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GROUND MOTION MEASUREMENTS AT LNF

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Abstract

Preliminary measurements of ground motion have been done at the LNF for Super B site characterization. Measurements done during 18 hours in the vertical direction near a main road on surface show that earth motion (from 0.2Hz to 1Hz) is around 70nm, and that cultural noise (from 1Hz to 100Hz) varies from about 12nm to 35nm between 17h40 and 8h00 and from 38nm to 65nm between 09h40 and 11h40 on average, but highly increases between 8h00 and 09h40 due to traffic of rush hours ([3; 30] Hz) up to 240nm. However, measurements done during 20 minutes simultaneously on the surface and a 50m depth hole show that cultural noise is well attenuated in depth on its entire bandwidth (from 1Hz up to at least 100Hz). Vertical ground motion measured for 20 minutes in three other points located near various vibration sources during non rush hours the day was shown to be almost the same, about 70-80nm from 0.2Hz to 100Hz and about 30-35nm from 1Hz to 100Hz on average. Also, ground motion measurements done during 20 minutes simultaneously in the three directions at two points (located also near different vibration sources) show that horizontal motion is not much higher than vertical motion compared to horizontal tolerances which should be much less strict than the vertical one. To finish, measurements of ground motion coherence has been done for different distances on two different floors close to each other at LNF (soft and rigid) and compared to the one of ATF2 where a special floor was built for stability. Results confirm that a rigid floor keeps the coherence at higher frequencies, and that the LNF floor is much better than the one of ATF2 although it was not built for stability.

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1 INTRODUCTION

After the ones of the Virgo team [1], more detailed preliminary ground motion measurements have been performed at the LNF site for the Super B project, which will produce beam whose size will be at the nanometer scale. Therefore, a mechanical relative stabilization of magnets will be probably needed, but this is not yet established since the specifications are not yet available. These measurements give a first characterization of ground motion in this site, and enable thus determining which future measurements have to be done.

First, results of vertical ground motion measurements done during 18 hours are shown at the basement of the new guest house in order to get an idea of the evolution of the amplitude of ground motion with time.

Secondly, measurements of ground motion performed at different locations on surface and situated near various vibration sources are compared in order to evaluate the influence of these sources. These measurements have been done simultaneously in the 3 directions of space, and so a comparison of the amplitude of ground motion between these directions is also done.

Then, results of ground motion coherence measured for different distances at two locations close to each other but with soft and rigid floor are compared. These measurements are compared to the ones done in the ATF2 beam line [2] where a special floor was built for stability [3]. By this way, one can evaluate if the LNF is a good site to use ground motion coherence properties for stability like it has been done for ATF2 [4].

To finish, conclusions about these measurements are done and future measurements which are planned to be done are described.

2 SET-UP

2.1 Measurement location

Measurements have been performed at different locations of the LNF site (see Fig.1). Each location presents various properties and has been chosen in order to compare the influence of various vibrations sources (traffic, air cooling, railway track...) and the influence of the quality of the concrete.

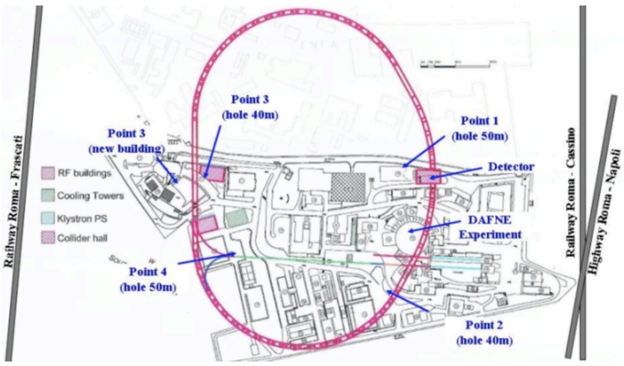

Figure 1: Layout of the LNF site and its future collider with the different strategic points where measurements have been done.

The first point where measurements were done corresponds to the location of the future detector. It is situated in the proximity of a main road where there is much traffic and of a power plant. Measurements have been done both at the surface and inside a hole, at a depth of 50m (see figure 02).

Figure 2: Layout of the set of measurements done at the point 1.

The second point of measurements was located near the DAFNE damping ring and the main pumping station of the DAFNE cooling plant (see figure 03). The original plan was to do a set of measurements at the surface and also in a dedicated hole (40m depth), but due to an important quantity of water accumulated in the hole, only surface measurements have been performed.

Figure 3: Layout of the set of measurements done at the point 2.

The last point of measurements was the point 3, where we performed coherence measurements on two different types of floor close to each other (see figure 04): on surface in the parking (soft floor) and on the concrete of the new guest house (rigid floor). The last set of measurements was realized in the basement of this new guest house in an acquisition session of 18 hours. Note that this point is also situated in the proximity of a main road as the point 1.

