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Section: Seismology

Report on the installation of two accelerometers at the Belgian Nuclear Research Centre (SCK-CEN), Mol

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2004-10-19

1. Introduction

It has been evidenced that large earthquakes can strike North-Western Europe. Indeed, paleoseismic investigations tell us that the normal faults bordering the Roer Graben are active and able to produce large earthquakes ($M_S > 6$) with surface ruptures. This has also been evidenced by historical investigations: for example, the Verviers earthquake in 1692 was heavily damaging in the epicentral area and weakly damaging up to Southern England. Its estimated magnitude is $6.0<M_S<6.5$. Though much smaller, two recent earthquakes near Liège (Belgium, 1983, M_S=4.6) and Roermond (the Netherlands, 1992, M_S=5.4) caused losses estimated to exceed 100 million € in the epicentral areas.
On Figure 1, one can see that the seismic hazard level for a return period of 475 years in Belgium is similar to the levels in Southern France or some North-African areas.

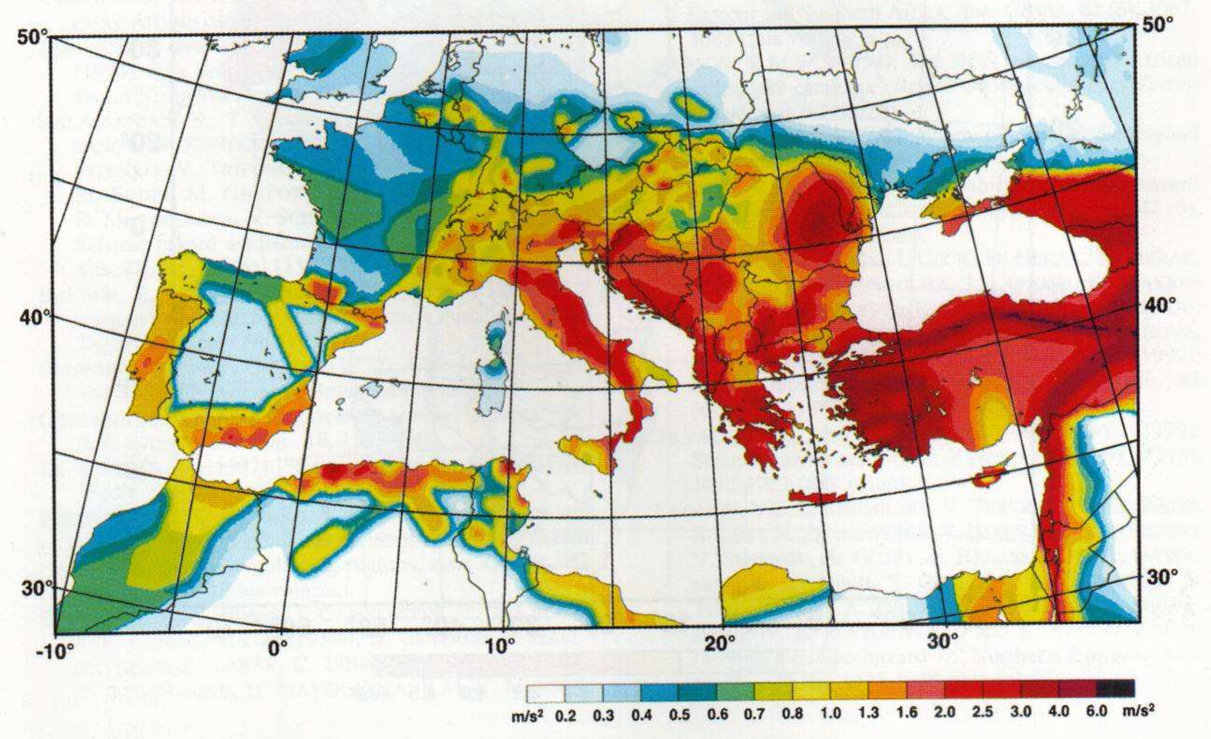

Figure 1: European-Mediterranean seismic hazard map in terms of peak ground acceleration at a 10% probability of exceedance in 50 years (or a return period of 475 years) for stiff soil condition

