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Identification and characterization of vibration sources for the Einstein Telescope in the Euregio Meuse-Rhine

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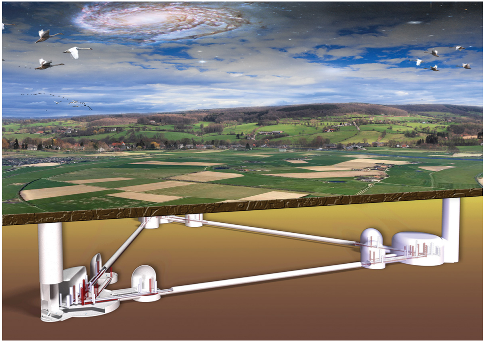
Introduction

- Identification of vibration sources in the Euregio Meuse-Rhine.
- Identification of dynamic soil characteristics and site response analysis.
- Dynamic soil-structure interaction (SSI) analysis of tunnels, caverns, and shafts.



- Longer term: Structural Health Monitoring (SHM) of deep underground infrastructure with various sensors, construction of digital twins.

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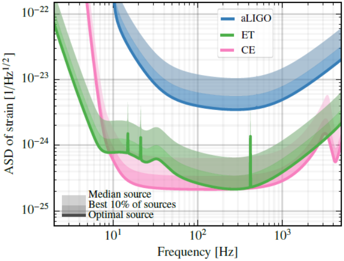
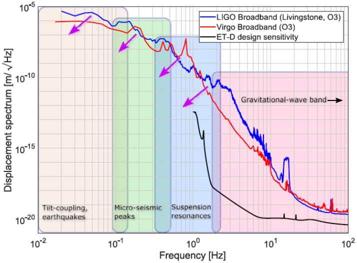
Targets

- Design sensitivity for ET compared to (a) Cosmic Explorer (CE) and Advanced LIGO (aLIGO) and (b) LIGO and Virgo performance [ET Design Report 2020].

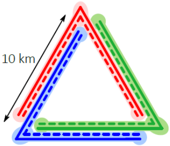


(a)



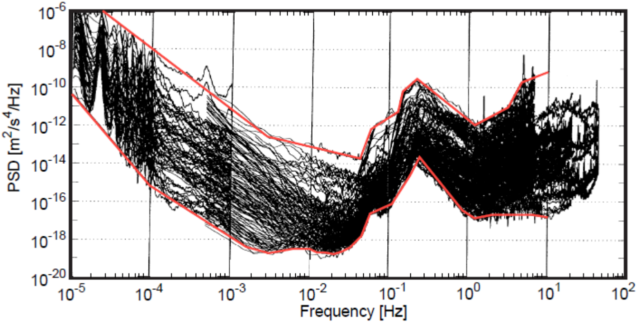
(b)

- Targets for ET (compared to existing Gravitational Wave detectors):
  - Improve accuracy by one order of magnitude.
  - Lower operating frequency to 3 Hz.
- Design choices to reach these targets:
  - Triangular shape with 3 nested detectors.
  - Increased tunnel length of 10 km.
  - Underground construction at a depth of 250-300 m.



Seismic noise

- Seismic noise spectra used in Peterson's background noise study (black) and low- and high-noise envelopes (red) [Peterson (1993)].



- 2.5×10^{-5} Hz: tidal motion (gravitional attraction by the Moon and the Sun);
- $0.1 - 1$ Hz: oceanic microseisms;
- $1 - 10$ Hz: anthropogenic vibration sources.

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Methodology

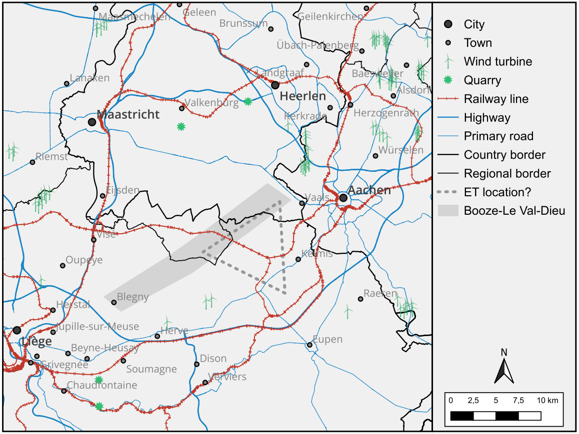
- Identification and characterization of vibration sources:
  - External vibration sources:
    - road and railway traffic
    - wind turbines
    - mining
    - construction and industrial activities
    - earthquakes



  - Internal vibration sources:
    - equipment (HVAC, pumps)
    - human induced vibration
- Supplement borehole measurements with numerical predictions, requiring knowledge about:
  - soil layering and properties;
  - vibration sources.
- Recommendations for anthropogenic vibration sources (perimeters).