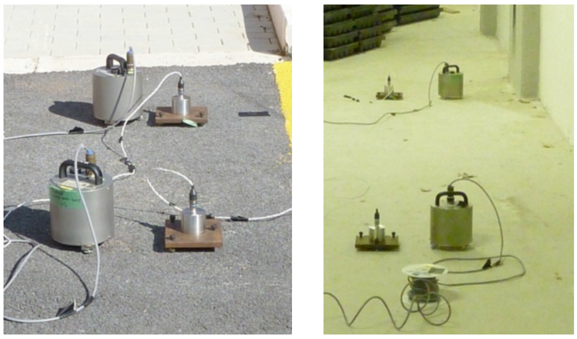

Figure 4: Layout of the set of measurements done at the point 3 on two different types of floor (at left: soft floor and at right: rigid floor).

We should point out that no measurements have been done in the holes located at the points 3 and 4 because one was blocked by a stone (point 3) and another one was filled with water (point 4) and that all these points are not far from the high way (Roma-Napoli) and the rail-way track (Roma-Napoli).

2.2 Instrumentation used

Ground motion has to be measured in the frequency range of about [0.1; 100] Hz. In fact, a beam-based feedback in accelerators is usually used to stabilize directly the beam below 0.1Hz (and often well above) and amplitude of ground motion is very low above 100Hz even for a noisy site.

In order to measure vertical ground motion in this wide frequency range, geophones and accelerometers are needed [5] [6]. In table 1 below, data sheet of the two types of sensors used for the study are shown:

Types of vibration sensor	Electromagnetic geophone	Piezoelectric accelerometer
Model	Guralp CMG-40T	Endevco 86
Company	Geosig	Brüel & Kjaer
Sensitivity	1600V/m/s	10V/g
Range [Hz]	[0.033; 50]	[0.01; 100]

Table 1: Vibration sensors used for the study

Guralp CMG-40T geophones [7] are high sensitive sensors which can measure velocity vibrations simultaneously on the vertical and the two horizontal directions. They have a flat frequency response from 0.033Hz to 50Hz. Although ground velocity is high at low frequencies, internal noise of vibration sensors decreases with frequency and is high at low frequencies. That's why these geophones can measure ground velocity only above 0.1-0.2Hz (depending on the amplitude of ground motion and consequently on the site) where their internal noise is well below the ground velocity signals and so where accurate measurements can be obtained.

Endevco 86 accelerometers [8] are high sensitive sensors which can measure acceleration vibrations on the vertical direction only. They have a flat frequency response from 0.01Hz to 100Hz. But because ground acceleration is low and sensor internal noise is high at low frequencies, signal to noise ratio is too low to enable measuring ground acceleration below 1-10Hz (depending on the site). These sensors are then used to measure vertical vibrations above 1-10Hz up to 100Hz where signal to noise ratio is high.

Because the Guralp geophones are less noisy than the Endevco accelerometers, their data were used up to the upper limit of their operational frequency range in the analysis of this campaign of measurements. Geophones data were consequently used from 0.2Hz up to 50Hz and accelerometer data from 50Hz to 100Hz for vertical ground motion analysis. Note that measurements of ground motion in the two horizontal directions could have been done only up to 50Hz with geophones, which is certainly sufficient since vibration tolerances in horizontal directions will be probably much less strict than the ones of the vertical direction.

Sensor data were acquired by the PULSE acquisition system with a controller of type 7537A (configured in 16 bits resolution) from Brüel and Kjaer Company [8]. Amplifiers were used to increase the dynamic range: 70mV rms channel sensitivity for the accelerometers and 700mV channel sensitivity for the geophones. The frequency acquisition was set at 256Hz in order to analyze data up to 100Hz.

The noise of the measurement chain, including the PULSE acquisition system, the Guralp geophones used from 0.2Hz to 50Hz and the Endevco accelerometers used from 50Hz to 100Hz, was measured at LAPP [9]. Results are shown in table 2 below for different bandwidths (Integrated RMS calculation).

Bandwidth [Hz]	[0.2;100]	[1;100]	[2; 100]	[4; 100]	[10; 100]	[50; 100]	[0.2; 1]
Noise [nm]	10.5	0.42	0.12	0.06	0.05	0.03	10.5

Table 2: Noise of the measurement chain calculated in different bandwidths.

This very low noise allows very accurate measurements of ground motion even for a quiet site. It has been plotted in each plot of this report where PSDs and integrated RMS of ground motion are shown (with as units m2/Hz and m respectively). Moreover, measurements of ground motion at LNF have been done with two Guralp geophones and two Endevco accelerometers put side-by-side on the floor in order to get coherences and transfer functions between sensors. This allowed determining exactly above which frequency measurements of each type of sensors are reliable [6] (high signal to noise ratio).

2.3 Data analysis

The calculations of the Power Spectrum Density (PSD), the Transfer Function, the Coherence and the Integrated Root Mean Square (RMS) are described in [10].