2. The seismometer and accelerometer networks

To be able to locate local earthquakes and to evaluate their source parameters with a good precision, it is necessary to record them with a relatively dense seismic network. The Belgian seismic network implanted progressively since 1985 is composed by ~ 25 stations (Figure 2). The stations are equipped with acquisition systems developed at the ROB and 14 of them are connected using ISDN to our central station in Uccle.

As traditional seismic stations saturate when the strong ground motion is higher than 0.005 g[1], seismologists generally loose valuable information for the scientific study of the earthquake and for the practical applications to the engineers, architects, insurance companies etc. Therefore a network of 15 strong ground motion accelerographs has been installed since 1999 (Figure 2); all but one are linked to the ROB by analog telephone lines.
The accelerometric network allows us to measure ground motion in the epicentral zone of earthquakes with $M_S > 3.5$, such as those of Liège, 1983 and Roermond, 1992.
In August 2004 two additional accelerometers were installed in the site of the SCK/CEN nuclear research centre near Mol. This work is done on request of the NIRAS/ONDRAF and in collaboration with the SCK/CEN.
The SCK/CEN accelerographs complete the Belgian accelerometric network. Of course, this will allow the seismologists to better study source processes, but this will also provide the engineers valuable information on the accelerations levels affecting engineered structures. In particular, the tunnel/surface configuration will be helpful to study the site response effects affecting the surface buildings and the seismic response of the tunnel.

