

Regular Article

Łukasz Ścisło, Łukasz Łacny* and Michael Guinchard

COVID-19 lockdown impact on CERN seismic station ambient noise levels

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Abstract: Seismic measuring stations do not only record seismic waves. They also pick up tremors caused by other factors: these are known as seismic background noise. In normal conditions, this environmental background is steady over a long time. This article presents the influence of high reduction of human activity due to COVID-19 initial lockdown on ground vibration in the Large Hadron Collider tunnel at the European Organization for Nuclear Research.

Keywords: LHC, COVID-19, power spectral density, PPSD, seismic stations

1 Introduction

Seismic monitoring setups and stations are not only used to record seismic waves. They can also pick up tremors caused by other sources known as seismic background noise. Human activity is partly responsible for these continuous movements of the ground. For instance, road traffic or industrial activities will cause an additional response of the ground motion. Due to periodic human activity, their impact is typically greater during the workdays and lower at nights and during the weekends. Wind, waves and weather also cause the Earth to vibrate constantly. International studies have shown that levels of human-induced seismic background noise have decreased

in many locations since the outbreak of the coronavirus pandemic [1,2]. Measuring stations were thus indirectly detecting the effects of the lockdown and the associated drop in human and industrial activity. This behaviour is especially interesting for places where ground motion conditions monitoring is important for the proper execution of research experiments. Research facilities like European Organization for Nuclear Research (CERN) (Switzerland) [3,4], EGO-Virgo experiment (Italy) [5,6] or SOLARIS (Poland) [7,8] require extensive research on the ground motion behaviour and its effects on the performance of their detectors. This article presents the observations of the seismic ambient noise at CERN during the 2020 strict lockdown around this research centre facilities due to the COVID-19 epidemic.

1.1 Influence of COVID-19 lockdown on seismic background noise in Switzerland

The Swiss Seismological Service (SED) has observed the reduction of seismic ambient noise phenomenon in Switzerland. Monitoring systems connected to the Swiss Strong Motion Network (SSMNet), many of which are located in highly populated areas, have recorded a significant decrease in seismic background noise. This has been the case especially for the stations in larger cities like Zurich, Basel and Geneva. Since the state of emergency was declared (16.03.2020), levels of background noise in these cities during workdays have nearly decreased to the levels recorded during weekends before the beginning of the lockdown. The decrease in ambient noise levels was also observed on the weekend evenings. The seismic noise levels recorded during this time has fallen to the level typically observed on a normal weekday evening in those cities. It is of note that due to the particularity of Swiss urban areas, more seismic noise is generated on weekends than on weekday evenings.

Conversely, rural or alpine stations belonging to the SDSNet have only recorded slight decreases in background noise because these areas are considerably less

* **Corresponding author: Łukasz Łacny**, Cracow University of Technology, Faculty of Mechanical Engineering, Department of Applied Mechanics and Biomechanics, al. Jana Pawła II 37, 31-864 Cracow, Poland, e-mail: llacny@pk.edu.pl

Łukasz Ścisło: Cracow University of Technology, Faculty of Electrical and Computer Engineering, Department of Automation and Computer Engineering, ul. Warszawska 24, 31-155 Cracow, Poland, e-mail: lscislo@pk.edu.pl

Michael Guinchard: Engineering Department, CERN, EN-MME Group, Mechanical Measurement Lab, 1211 Geneva 23, Switzerland, e-mail: m.guinchard@cern.ch

affected by vibrations from road traffic, trains and other human activities. However, strong winds and other weather factors may nevertheless lead to increased levels of background noise in specific areas.

The additional side effect of the lockdown was the possibility for monitoring stations to detect earthquakes of lesser magnitude for which the signals would otherwise be lost in the background noise. The COVID-19 lockdown has therefore increased the sensitivity of earthquake monitoring in some parts of Switzerland, although the overall effect at just 0.1–0.2 magnitude units. By way of comparison, the sensitivity of monitoring is on average 0.5 magnitude units greater during the night than during daytime working hours [9].