The FFT parameters used for the analysis of measurements done during 18 hours are the following:

- Window: Hanning
- Overlap: 66.67%
- Frequency resolution: 0.016Hz

- Time resolution: 20 minutes (trigger of the multibuffer, whose size is of 54)
- Averaging: Exponential (2*Tau=1195s) with 54 averages (data sets of 64 seconds averaged)

For the analysis of the other measurements, the FFT parameters used are the described below:

- Window: Hanning
- Overlap: 66.67%
- Frequency resolution: 0.016Hz
- Averaging: Linear with 50 averages (data sets of 64 seconds averaged)
- Measurement time: 20 minutes

These parameters are used to have knowledge of the average amplitude of ground motion at the LNF site (single event noise is smoothed out), and to get accurate measurements of vibration transfer function and ground motion coherence for different distances. The choice of these parameters is explained in [10].

Note that measurements of ground motion in various sites have been performed by the Desy team [11]. They measured also ground motion PSDs during 60s and averaged these spectra for every 15 minutes or longer, and then calculated the integrated RMS in the same way than us. Consequently, amplitudes of ground motion measured at LNF by us can be compared to the ones measured in various sites by Desy team.

3 GROUND MOTION AMPLITUDE WITH TIME

In order to analyze the evolution of the amplitude of ground motion with time, ground motion measurements have been performed during 18 hours in the vertical direction from 15th October at 17h40 to 16th October at 11h40. The site chosen is the basement of the new guest house (point 3) for its rigid floor.

From these measurements, the PSDs of ground motion have been calculated and plotted in figure 05 versus time and frequency. It should be noticed that results are reliable and consequently shown only above 0.2Hz due to low signal to noise ratio below this frequency.

Note that for the first spectra (17h40), no averages were done and calculations were thus performed for a period of 64s (the next spectra was then calculated from measurements acquired between 18h00 and 18h20 and so on).

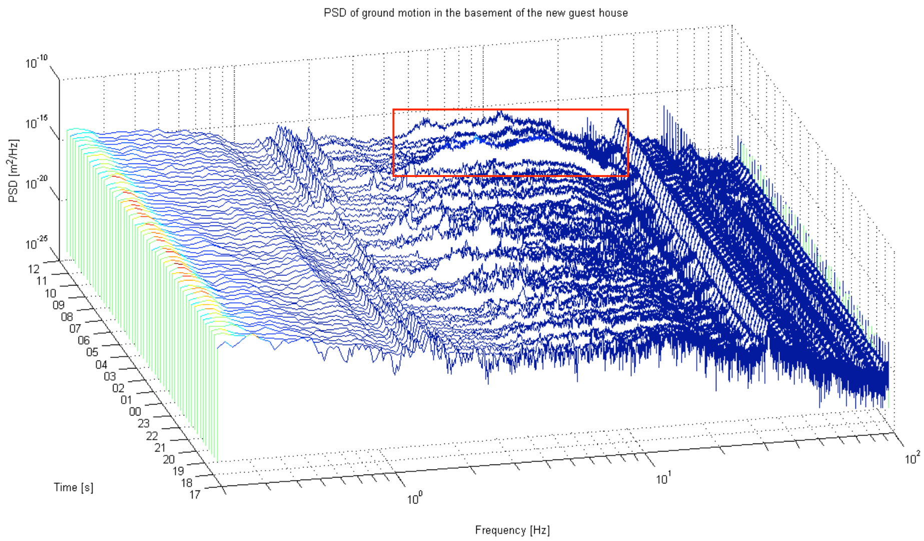

Figure 5: PSD of ground motion at point 3 (basement of the new guest house) versus time and frequency.

The PSDs have quite the same spectra with time, except between 8h00 and 9h40 where their amplitude increases much in the frequency range [3; 30] Hz (see red rectangle). This increase is certainly due to traffic since the time corresponds to rush hour and other studies have shown that vibrations due to traffic are exactly in this frequency range [12].

In order to have a better view of the amplitude increase, the PSDs are shown in figure 6 (data reliable above 0.2Hz) in 2 dimensions (amplitude, frequency) only in the time area where the amplitude increases.

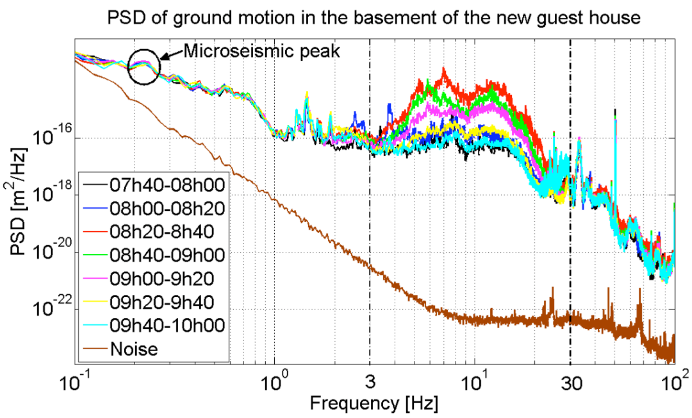

Figure 6: PSD of ground motion at point 3 (basement of the new guest house) versus frequency.

