF – Seneffe




**Geology & lithology:**
- Lives Formation (under the paleogene) as part of 700m of Carboniferous
- Limestone bedrock

**Array information:**
- linear arrays for active hammer shots
- 20 fixed & 1 mobile sensors, 2.5 m and 5 m spacing

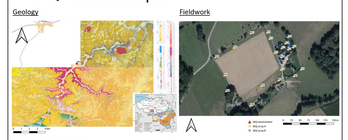


**Site characterization results**
- input: active refraction, MASW and rayleigh wave ellipticity
- inversion of 2 layers, as lack of control at greater depths (soft soil over bedrock)
- $V_{s30}$ derived from bedrock velocity as sensor is in shallow borehole

| Orfeus Stationbook parameters | |
|---|---|
| Geological Unit | Sand (UCC) - Lede Fm) and siste/quartzite (UCCB: Tubize Fm) |
| Morphology Class | T1 |
| Ground Type EC8 | B |
| Groundwater Depth [m] | unknown |
| $v_s30$ [m/s] | 280 (UCC) - 1800 (UCCB) |
| $f_0$ [Hz] | 0.9 |
| Amp($f_0$) | 14 |
| Basin Flag | True |
| Bedrock Depth [m] | 115 |
| Description | |

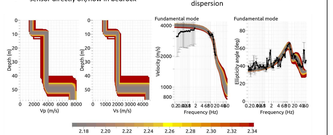
**Summary:**
**SNF** is a bedrock station with $v_{s30}$ of ~1200 m/s, inside a shallow borehole reaching the bedrock.

### SKQ – Steenkerque




**Geology & lithology:**
- Silurian Steenkerque formation (cleaved mud- and siltstone)
- sensor directly on/now in bedrock

**Array information:**
- 2 arrays of 21 minions with 250 m and 150 m aperture
- ambient noise, active through qb dispersion

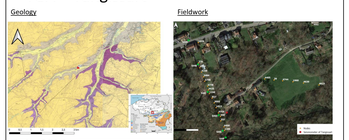


**Site characterization results**
- input: array and quarry blast dispersion curve, rayleigh wave ellipticity
- inversion of 3 layer model for array (soil, weathered layer, bedrock)
- $V_{s30}$ derived from averaging ggprofile outputs (geopsy software), misfit < 2.5

| Orfeus Stationbook parameters | |
|---|---|
| Geological Unit | Mudi- to Siltstone (Steenkerque formation) |
| Morphology Class | T1 |
| Ground Type EC8 | A (hard rock) |
| Groundwater Depth [m] | < 10 m |
| $v_s30$ [m/s] | 1492 +/- 28 m/s |
| $f_0$ [Hz] | n/a |
| Amp($f_0$) | n/a |
| Basin Flag | False |
| Bedrock Depth [m] | 0 (borehole sensor in (altered) bedrock) |
| Description | |

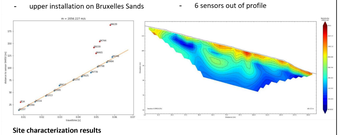
**Summary:**
**SKQ** is a bedrock station with $v_{s30}$ of 1492 +/- 28 m/s, located on top of (station upgrade to posthole in) bedrock, likely leading to a higher $V_{s30}$ value for the sensor.

### TGA – Tangissart




**Geology & lithology:**
- station (+ lower half of line installation) in Mousty formation (Cambrian bedrock)
- upper installation on Bruxelles Sands

**Array information:**
- line installation for active hammer shots
- parallel ERT profile
- 6 sensors out of profile



**Site characterization results**
- ERT and HVSR analysis for understanding subsurface geometries
- refracted p-wave onset picking for $v_p$ estimation
- $V_s$ estimation from literature $v_p/v_s$ values (V3)

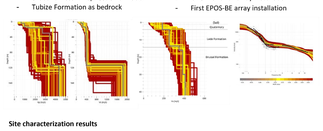
| Orfeus Stationbook parameters | |
|---|---|
| Geological Unit | Shale (Mousty Formation) |
| Morphology Class | T2 |
| Ground Type EC8 | A (hard rock) |
| Groundwater Depth [m] | 7 m |
| $v_s30$ | 1188 +/- 170 m/s |
| $f_0$ [Hz] | n/a |
| Amp($f_0$) | n/a |
| Basin Flag | False |
| Bedrock Depth | < 0.1 m |
| Description | |

**Summary:**
**TGA** is a bedrock station with $v_{s30}$ of 1188 +/- 170 m/s, located on top of bedrock; the local cambrian Mousty formation, as part of the Cambro-Silurian Brabant Massif.

### UCC(A/B) – Uccle


**Geology & lithology:**
- 114 m soft sediment geology above Brabant Massif. Top: Lede Formation
- Tubize Formation as bedrock

**Array information:**
- Regular cross installation
- One month or array installation
- First EPOS-BE array installation



**Site characterization results**
- input: fk dispersion curve, rayleigh wave ellipticity
- inversion of 4 layers with prior borehole knowledge (soft soil over bedrock)
- $V_{s30}$ derived from soft sediment/bedrock velocity profile, Vp soft sediment profile less resolved

| Orfeus Stationbook parameters | |
|---|---|
| Geological Unit | Limestone (Lees formation) |
| Morphology Class | T1 |
| Ground Type EC8 | A (hard rock) |
| Groundwater Depth [m] | 13 m from surface, < 2 m from seismometer |
| $v_s30$ [m/s] | 1200 |
| $f_0$ [Hz] | n/a |
| Amp($f_0$) | n/a |
| Basin Flag | False |
| Bedrock Depth [m] | 0 |
| Description | |

**Summary:**
**UCC** is a soft sediment surface station with a low $V_{s30}$ (280 m/s). Vs of the Brussels sands predominate the Vs in the first 115 m
**UCCB** is the borehole station placed in the Tubize Formation of the Brabant Massif with a fast bedrock velocity ($V_{s30}$ = 1800 m/s).