Vibration sources

- External vibration sources in the Euregio Meuse-Rhine.



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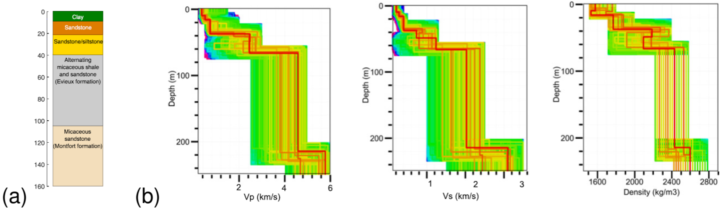
Soil layering and properties

- Experimental campaign in Terziet (The Netherlands) [Bader et al. (2022); Koley et al. (2022)]:
  - Borehole samples: lithology.
  - Resistivity, sonic and gamma-ray logging: lithology, density ρ, shear wave velocity C_{s} and dilatational wave velocity C_{p}.
  - Beamforming (two seismic arrays): shear wave velocity C_{s}.
  - Refraction tomography: dilatational wave velocity C_{p}.
- (a) Lithology and (b) P-wave, S-wave and density models [Koley et al. (2022)].



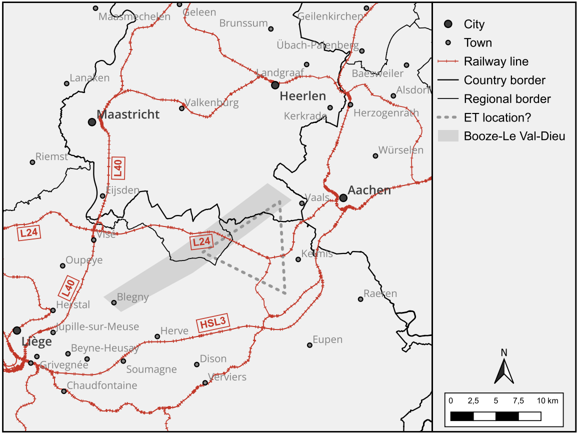
- Dynamic soil characteristics [Bader et al. (2022)].

Layer	Description	h [m]	C_{s} [m/s]	C_{p} [m/s]	ρ [kg/m^3]	β_{s} [-]	β_{p} [-]
1	Clay	5.7	165	385	1950	0.020	0.020
2	Sandstone/siltstone	10.2	270	445	2250	0.010	0.010
3	Sandstone/siltstone	18.9	335	685	2500	0.010	0.010
4	Quartzite/shales	58.2	1240	2810	2800	0.005	0.005
5	Silcified shales	∞	2430	4050	2800	0.005	0.005

Railway induced vibration

Railway lines

Line	Traffic type	Speed limit
L24 Tongeren-Aachen	Freight	90 km/h
L40 Liège-Maastricht	Passenger	120 km/h
HSL3 Liège-Kelmis	Passenger	260 km/h



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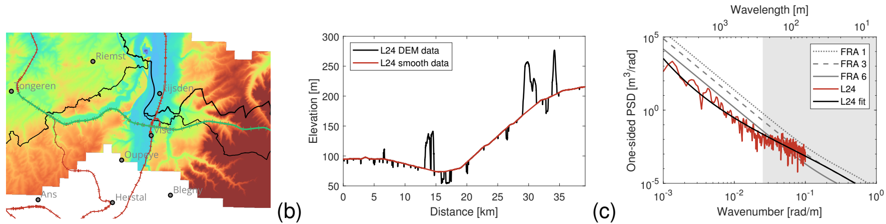
Railway induced vibration

Track unevenness

- Ground borne vibration is due to track (and wheel) unevenness:
  - track alignment;
  - rail corrugation;
  - rail joints.
- Measurements:
  - trolleys;
  - track recording cars;
  - digital elevation model (DEM).
- (a) Line L24 on DEM, (b) elevation profile and (c) one-sided PSD indicating the relevant wavenumber range for excitation by freight trains between 0.1 and 10 Hz.