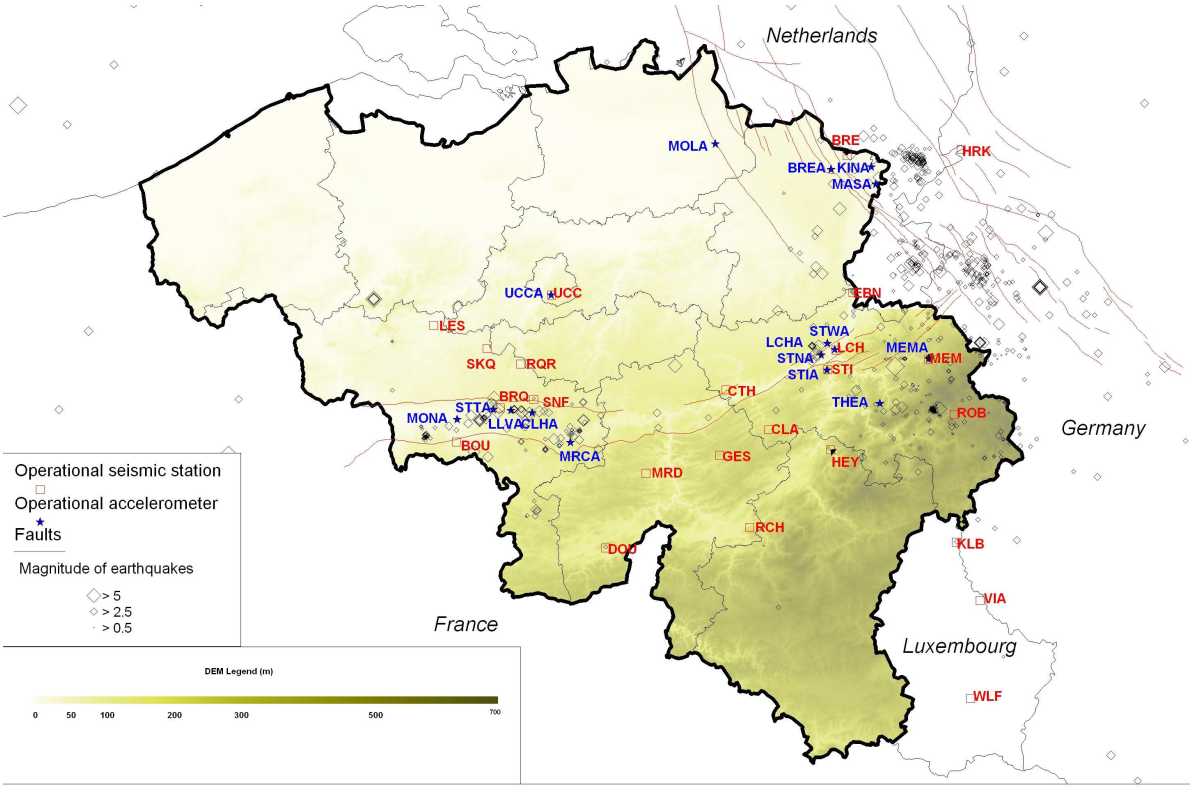

Figure 2. The Belgian seismometric and accelerometric networks (October 2004).

[1] For example, during the Ms=4.6 Alsdorf Earthquake (2002-07-22), the Membach (Baelen), Eben Emael and Sart Tilman seismometers were saturated. The maximum acceleration recorded by the accelerometric network was 1.1 % *g* in Alleur (at that time the Membach and Theux accelerometers were not yet installed).

3. The accelerographs

All the accelerographs but one are the ETNA from the Kinematics company (Pasadena, USA). The ETNA contains a triaxial EpiSensor force balance accelerometer, a 24 bits ADC, a GPS receiver to provide the accurate timing (and incidentally, the position), a battery, a PCMCIA memory card and a modem card. The battery keeps the accelerographs functioning during 24 h at least.
At the Mol station, as a second accelerometer had to be placed, a 6-channel K2 system was chosen. K2 is very similar to the ETNA, the main differences are 1) ability to record up to 12 channels and 2) the dynamic range is 114 dB (108 dB for ETNA).
As for the other Belgian accelerometric stations, the sampling rate is 250 Hz and the full scale range is ± 1 *g*. This can be modified easily to 0.25, 0.5, 2 or 4 *g* but 1 *g* is a maximum that can be expected.
The complete specifications of the Etna and K2 accelerographs, and the EpiSensor accelerometer, are in Annexes A, B & C.

4. Installation

The K2 accelerograph is located at the surface, in the shelter housing the old lift machinery (Figure 3). The other accelerometer EpiSensor is installed in the oldest part of the 224 m deep tunnel (Figure 4). A 305 m cable was drawn via the old lift shaft to connect the EpiSensor to the K2
As in the other accelerometric stations, the timing is provided using a GPS receiver. The antenna is installed on the roof of the shelter (Figure 5) and the signal is very good.

- Installation : August 17-18, 2004
- SCK-CEN station identity: “MOLA”
- MOLA accelerograph phone number is : 014 332 164
- Coordinates : 51.214413° N, 5.086079° E (from GPS connected to the K2)
- Elevation: Surface: 25 m (from NGI map)
  Tunnel: -224 m (from the surface), so EpiSensor @ -223 m
- Tunnel excavated in clay
- Surface: sand (thickness: 188 m)

Figure 3. Installing the K2 accelerograph in the shelter housing the old lift machinery.

Figure 4. The GPS antenna and the old lift.