In the frequency range [3; 30] Hz, it is clearly seen that the amplitude slowly increases from 08h00 to 08h20, then highly increases from 08h20 to 8h40, and finally slowly decreases from 8h40 to 10h00 down to the same amplitude before 08h00.

Note that below 1Hz, ground motion is due to earth motion and that above 1Hz, ground motion is due to cultural noise, that is to say human activities [13]. Especially in the frequency range [0.1; 1] Hz, ground motion is mostly due to the microseismic peak (motion of waves in the ocean), whose frequency can be seen around 0.2Hz in figure 06.

In order to have values of the amplitude of ground motion with time, the PSDs shown above have been integrated in different bandwidths (integrated RMS calculations): from 0.2Hz to 100Hz, from 1Hz to 100Hz, from 10Hz to 100Hz and from 50Hz to 100Hz. Results are shown in figure 07 below.

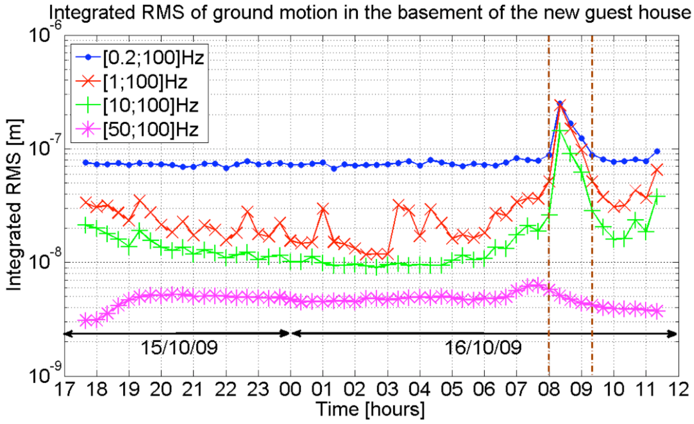

Figure 7: RMS of ground motion versus time at point 3 (basement of the new guest house) integrated in different bandwidths.

In the bandwidths [1; 100] Hz and [10; 100] Hz, amplitudes of ground motion vary from 12nm to 35nm and from 9nm to 21nm respectively between 17h40 and 8h00 (smallest values the night due to reduced human activities), and increase from 38nm to 65nm and from 20nm to 38nm respectively between 09h40 and 11h40 (increase due to the beginning of the day). However, the amplitudes highly increase up to 240nm above 1Hz and up to 144nm above 10Hz between 8h00 and 9h40. This time period corresponds to the peaks observed on the PSDs between 3Hz and 30Hz. These results consequently show that traffic can highly increase ground motion (more than a factor 10).

In the bandwidth [50; 100] Hz, amplitudes go from 3nm to 6nm. Remember that this bandwidth is not subjected to the traffic, whose frequency range was observed in the PSDs to be [3; 30] Hz.

In the bandwidth [0.2; 100] Hz, amplitudes go from 70nm to 250nm but vary with time in the same way than in the ones of the bandwidths [1; 100] Hz and [10; 100] Hz. These variations are consequently mostly due to cultural noise. In order to have the amplitudes only due to earth motion, the RMSs of ground motion have been calculated in the bandwidth [0.2; 1] Hz and are shown versus time in figure 08 below. Amplitudes vary from 65nm to 76nm, which is low but may be much higher on a longer time scale.

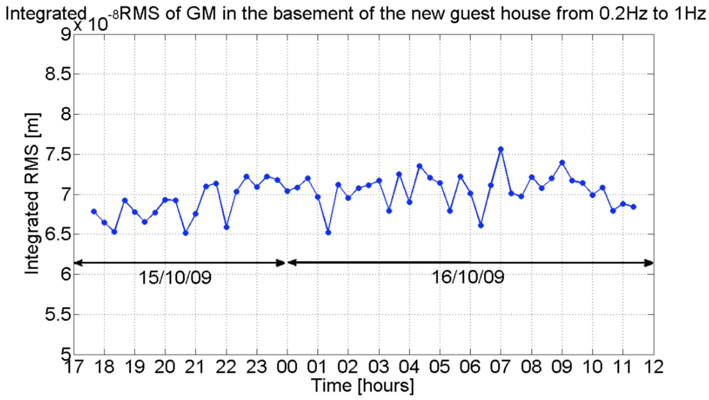

Figure 8: RMS of ground motion versus time at point 3 (basement of the new guest house) integrated in the bandwidth [0.2; 1] Hz.

4 GROUND MOTION AMPLITUDE AT DIFFERENT LOCATIONS

4.1 On surface

Amplitude of ground motion has been measured on surface at point 1 (first location) the 14th October 09 and at point 2 (second location) and point 3 the 15th October 09.