(a)



(b) (c)

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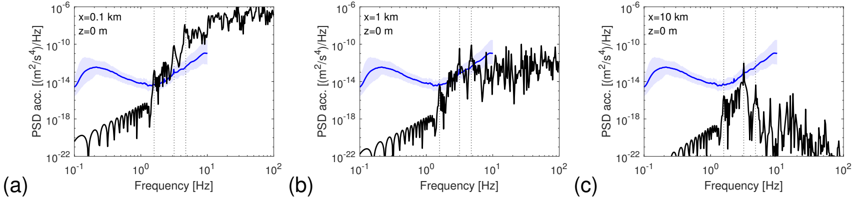
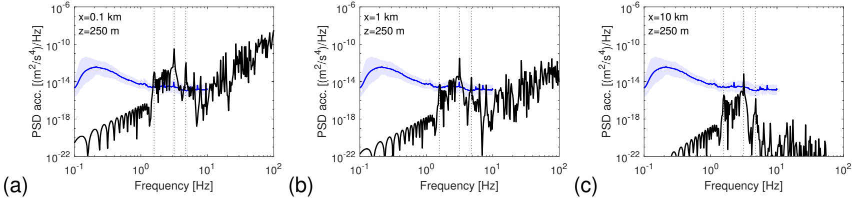
Railway induced vibration

Vibration levels

- Predicted one-sided PSD of the acceleration (black) due to a freight train running at 90 km/h; and measured seismic noise (blue) from surface and borehole seismometers in Terziet [Koley et al. (2022)].
  - Receivers at free surface: (a) 0.1 km, (b) 1 km and (c) 10 km.



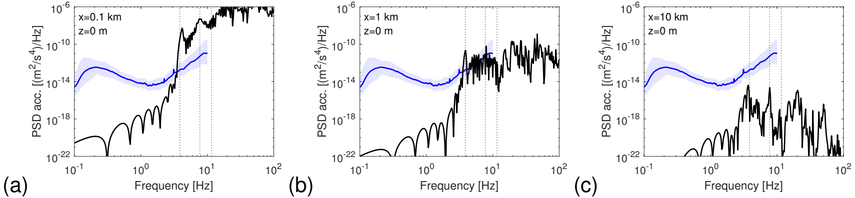
  - Receivers in borehole: (a) 0.1 km, (b) 1 km and (c) 10 km.



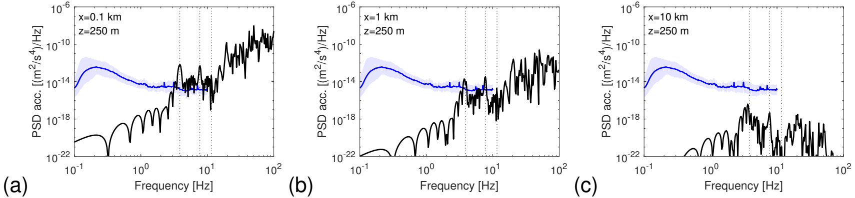
Railway induced vibration

Vibration levels

- Predicted one-sided PSD of the acceleration (black) due to a Thalys train running at 260 km/h; and measured seismic noise (blue) from surface and borehole seismometers in Terziet [Koley et al. (2022)].
  - Receivers at free surface: (a) 0.1 km, (b) 1 km and (c) 10 km.



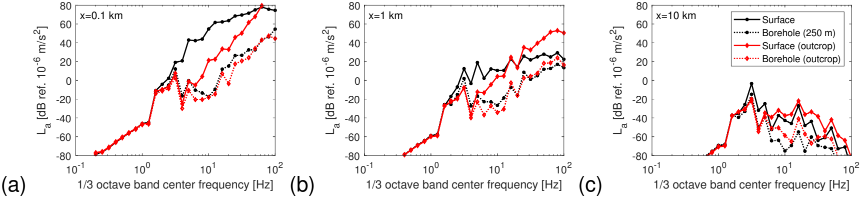
  - Receivers in borehole: (a) 0.1 km, (b) 1 km and (c) 10 km.



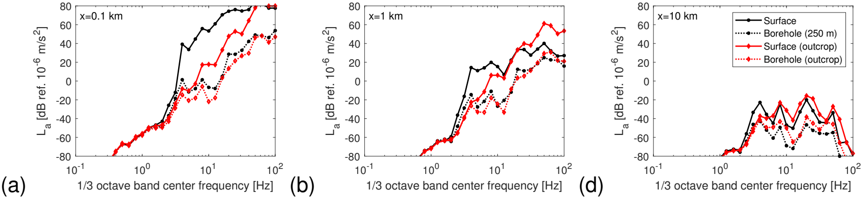
Railway induced vibration

Vibration levels

- Predicted acceleration level [dB ref. 10^{-6} m/s^2] at the free surface (solid) and at 250 m depth (dotted) at (a) 0.1 km, (b) 1 km, and (c) 10 km for the Terziet soil (black) and for outcrop (red).
  - Freight train running at 90 km/h.