1.2 CERN monitoring system for seismic activity

Large Hadron Collider (LHC) is a part of an international collaboration facility at CERN. It is situated in the underground tunnels beneath the border of France and Switzerland, in the close vicinity to Geneva (Switzerland). It is currently the world largest and highest energy particle accelerator in the world. The underground placement of the accelerator was chosen in order to diminish the influence of undesirable vibrations and disturbances on the operation of this extremely precise scientific apparatus. The cultural noise related to human activity on the surface is typically not strong enough to disturb the current measurements performed in LHC. However, one might expect that either strong ground motion, e.g., caused by a nearby earthquake or a long-term heavy machinery work performed in the close vicinity of the accelerator, might impact its operation and in the worst-case scenario invalidate the data collected during its run. In addition, for future upgrades (LHC-HL) and future strategical investments (FCC), the matter of seismic ambient noise will be a serious matter.

Therefore, for the purpose of monitoring the ground vibration activity in the areas close to the accelerator, a

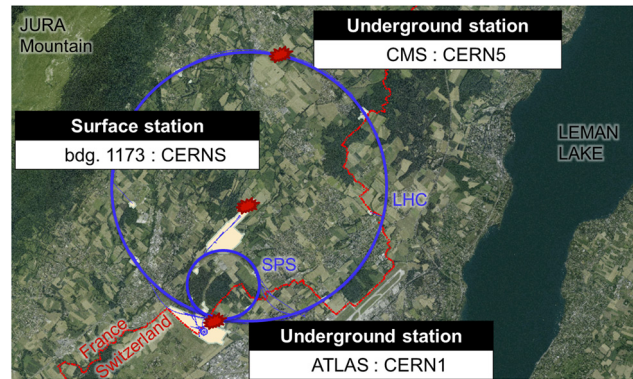


Figure 1: Map of CERN Seismic Network with specified locations of separate seismic stations [11].

CERN Seismic Network has been established thanks to a collaboration between CERN (EN-MME, EN-STI groups) and Swiss Seismological Service SED [10]. It consists of three separate seismic stations (vaults) as shown in Figure 1: two underground stations, placed in the tunnels at Point 1 (near ATLAS detector) and at Point 5 (near CMS detector) and a third surface station located approximately in the centre of the accelerator ring.

Each of the three seismic stations has been equipped with a pair of highly precise vibration measuring devices, chosen in such a manner as to complement the measurements obtained from one another. The strong motion sensor of sensitivity of $2.548 \times 10^{-4} \text{ mV}/(\mu\text{m/s}^2)$ have been selected for the purpose of detecting the ground excitation of high magnitude such as intense earthquakes or nearby machinery work. On the other hand, the broadband vibrometers of high sensitivity have been chosen to measure with good precision both the response from minor excitation sources and the ambient vibration levels, within a broad frequency range (1/60–100 Hz). The sensitivity of the ones used in the underground stations was $2.5 \text{ mV}/(\mu\text{m/s})$, while the sensitivity of the one on the surface was $0.8 \text{ mV}/(\mu\text{m/s})$. Table 1 lists and compares the basic specification of the three selected sensors. All of the sensors have been calibrated before installation using a calibration bench and a Laser Doppler vibrometer (LDV).

Table 1: Sensor parameters

Model	Guralp 6T (geophone)	Guralp 40T (geophone)	Kinemetrics EpiSensor ES-T (str. motion)
Frequency range	1/30–100 Hz	1/60–100 Hz	DC – 200 Hz
Sensitivity	2.5 mV/($\mu\text{m/s}$)	0.8 mV/($\mu\text{m/s}$)	$2.548 \times 10^{-4} \text{ mV}/(\mu\text{m/s}^2)$
Sensor output	$\pm 20 \text{ V}$ diff.	$\pm 20 \text{ V}$ diff.	$\pm 5 \text{ V}$ diff.
Sensor dynamic range	137 dB @ 5 Hz	151 dB @ 5 Hz	155 dB
Supply voltage	10–30 V	10–36 V	$\pm 12 \text{ V}$



Figure 2: Vibrometers placed inside the Point 5 seismic station: strong motion sensor (left) and broadband sensor (right).