For each of the first and second point, measurements were performed simultaneously in the three directions of space (up to 50Hz in the horizontal directions and up to 100Hz in the vertical direction). Note that the north/south and east/west directions of the sensors were not oriented in the real cardinal points, and so that ground motion measured in the horizontal directions cannot be compared between point 1 and point 2. However, the goal was to compare ground motion in the vertical direction with the one in the horizontal directions for each of these two points.

For the third point, we performed measurements in the vertical direction on the parking (third location) and on the basement of the new guest house (fourth location).

In order to analyze if the amplitude of ground motion varies much depending on the location, the PSD and the integrated RMS of vertical ground motion have been calculated and plotted for these four locations (see figure 09). Results are shown above 0.2Hz since below this frequency, signal to noise ratio was too low. In order to allow a good comparison between the four different sites, these plots are shown for measurements done the day during non rush hours since it has been shown that the amplitude of ground motion was quite the same during this period although the site was located near a main road (see chapter 3): at 17h30, at 10h45, at 13h and at 16h for the first, second, third and fourth location respectively.

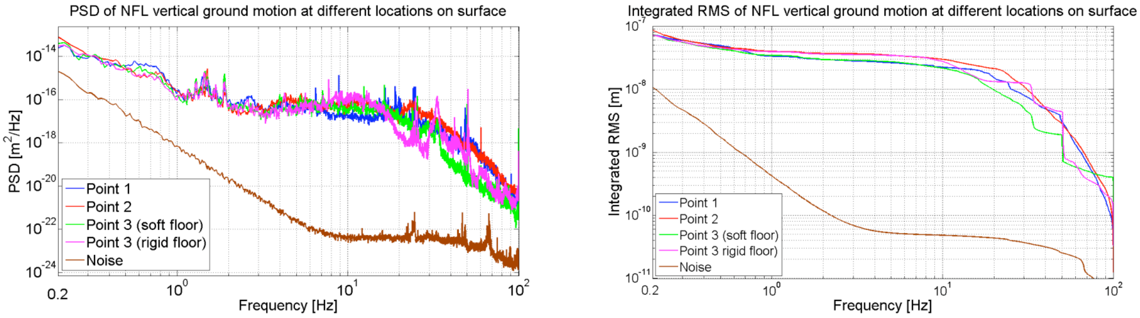

Figure 9: PSD (at left) and integrated RMS of vertical ground motion (at right) for different locations on surface at the LNF.

The results show that the distribution of motion versus frequency (at left) is quite the same for the four locations and that the amplitude of motion (at right) is almost the same, around 70-80nm above 0.2Hz and around 30-35nm above 1Hz.

In order to compare ground motion in the vertical and horizontal directions, PSDs and integrated RMS of ground motion have been calculated from measurements done simultaneously in the three directions at point 1 (16h45) and point 2 (11h30).

Figures 10 and 11 show the results at point 1 and point 2 respectively (at left: PSDs and at right: integrated RMS) above 1.3Hz (problem with one of the Guralp geophone below) and above 0.3Hz (low signal to noise ratio below) respectively.

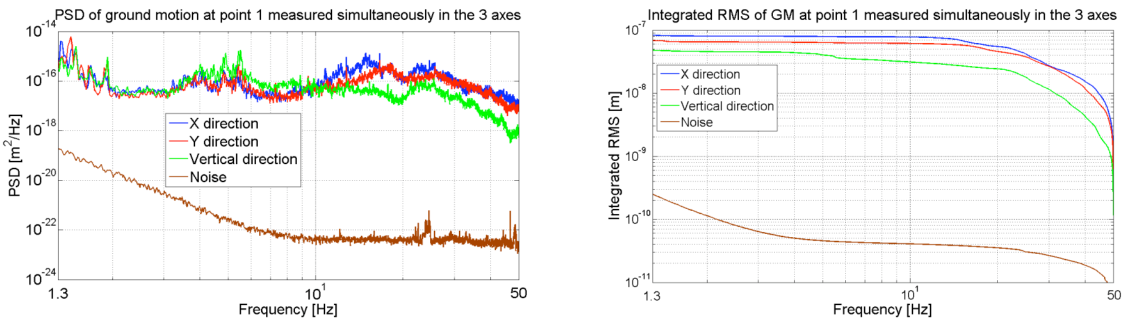

Figure 10: PSD (at left) and integrated RMS of ground motion (at right) in the three directions at point 1.

