Seismic noise at the 1500WA building

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This is a first study of the vibration noise of the floor platform of the test facility building located at middle of Virgo West arm (1500WA). This building hosts the Cryogenic Super-Attenuator test facility, the new clean room used for MS payload assembling and silica fiber production, and it will host the EIB-SAS for pre-commissioning measurements. These setups foresee precision measurements of mechanical transfer functions and modal studies, which can be affected by the seismic motion of the building floor. Aim of this study is to determine the level of seismic vibration of the 1500WA building floor platform, and in particular to determine if and to which extent building structural resonances amplify the soil seismic noise.

1. The 1500WA building

The 1500WA building measures approximately 30mx40m in width and 10m height. The building has no deep foundations. The foundation consists of a grid of armed concrete beams with 6mx14m cell spacing and about 2m in height below soil level (see **Figure 1**). The foundation grid supports the floor which is made of concrete slabs, and a steel frame anchored to the foundation grid which supports the walls. Walls are made of corrugated steel plates (two sandwiched foils 6 and 8 mm think with thermal insulator in between) bolted to the frame. These characteristics make the 1500WA building a much lighter and less rigid structure with respect to the Central Building, which has a very heavy foundation sitting on 30m deep pillars and has a double layer of steel plates walls interconnected to increase rigidity.

The 1500WA building hosts several machineries which act as vibration noise source: air conditioning, cryostat pumps, racks and vacuum pumping stations. Some run continuously and some have an on/off cycle. No thorough mitigation action of the noise emissions has been pursued; apart for machines which have been installed recently (i.e. HVAC serving the clean room has anti-vibrating supports).

2. Measurements

One single seismometer has been used. This is one Guralp 3TD, a tri-axial velocimeter with 0.001Hz to 100Hz response bandwidth. The seismometer has been deployed in four different locations on the building floor: two inside the SA tower pit (pos. 1 and pos. 2), and two outside (pos. 3 and pos. 4) as shown in **Figure 1**. The seismometer has been oriented with its "N" axis aligned along the Virgo North arm. The data sampling rate has been set to 250Hz, the maximum permitted by the Guralp digitizer, thus allowing measuring spectral noise up to about 100Hz. For three locations a six hour long seismic track has been recorded, while in the fourth location (pos. 4) a four-day seismic track has been recorded which also contains a period of intense wind activity. To characterize the soil seismic background we used a record of a few hour seismic data which was acquired with the same sensor deployed in the soil at 550mW along the West tube in the summer of 2009. The comparison with Central Building (CB) seism uses a two hours data synchronously recorded by the seismometer (Guralp mod. 40T, 0.03Hz to 100Hz frequency response range) permanently located on the CB ground floor next to BS tower.