The data obtained from the broadband sensors have been used in the following analysis and calculations.

Although, the system was calibrated to measure in the frequency range 1/30–100 Hz, from the point of the LHC and current and future civil engineering operations within the range of 10–50 Hz are of much more importance, because of the natural frequencies of the magnets located in the LHC tunnel. The first two (and most prominent) natural frequencies for the magnets are at 8 and 22 Hz. Although the stations measure vibrations with good trueness, the signal might be perturbed by excessive cultural noise or electronic noise, reducing the quality of the data acquired. The broadband seismometer DAQ modules were chosen especially to present a noise level lower than LHC usual level of vibration between 1/30 and 100 Hz. Additional tests have been performed in the LHC for the purpose of selecting the most adequate modules. The modules have been connected to two Guralp 6T sensors to calculate the noise present in each acquisition chain. The measurement showed similar vertical ground motion levels, which was also verified using the reference equipment. This test confirmed that the module NI9239 is compliant with

specific CERN noise requirements and showed that for a broadband seismometer, the noise in the acquisition chain comes mainly from the sensor. Out of the electrical noise, it is possible to point out the typical seismic signals shown in the literature. The strong motion sensor measures the vibration up to 2g. Contrary to broadband seismometers, its noise is low and comes mainly from the acquisition chain. Taking this into consideration, the NI9239 module had also been selected because of its ± 10 V range.

The chosen data acquisition system for seismic stations was an eight-channel CompactRIO from the National Instruments, complemented with two NI9239 modules each equipped with four differential channels. The selected modules allow a 24-bit simultaneous sampling on ± 10 V range with 11 μ V rms input noise. The DAQ controller is supplied by the PS15 24 V power supply from the National Instruments. It is cut-off from the 230 V supply by a PDU power control, which makes it possible to perform a remote reboot in case of a major software issue.

Figure 2 presents a seismic station located at Point 5 with both the strong motion sensor (left) and the broadband sensor (right) placed inside.

2 Influence of COVID-19 on background noise in LHC tunnel

2.1 CERN measures to fight the COVID-19 pandemic

The users presence on the CERN sites from the middle of March 2020 was strongly limited to only the personnel essential for ensuring the security and safety of the facilities and the equipment. All the works on the site were halted, and all equipment and systems that were not required were switched off. CERN has been in a strict

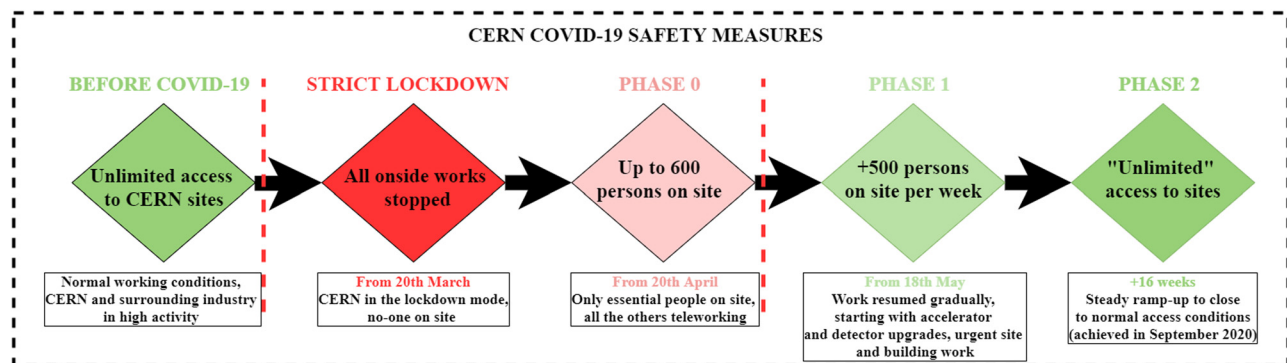


Figure 3: Phases of limitation of users' access to CERN facilities.

safe mode since 16.03.2020, with the majority of personnel working remotely. During this period, a maximum of around 600 people (of the typical 7,000) have been granted occasional permission to enter CERN to ensure the safe maintenance of the sites and facilities. The full plan of access to site restrictions is shown in Figure 3.