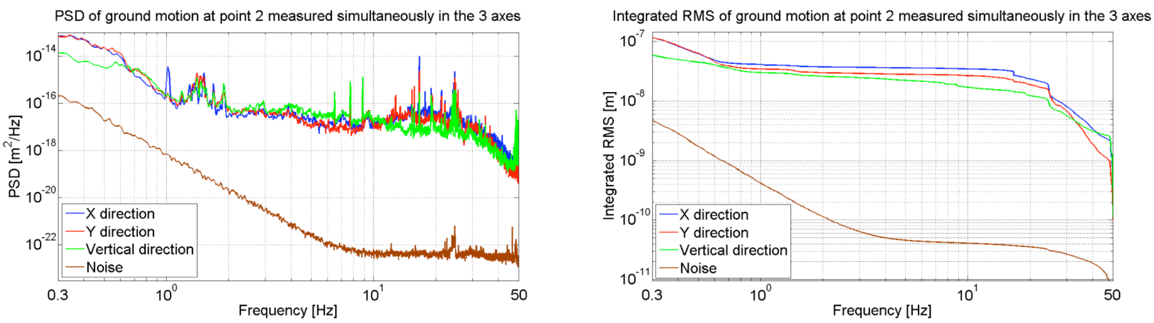

Figure 11: PSD (at left) and integrated RMS of ground motion (at right) in the three directions at point 2.

For both points 1 and 2, ground motion PSD is slightly higher in the vertical direction than in the two horizontal directions below 9Hz, but becomes lower above this frequency (figures 09 and 10 at left). For point 2, it is lower in the vertical direction than in the two horizontal directions below 0.7Hz.

At point 1, ground motion above 1.3Hz was measured to be of 48nm in the vertical direction while it was of 68nm and 83nm in the two horizontal directions (figure 10 at right).

At point 2, ground motion was of 57nm in the vertical direction while it was of 112nm in the two horizontal directions above 0.3Hz, and of 29nm in the vertical direction against 34nm and 40nm in the two horizontal directions above 1.3Hz (figures 11 at right).

For both points, horizontal ground motion is not so much higher than vertical ground motion compared to horizontal tolerances which should be much less strict than the vertical one. In fact, the nominal horizontal beam size should be 160 times larger than the vertical one (σx^*=5.657µm and σy^*=35nm [14]). That's why ground motion has only been measured in the vertical direction for the other locations.

4.2 Comparison between surface and underground

At point 1, ground motion has been measured simultaneously on the surface and on the hole of 50m depth with Endevco accelerometers (vertical direction). In fact, Guralp geophones have a too large diameter to be put inside the hole whose diameter is of 70mm.

From these measurements, ground motion PSDs on the surface and inside the hole as well as the vibration transfer function between the surface and the bottom of the hole have been calculated and are plotted in figure 12 at left and right respectively. Results are shown above 1.3Hz, frequency from where data are reliable (high signal to noise ratio).

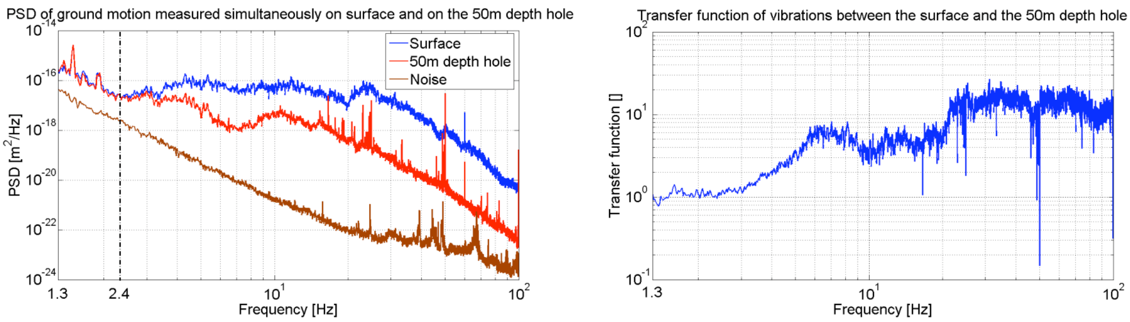

Figure 12: PSD of ground motion measured simultaneously on the surface and inside the 50m depth hole (at left) and vibration transfer function between the surface and the hole.

It can be clearly observed that vibrations are damped in the hole above 2.4Hz (beginning of human activities). Above 20Hz, the factor of damping goes up to 20.

In order to get values in nanometer, the integrated RMSs of ground motion on the surface and inside the hole has been calculated and is plotted in figure 13.

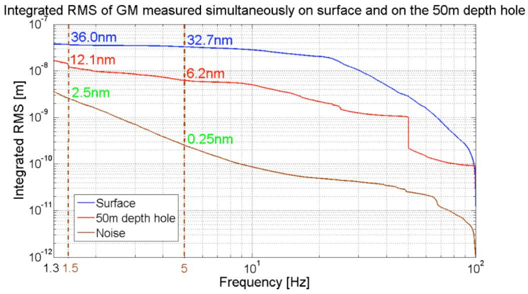

Figure 13: Integrated RMS of ground motion measured simultaneously on the surface and inside the 50m depth hole.

Above 1.5Hz, ground motion is of 36.0nm on surface and of 12.1nm inside the hole, that is to say a factor 3.0 of damping. Above 5Hz, it is of 32.7nm on surface against 6.2nm inside the hole, which gives a factor 5.3 of damping. This factor would be probably well higher during rush hours since cultural noise is much more important.