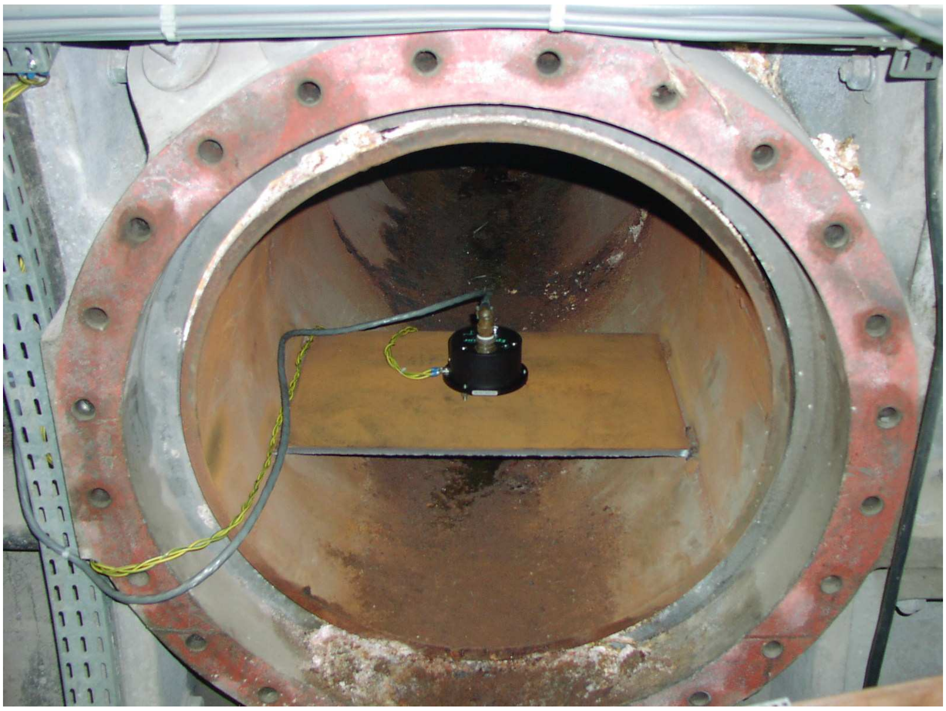

Figure 5. Triaxial EpiSensor accelerometer in the tunnel, connected to the K2 using a 305 m long cable.

5. Operating the MOLA station

5.2 Routine controls

The seismometer network records earthquakes everyday, such that it is continuously controlled. On the other hand, the accelerometric network, much less sensitive, records very few events. So, to ensure the network is operating optimally, remote controls are performed every week.

5.2.2 MOLA calls the Observatory

This test is performed to check the ability of the accelerograph to call the Observatory. Therefore, like the other accelerometric stations, MOLA calls the Observatory every Saturday morning. An automatic functional test is performed at 06h30 (UT); this consists in applying a dual polarity pulse on the EpiSensor (Figure 6). The then created file is automatically downloaded to the Observatory and controlled every Monday.