Starting from 18.05.2020, on-site activities were extended to a limited number of CERN personnel and contractors, beginning with the personnel whose work was related to CERN maintenance period (Long Shutdown 2), accelerator and detector upgrades and urgent site and building construction activities. The aim is to allow additional 500 people the access to CERN site each week and by doing so restart crucial activities and experiments. The statistical data of the number of users at the site each day is shown in Figure 4.

3 Seismic noise comparison due to COVID-19

A typical approach when analysing vibration is to transform the time-domain quantitative data into frequency-domain qualitative data, such as power spectral density.

The analysis of the power spectral density of the data under consideration, provides the information regarding which frequencies (if any) are dominant in the area of the station, and makes it possible to determine how they are related to the nearby activities. The amplitude of vibration ranging from 10 to 100 Hz is mostly stable during the period of standard operation in the vicinity of the station (black line on Figure 5). However, the CERN closure from 16.03.2020 and subsequent limitation of human activity had a visible effect on the amplitude of vibration in the frequencies responsible for cultural noise for both the seismic station on the surface (Figure 5) and the one underground at CERN point 5 – CMS experiment (Figure 6).

In addition, the data gathered in Figure 6 are presented as a 1/6th octave band graph (Figure 7). The whole frequency range (in this case 0–100 Hz) is divided into sets of frequencies called bands. Each band covers a specified range of frequencies. This approach allows more statistical way to calculate which frequencies are being activated. Finally, the yellow and red horizontal lines shown in Figure 7 correspond to the warning and alarm levels that have been decided upon for the vibration works at LHC. These have proven useful to the team monitoring the works, as a quick indicator for the severity of vibration caused by the heavy machine operation. It can be observed that the monitoring team has decided to