All these results consequently clearly show cultural noise is really well attenuated in depth.

5 GROUND MOTION COHERENCE

Measurements of ground motion coherence were performed in the vertical direction at point 3 on the parking (soft floor) and on the basement of the new guest house (rigid floor) in order to confirm the importance of a rigid floor for stability [15].

These measurements have been done up to 10m since coherence is lost down to low frequencies above this distance. In figure 14, results are shown at left for the parking and at right for the basement of the new guest house. Results are shown above 3Hz since coherence was lost below this frequency (problem with one of the Guralp geophone). However, coherence is still at 1 for the highest distance (10m) from 3Hz to 6Hz (left) and from 3Hz to 4Hz (right) and is thus in reality at 1 below 3Hz. Figure 15 shows ground motion coherence measurements done on the ATF2 beam line where a special floor was built for stability (same data analysis performed than for the LNF site). Results are shown above 0.3Hz, frequency from where data are reliable (high signal to noise ratio).

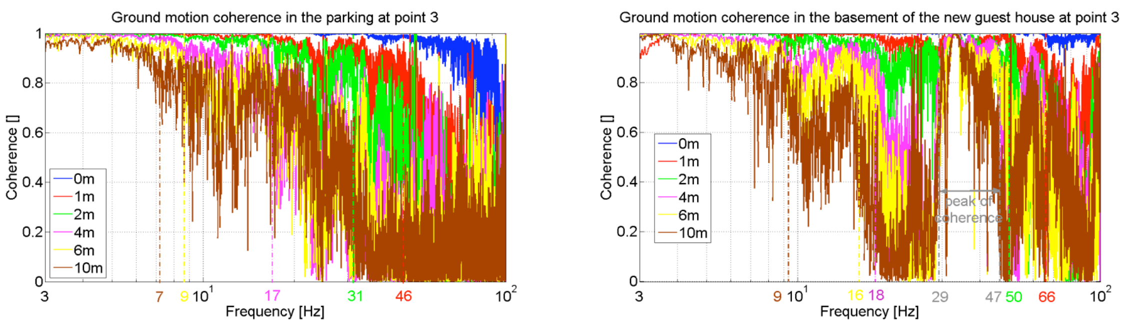

Figure 14: Ground motion coherence for different distances at point 3 on the parking whose floor is soft (at left) and in the basement of the new guest house whose floor is rigid (at right).

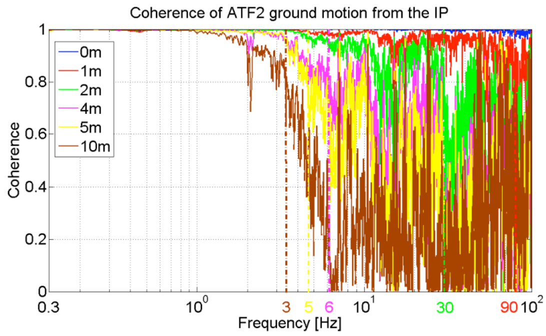

Figure 15: Ground motion coherence from the IP for different distances in the ATF2 beam line.

In the 3 plots, the frequency where the coherence highly falls under a value of 0.8 is indicated for each distance in order to make a comparison between these 3 different floors. Note that for the basement of the new guest house, a peak of coherence appears between 29Hz and 47Hz even if the coherence has already fallen below this frequency range due to the distance. This peak of coherence may be due to the pylons (see figure 16) which transmit vibrations as seen in the measurements of ground motion coherence in the LHC tunnel [16]. This peak of coherence was consequently not taken into account to determine the frequency where the coherence highly falls.

Figure 16: Basement of the new guest house with pylons (point 3).

These last results are summarized in figure 17 below for the 3 floors where the abscise represents the distance and the ordinate represents the frequency where the coherence falls.

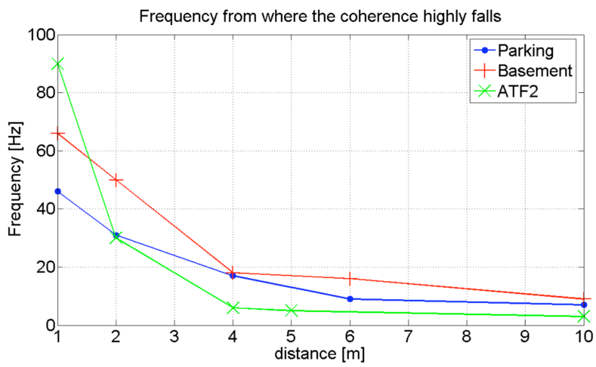

Figure 17: Frequency from where ground motion coherence highly falls for measurements done on the parking (soft floor), on the basement of the new guest house (rigid floor) and in the ATF2 beam line.

This figure clearly shows that the basement floor keeps the coherence at higher frequency than the parking floor, which confirms that a rigid floor is very important for good ground motion coherence.