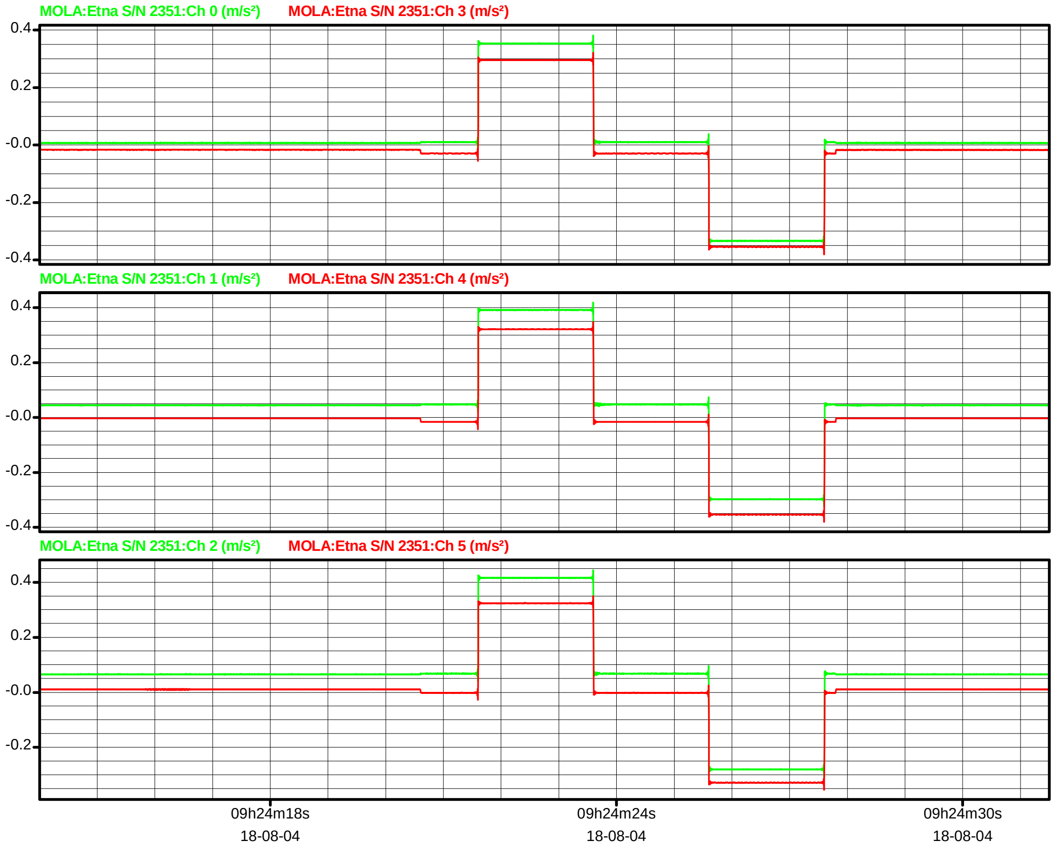

Figure 6. MOLA data when operating a functional test. A dual polarity pulse is applied on the EpiSensor. [Green] Time series from the surface accelerometer, [red] from the tunnel one (same scale). From top to bottom: X, Y, V components.

5.2.3 The Observatory calls MOLA

In order to perform a complete test of the accelerographs, the Observatory calls all accelerometric stations every Thursday. To the request of NIRAS/ONDRAF, MOLA is also called on Monday. The following tests are performed:

1. *Functional test and sensor response test*: This is similar to the functional test described in 5.2.2 and confirms that the system can trigger and that the sensors are operational;
2. *Checking sensor offsets*;
3. *Checking system status*: to control the GPS (clock), the memory, the battery voltage, the charger voltage, the internal temperature and the number of events.

5.3 Maintenance

If the tests are satisfactory, a maintenance visit is necessary every 2-3 years. The battery and the desiccant are replaced and if necessary, the sensors are centred.

5.4 Settings

- Pre-event time: 6 s (The primary compressional P waves have smaller amplitude than the secondary shear S waves. If the accelerograph is triggered by the S-waves, this allows recording the P-waves for any earthquake closer to 50 km).
- Post-event time: 15 s
- Sampling rate: 250 Hz
- The channels numbers are:
  1=X surface, 2=Y surface, 3=Z surface, 4=X tunnel, 5=Y tunnel, 6=Z tunnel.
  Components:
  - X= E/W
  - Y=N/S
  - Z= Vertical
- Sensitivity (all channels): 5 m*g*
- Votes = 1-1-1-1-1-1
- Weight = 1: triggering needs one channel only.

With such settings, 14 events were observed from 2004-09-11 to 2004-10-11, due to the lift movements (Figure 7).
In order to avoid most of these parasitic triggering, we reconsidered the triggering parameters on 2004-10-15:

- Sensitivity (channels 1-3): 5 m*g*
- Sensitivity (channels 4-6): 0.5 m*g* (as for most of the other accelerometers)
- Votes = 1-1-1-2-2-2
- Weight = 4. This means that if all the upper channels are triggered, at least one in the tunnel is also necessary. On the other hand, only two channels in the tunnel can trigger the system. If necessary, these parameters could be slightly modified in the future.