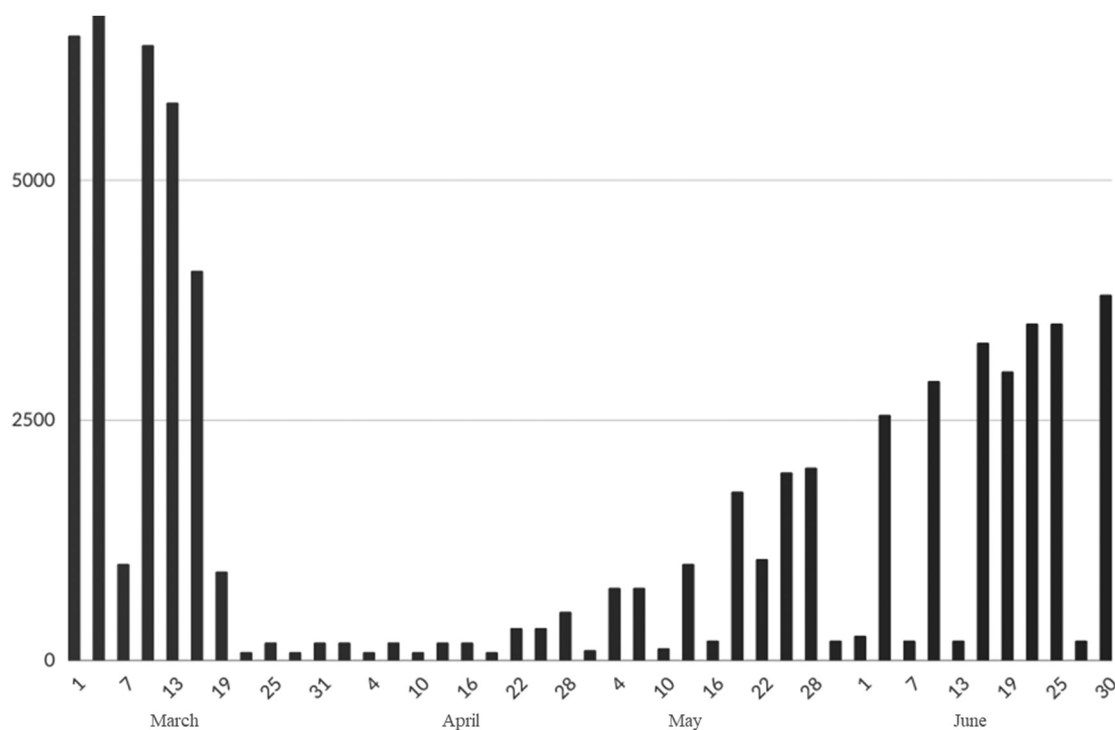


Figure 4: Number of CERN users at the site from March to June 2020 by CERN SUSI (SURveillance des Sites).

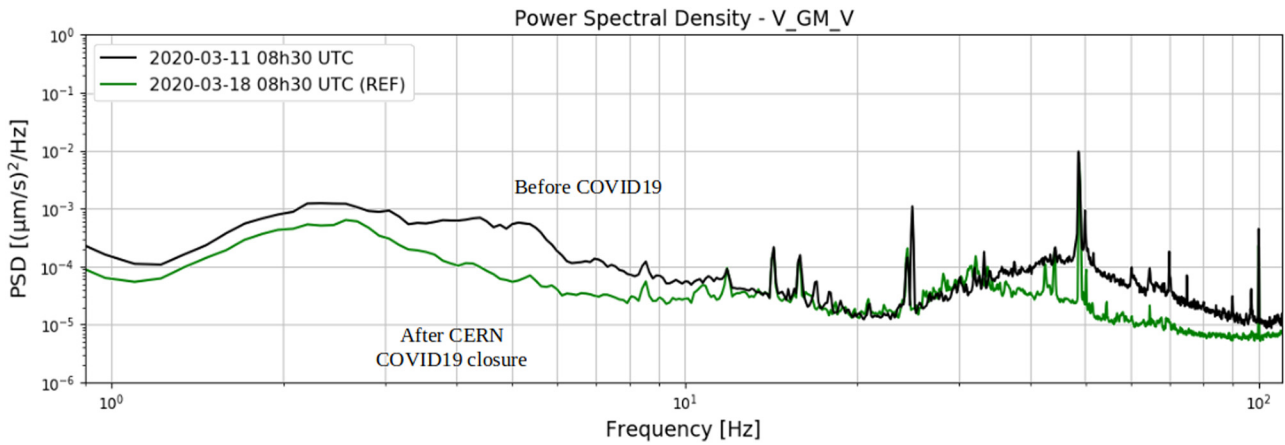


Figure 5: PSD graph for the 20-min data block from seismic station at the surface (CERNS) before (black line) and after (green line) COVID-19 CERN closure.