Moreover, the basement floor is really better than the ATF2 floor for ground motion coherence (and the parking floor keeps also the coherence at higher frequency), although the ATF2 floor was built to get good stability whereas the basement floor (and the parking floor) was not. Moreover, the guest house basement is not so stiff and also there are empty volumes below. This shows that the ground of the LNF is very promising for good coherence properties.

6 CONCLUSION

Preliminary measurements of ground motion at the LNF site give already very important results.

First, measurements of vertical ground motion have been performed during 18 hours on surface (rigid floor) at point 3 which is located near a main road where there is much traffic. Measurements have been done from the 15th October 09 at 17h40 to the 16th October 09 at 11h40.

From 0.2Hz to 1Hz, frequency range corresponding to earth motion and especially to the microseismic peak, ground motion goes from 65nm to 76nm, which is low compared to measurements done in many other sites in the world (almost same data analysis performed) [11], but which may be much higher on a longer time scale.

From 1Hz to 100Hz, frequency range corresponding to cultural noise (that is to say, human activities), ground motion varies from about 12nm to 35nm between 17h40 and 8h00 (lowest values the night since human activities are reduced) and increases from 38nm to 65nm between 09h40 and 11h40 (beginning of the day), which is really reasonable and low compared to some other sites in the world [11]. However, the amplitude highly increases up to 240nm from 8h00 to 9h40, which is certainly due to traffic during rush hours since the increase of vibrations was observed from 3Hz to 30Hz, frequency range of traffic vibrations. Consequently, traffic can make ground motion be very high at the LNF site, and it is important to analyze if ground motion is less subjected to cultural noise in underground.

Measurements have been thus done during 20 minutes at point 1 (situated near a power plant and a main road where traffic is high) simultaneously on surface and inside a hole of 50m depth.

Results clearly show that ground motion is well attenuated in depth from 1Hz up to at least 100Hz, which corresponds to the entire frequency range of cultural noise. The huge increase of vibrations due to traffic observed from 3Hz to 30Hz should be thus well attenuated in depth, and the amplitude of ground motion should be low compared to many other sites in the world.

Note that the amplitude of vertical ground motion was also measured for 20 minutes during non rush hours the day on surface in three other locations (point 1, point 2 and another location whose floor is soft at point 3) situated in the proximity of various sources of vibrations. It was observed to be quite the same than the one of point 3 (around 70-80nm from 0.2Hz to 100Hz and around 30-35nm from 1Hz to 100Hz). This shows that ground motion measured during 18 hours at point 3 is well representative of ground motion of the LNF site. However, it should be noticed than the data analysis was done to get knowledge of the average amplitude of ground motion, and that the amplitude may vary much more for transient events (passage of trains, big tracks…).

Note also that measurements of ground motion done during 20 minutes simultaneously in the three directions at two different locations (point 1 and point 2) show that horizontal ground motion is not much higher than the vertical one compared to horizontal tolerances which should be much less strict than the vertical one. That’s why horizontal ground motion was not measured in the two other locations and during 18 hours.

Finally, measurements of ground motion coherence have been done for different distances at point 3 at two different locations close to each other but with two different floors: on the parking whose floor is soft and on the basement of the new guest house whose floor is rigid.

The results confirm that a rigid floor keeps the coherence at higher frequencies than a soft floor.

Moreover, a comparison has been done between these measurements and measurements of ground motion coherence done in the ATF2 beam line where a special floor was built for stability. Results show that the basement floor of the LNF new guest house keeps the coherence at much higher frequencies than the floor of ATF2 although it was not built for stability (it is not so stiff and also there are empty volumes below). Note that even the soft floor of the LNF parking gave better results than the one of ATF2 in terms of coherence.

As a conclusion, the LNF can be a very good site for an accelerator with beam size at the nanometer scale if the tunnel is built by taking into account two specifications.

First, the tunnel should be in underground since ground motion can be high in surface due to traffic but should be low in underground compared to many other sites.

Secondly, the floor of the tunnel should be rigid, so that very good ground motion coherence can be obtained.

For now, it is planned to build the Super B tunnel in 25m depth and to make the tunnel floor in stiff concrete plate especially in the final focus area. However, vibration tolerances are not yet defined, so it is not possible to tell now if it is needed.

7 FUTURE PROSPECTS

Other holes are planned to be made all around the future site of Super B in order to do other campaigns of measurements (transient, 20 minutes average, long time measurements) whose goal will be to confirm the good damping of cultural noise everywhere.

However, it takes time to perform all these measurements and it seems not so easy to make holes without water inside (a simple solution which may work would be to perform measurements on summer, but some more investigations have to be done).

That's why it will be very interesting to have vibration tolerances (amplitude, frequency range, which sections need to be stabilized) and informations about magnets (mechanical resonances, distance between final doublets) in order to know which measurements are important to do (underground measurements necessary or not, low frequency measurements to perform or not, coherence measurements up to which distance, at which locations of the future site measurements should be done).

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