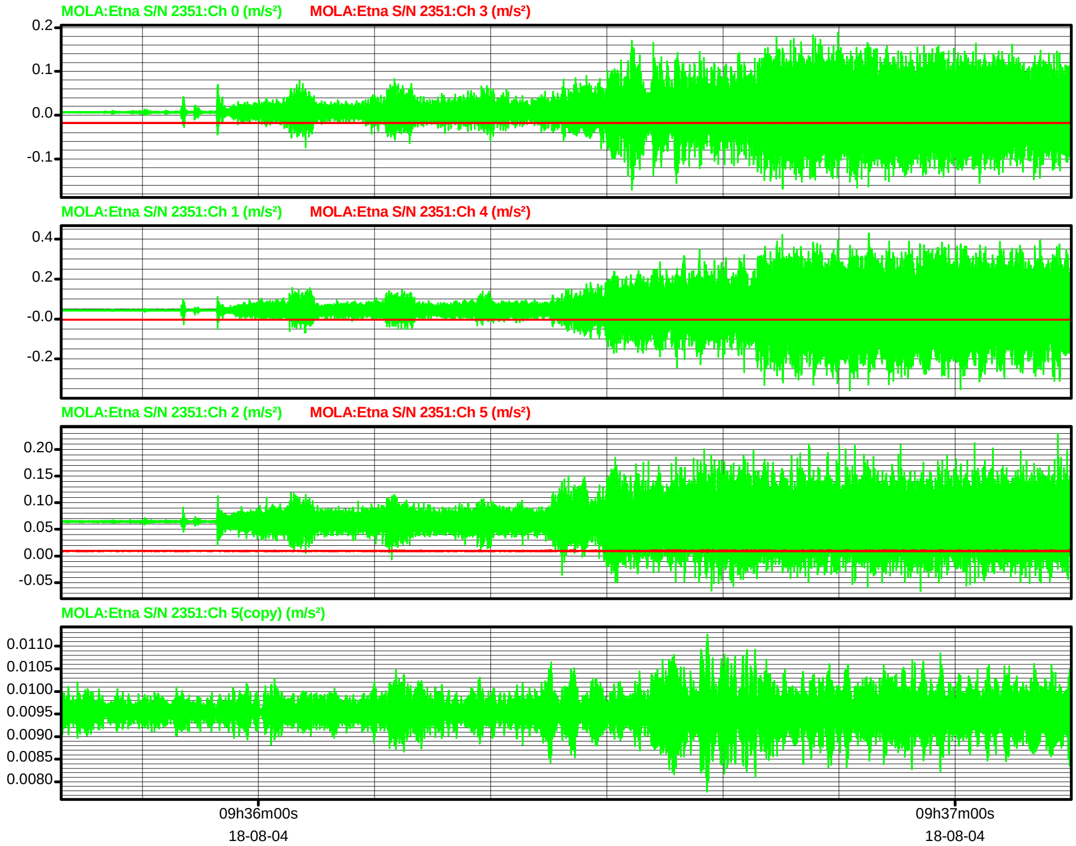

Figure 7. MOLA recording when lift starting. In green time series from the surface accelerometer, in red from the tunnel one (same scale). From top to bottom: X, Y, V components and the same V component in the tunnel only (enlarged scale: a remaining effect is still present). The lift induces accelerations up to 0.04 g (0.4 m/s²).

5.5 Noise level

Figure 8 shows a time series from the vertical component during a quiet period. An amplitude gain of 20 dB can be observed between the surface and the tunnel. A time series recorded at the quiet Membach station is also shown for comparison. The horizontal components provide similar results.
The power spectra of these times series are given on Figures 9 & 10 for the Y (N/S) and Z (V) components. The V component in the tunnel is affected by a strong noise around 80 Hz. This noise could be due to the free oscillation of the iron plate on which the EpiSensor is installed (but this seems quite low frequency) or of the pipe in which the iron plate is soldered. However, this noise can be removed easily by applying a low-pass filter. An example of filtered V time series is given in green on Figure 8: the level becomes quite similar to the Membach or to the MOLA-tunnel horizontal ones after applying a 2 poles Butterworth 75 Hz low-pass filter. This is not problematic as 1) the amplitude remains weak and 2) most of the valuable signal for engineering seismology is below 30 Hz.
Other peaks appear at 47.5 Hz in MEMA, due to a neighbouring compressor and at 50 Hz in MOLA-surface and tunnel, well known effect due to the power supply network.