  - Thalys train running at 260 km/h.



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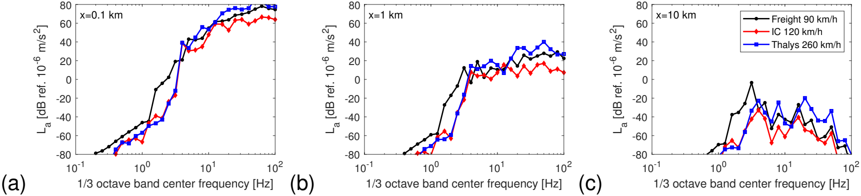
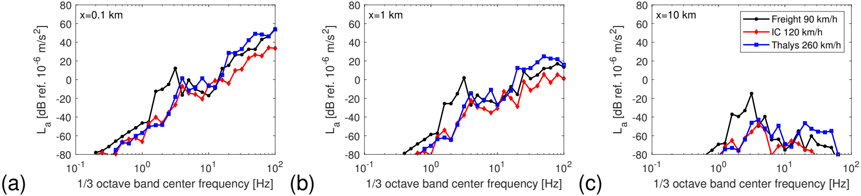
Railway induced vibration

Vibration levels

- Predicted acceleration level [dB ref. 10^{-6} m/s^2] at the free surface at (a) 0.1 km, (b) 1 km, and (c) 10 km during the passage of a freight train at 90 km/h (black), an IC-train at 120 km/h (red), and a Thalys train at 260 km/h (blue).
  - At the free surface.



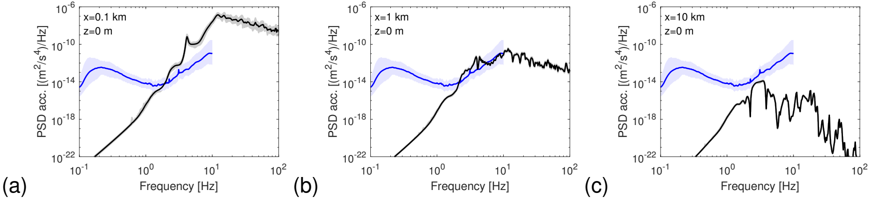
  - At a depth of 250 m.



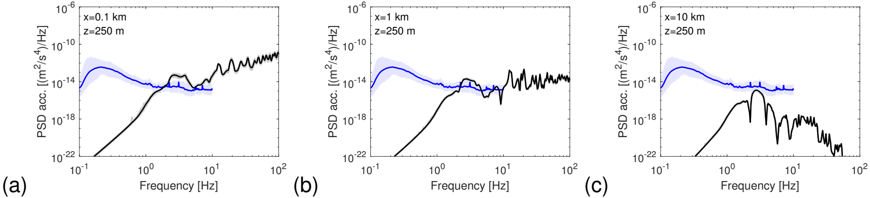
Road induced vibration

Vibration levels

- Predicted one-sided PSD of the acceleration (black) due to road traffic at 120 km/h on an uneven road (ISO A); and measured seismic noise (blue) from surface and borehole seismometers in Terziet [Koley et al. (2022)].
    - Receivers at free surface: (a) 0.1 km, (b) 1 km and (c) 10 km.



    - Receivers in borehole: (a) 0.1 km, (b) 1 km and (c) 10 km.



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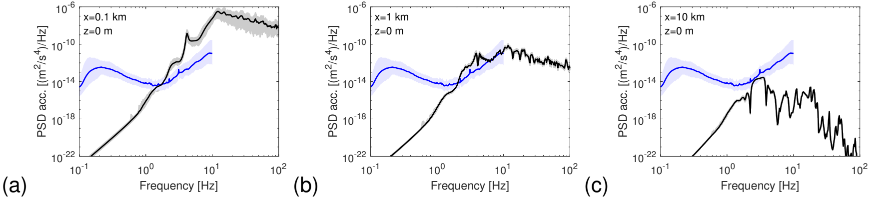
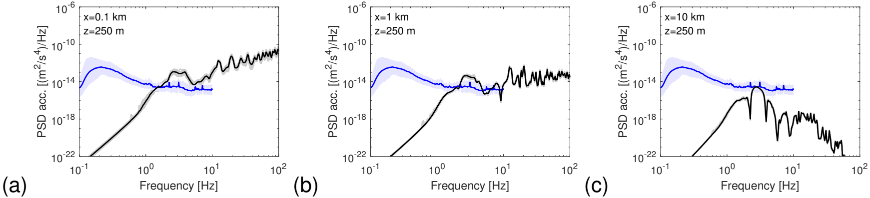
Road induced vibration

Vibration levels

- Predicted one-sided PSD of the acceleration (black) due to road traffic at 50 km/h on an uneven road (ISO C); and measured seismic noise (blue) from surface and borehole seismometers in Terziet [Koley et al. (2022)].
  - Receivers at free surface: (a) 0.1 km, (b) 1 km and (c) 10 km.