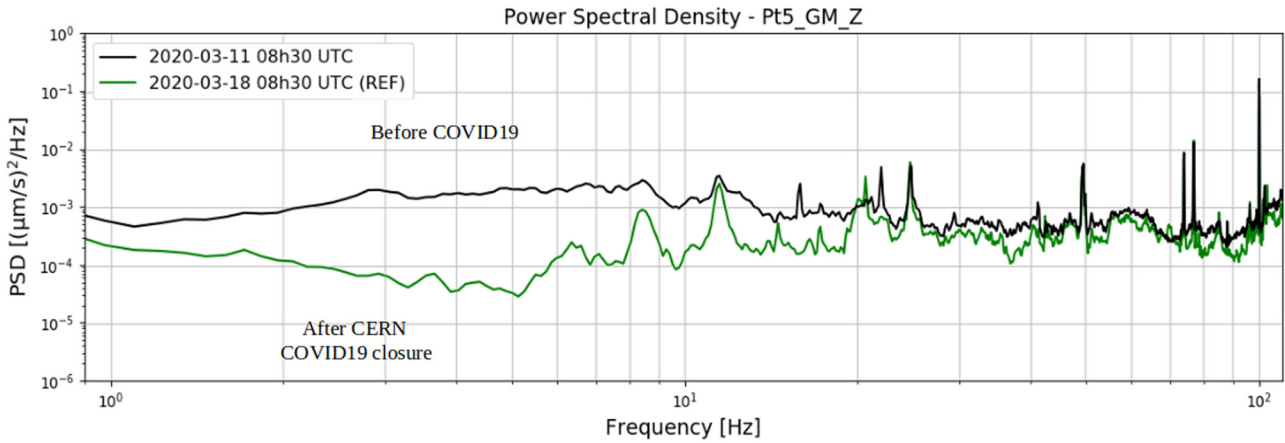


Figure 6: PSD graph for the 20-min data block from the seismic station at LHC tunnel (CERN Point 5 – CMS) before (black line) and after (green line) COVID-19 CERN closure.

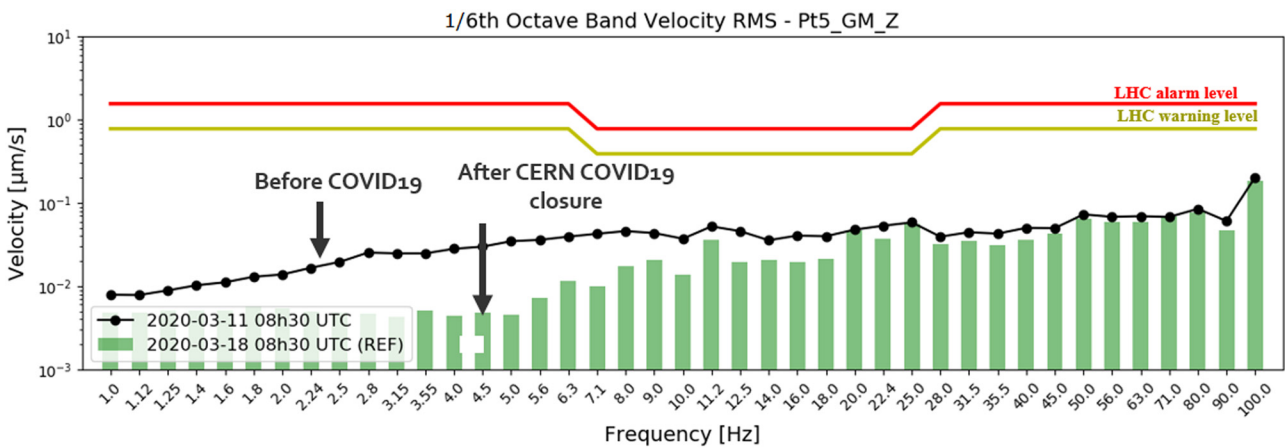


Figure 7: The 1/6th Octave Band Velocity RMS for 20-min data block, comparison of data before and after the lockdown at CERN point 5 (CMS) seismic station.