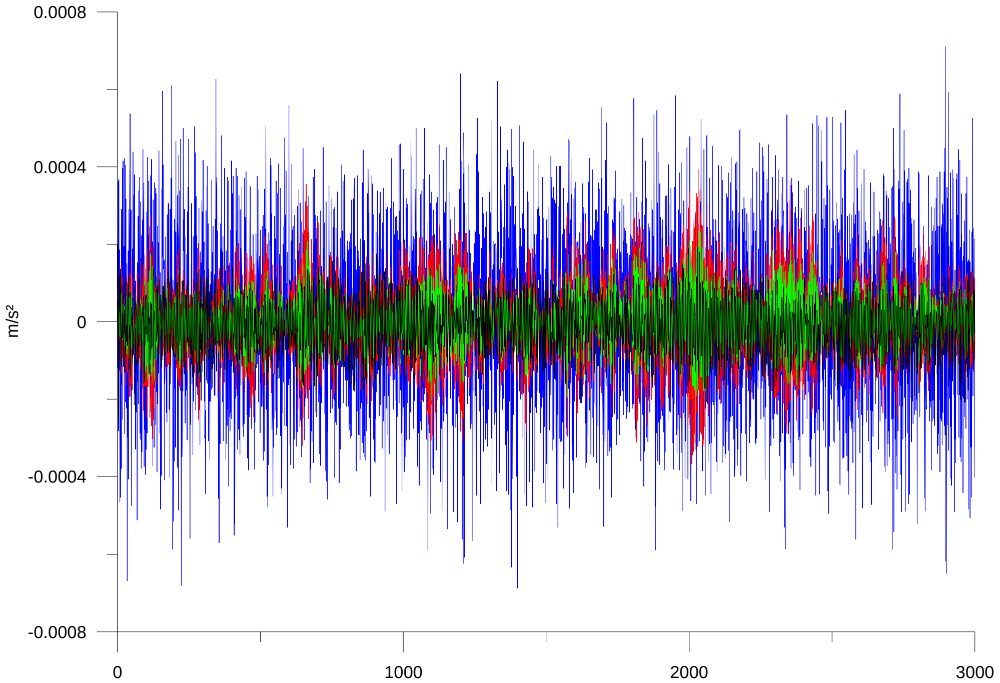

Figure 8. Noise time series on the Z component at MOLA and MEMA stations. [Blue] MOLA-surface, [Red] MOLA-tunnel, [Green] MOLA-tunnel + Butterworth low-pass filter @ 75 Hz, [Black] MEMA.