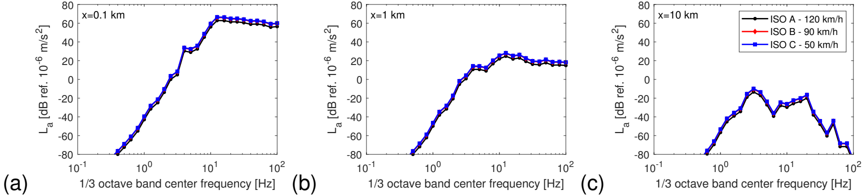
  - Receivers in borehole: (a) 0.1 km, (b) 1 km and (c) 10 km.



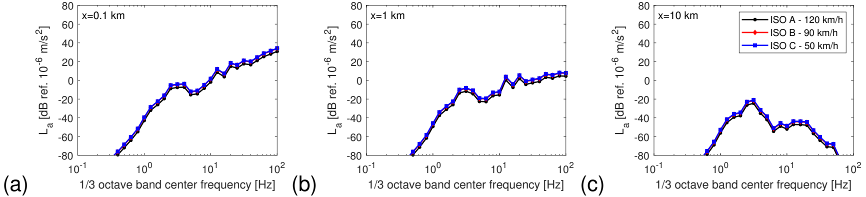
Road induced vibration

Vibration levels

- Predicted acceleration level [dB ref. 10^{-6} m/s^2] at the free surface at (a) 0.1 km, (b) 1 km, and (c) 10 km for road traffic at 120 km/h (ISO A) (black), 90 km/h (ISO B) (red) and 50 km/h (ISO C) (blue).
  - At the free surface.

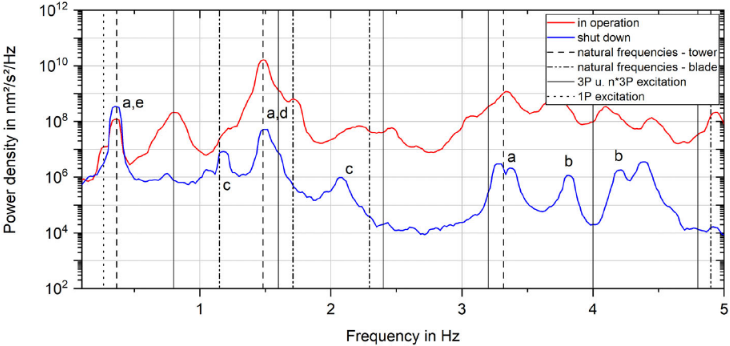


  - At a depth of 250 m.



Wind turbines

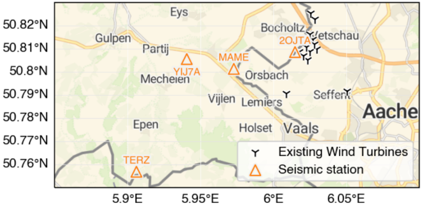
- Power spectral density of the ground velocity near the foundation of a wind turbine (figure taken from [Nagel et al. (2021)]).



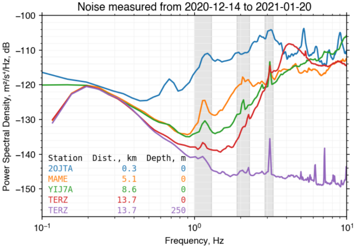
  - peaks related to rotor speed (1P and 3P excitation);
  - eigenfrequencies of tower and blades.

Wind turbines

- (a) Location of surface and borehole seismometers in South-Limburg and the Aachen wind park and (b) PSD of the measured acceleration [Shani-Kadmiel (2022)].



(a)



(b)

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Outlook

- Link vibration fields to Newtonian noise.
- Need for reliable soil data: layering and properties (including material damping).
- Need for additional borehole measurements.
- Various sources of vibration:
  - wind turbines
  - railway traffic
  - road traffic
  - mining
  - industry
  - earthquakes
- Develop vibration maps with perimeters depending on source type.