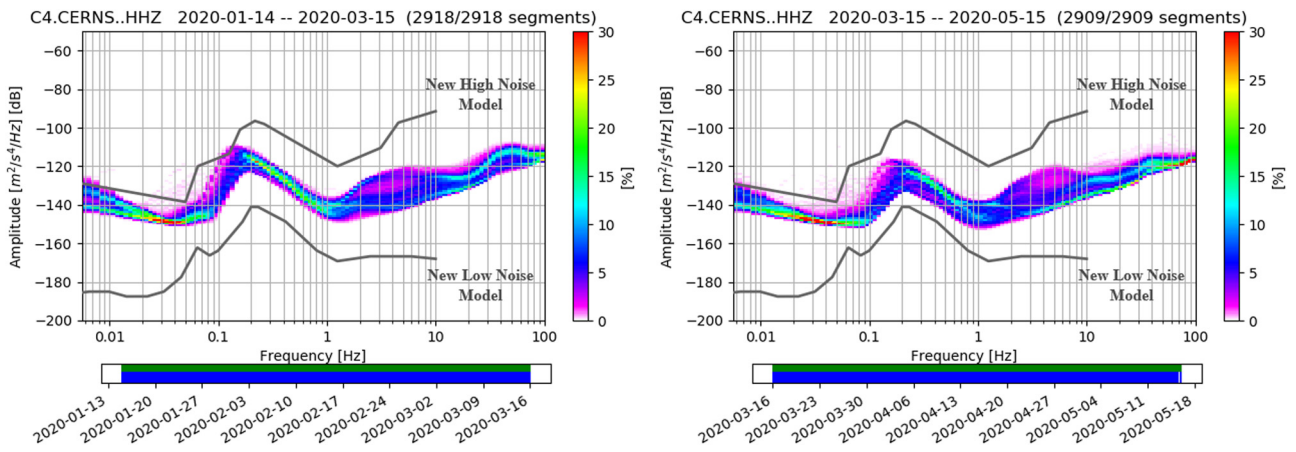


Figure 8: Probabilistic Power Spectral Density of CERN Seismic Station at the surface (CERNS) calculated over a period of 2 months before (left graph) and 2 months after (right graph) the CERN COVID-19 closure.

lower the warning and alarm levels within the frequency range 7–28 Hz. This is dictated by the fact that the first two and most prominent natural frequencies of the magnets located in the tunnel lie within this range, specifically at 8 and 22 Hz. As such, the ground vibrations at these frequencies were going to have a stronger impact on the magnets and the beam circulating within them.

When analysing the data using Power Spectral Density, the aim of the analysis and the limitation imposed upon this technique must be considered, specifically the condition for the collected data to be stationary. One can simply assume this for short-term measurements (typically 5–20 min) when no sudden excitation is present. However, if the goal is to analyze the data over a long time, it is necessary to implement a different approach. One of the possibilities is to utilize the probabilistic power spectral density (PPSD)

method, which combines the information from multiple PSD data streams to describe the long-term seismic behaviour of the observed area [11].

The data obtained for the analysis and calculation of the PPSD have been downloaded directly from the publicly available servers set up by SED. The detailed procedure for calculating and plotting PPSD is specified in refs [12,13]. In general, for each of the PSD graph acquired from the measurement, the calculation is performed to obtain the values of full-octave averages in 1/8 intervals, which are afterwards allocated in 1 dB power bins inside the PPSD map, under the assumption that the reference value is $1 \text{ (m/s}^2\text{)}^2\text{/Hz}$ [14]. The percentage value for a given 1 dB power bin and octave range corresponds to the ratio between the number of averaged power values located inside that 1 dB power bin, in comparison to the