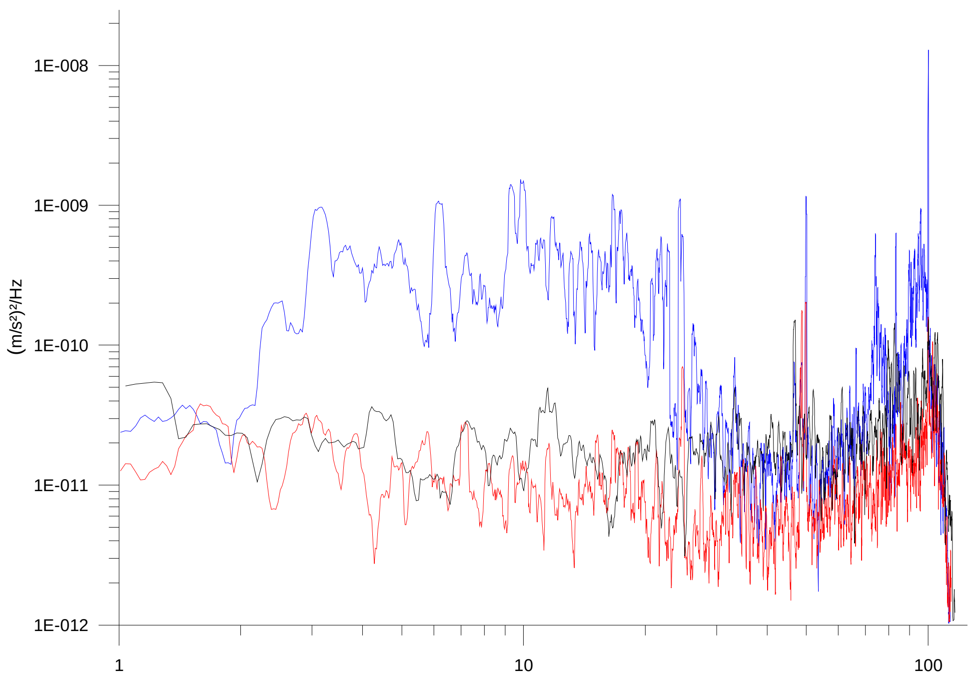

Figure 9. Background noise power spectrum of the Y component: [Blue] MOLA-surface [Red] MOLA-tunnel [Black] MEMA.

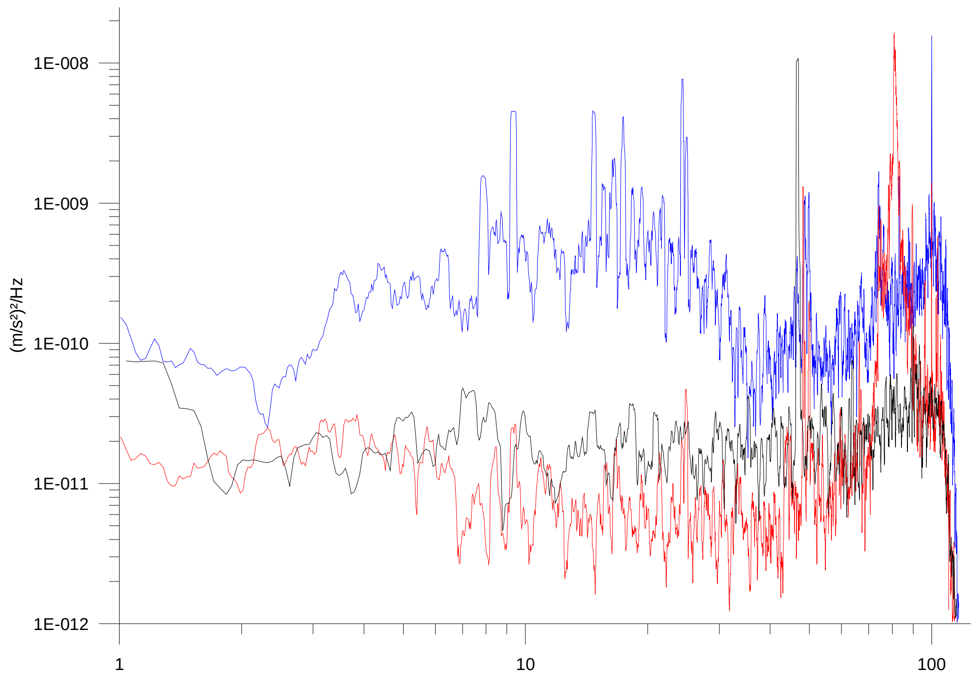

Figure 10. Background noise power spectrum of the Z vertical component: [Blue] MOLA-surface [Red] MOLA-tunnel [Black] MEMA.

5.6 In case of Earthquake

The files from MOLA are automatically downloaded to the Observatory. A written report is sent to the NIRA and the SCK/CEN as soon as possible.

5.7 Contacts

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