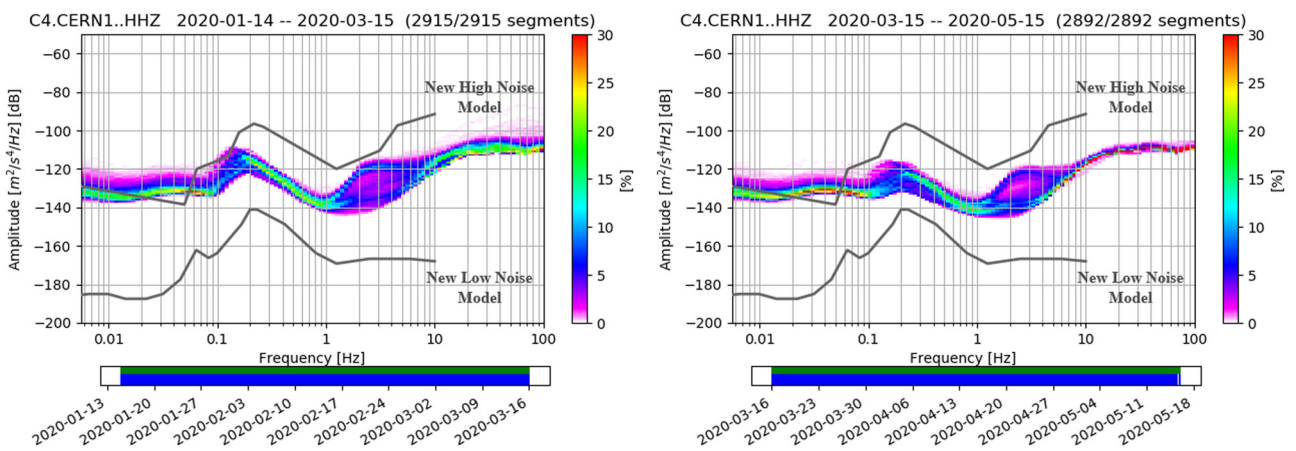


Figure 9: Probabilistic Power Spectral Density of CERN Seismic Station at Point 1 (ATLAS) calculated over a period of 2 months before (left graph) and 2 months after (right graph) the CERN COVID-19 closure.

number of all the averaged power values within that octave range (same as the number of all available PSD graphs).

The PPSD graphs for 2 months before the lockdown and 2 months after implementation of the safety measures are shown in Figure 5 for the CERN surface seismic station and Figure 6 for one of the underground seismic stations (in this case, station at CERN Point 1 – ATLAS experiment).

The thick black lines on the graphs correspond to the so-called new high noise model (upper line) and new low noise model (lower line) as specified in ref. [12]. These lines represent the highest and lowest measured levels of ambient natural Earth noise sources. Taking into account the sources of the seismic noise, the graphs are shown in Figures 8 and 9, and it is suggested that they can be subdivided into three approximate frequency regions. The first one located within the frequency range between 0.1 and 1 Hz, shows an amplitude maximum at 0.15–0.2 Hz and a sudden drop afterwards. This behaviour is consistent over a period of four examined months. This range corresponds to the so-called micro-seismic vibration caused by the movement of Earth's oceans. Therefore, limiting the human activity during the lockdown has no noticeable effect on the vibrations in this frequency range.

When regarding Figures 8 and 9, both left and right graphs, two amplitude curves are readily visible within the frequency range from 1 to 10 Hz. Those can be interpreted as the vibration caused by human activity, known also as “cultural noise” (operating machines, manufactures, public transport, etc.), with the upper line corresponding to the peak-level of human activity during the day and the lower one to the nightly hours. It is already visible that the amplitudes decreased especially in the case of measurements for the tunnel (CERN1). For the surface station, this effect is much lower due to the location of the surface station in the fields far away from human activities. This behaviour corresponds to the observations done by the Swiss Seismological Service (SED) for rural or alpine stations where only a slight decrease in background noise was recorded.

Finally, within the last frequency range of 10–100 Hz a mostly stable amplitude curve can be seen. As the CERN1 station is located in an underground tunnel (close to ATLAS experiment), the influence of the vibration sources operating within this range on the surface in most part is diminished and thus negligible over a long period. This means that the curve represents the actual ambient noise level inside the tunnel. However, at this location, extensive civil engineering works have been in progress before the lockdown (new caverns excavations), and the effect of the lockdown is clearly visible in Figure 9.

The levels for this range after the lockdown have visibly decreased, which can be attributed to the reduction of the additional (human-based) sources of vibration.

4 Summary and future prospects

The COVID-19 limitation of human and industry activity presented in this article has proven convenient for determining the actual impact of these activities on seismic data from the CERN Seismic Network. This study is especially useful in case of discussion about commissioning future generation of accelerators, the operation of which will be highly dependant on seismic noise and maintaining low vibration levels. This analysis makes it possible to obtain an estimate of how much the noise level can be reduced with the limitation of human activity, both on the surface and inside an underground location. Finally, the utilisation of PPSD approach to analyse ambient seismic noise is advantageous for presenting the long-term vibrational impact of human activity on the environment inside the caverns and tunnels at CERN.

Due to the higher energies and precision of LHC and the planned FCC project, it will be essential to monitor human activity directly above the accelerator line. The presented tools will provide a useful utility for a quick and easy way to evaluate seismic conditions in the whole CERN accelerator complex.

Conflict of interest: Authors state no conflict of interest.

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