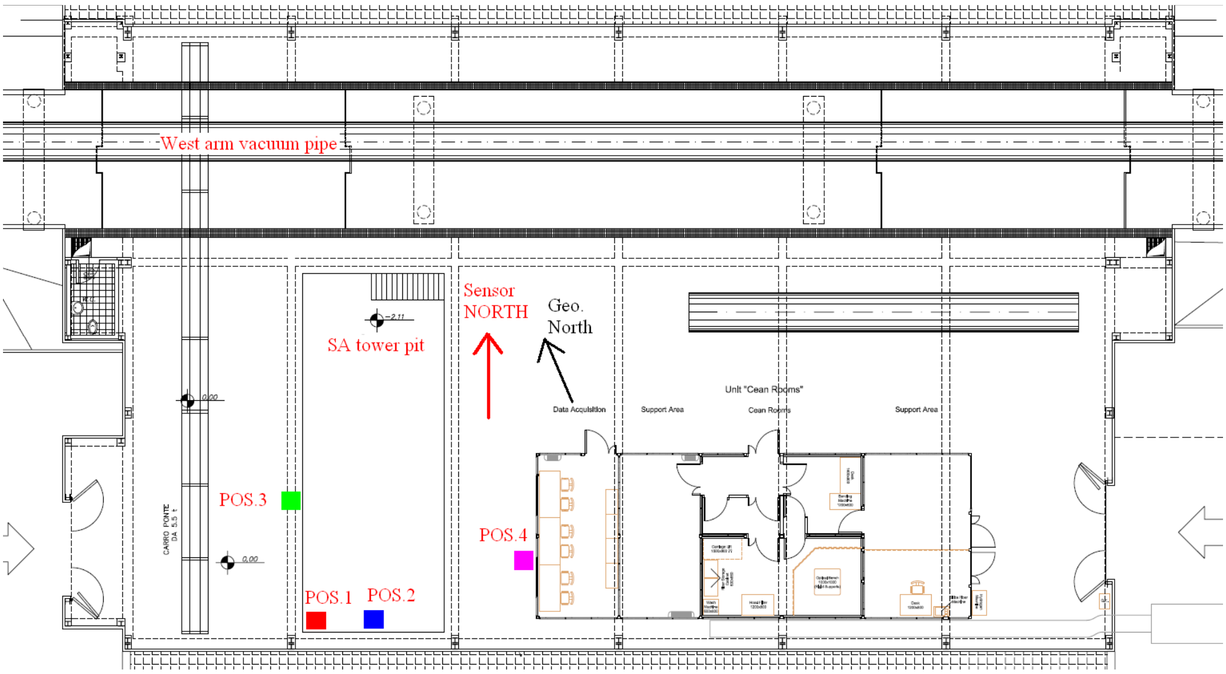


Figure 1. *Map of 1500WA building. Colored circles mark the sensor deployment locations: RED is pos.1 (inside pit, SW corner of pit), BLUE is pos.2 (inside pit, South side of pit), GREEN is pos.3 (SW corner of building), MAGENTA is pos.4 (West of computer room). Dashed lines represent the foundation grid.*

3. Seismic noise characteristics

Figure 2 shows the spectral seismic noise measured at pos.1 location during 6 hours. One can recognize persistent peak structures a few to some Hz in width: a first peak has central frequency of about 5Hz; a few narrow ones are between 5 Hz and 10 Hz; then several wider bumps up to 100Hz (the maximum measured frequency). **Figure 3** shows the average seismic spectral noise along the three orthogonal components, in the four measured locations (all spectra are taken during working hours and low winds condition). Data are not synchronous, however if we assume peaks are stable in time (as we might expect if they are due to structural resonance) the comparison is meaningful. We note that similar structures are present in all spectra: some peaks have similar central frequency although differ in amplitude. Other peaks are markedly different. Measurement in pos. 4 shows a marked prevalence of vertical motion above a few Hz. Measurements in positions 1,2 and 3 are more similar (locations are about 5m apart) and show a prevalence of vertical motion at structures between 5 and 10Hz and a prevalence of horizontal motion above 10 Hz. In the concluding section (Sec. 5) we attempt an explanation of these spectral characteristics.

It is interesting to compare the seismic noise of the 1500WA floor with the external soil and with the floor of Virgo experimental buildings. This is done in **Figure 4**. For the experimental building I take two hours of simultaneous data recorded at the Central Building floor by the sensor next to BS tower. For external soil I use seismic data recorded in summer 2009 at 550W close to the bridge crossing the Virgo West arm. Data were recorded using the same Guralp 3TD seismometer thus mis-calibration effects are unlikely. In order to avoid the measurement is spoiled by seismic transient due to crossing traffic I selected 1 hour of stationary data which I inspected to be free from visible transient events. However, this measuring site is located 1km far from 1500WA and effects of site noise sources as well as soil amplification effects cannot be completely excluded. Velocity spectra are compared in **Figure 4**: the seismic noise at 1500WA building floor is significantly larger than both at the external soil and at the Central Building starting from 10 Hz. The excess noise is a factor 50 at 30Hz.

This increased noise inside WA1500 shall be interpreted either as due to seismic emissions from local sources (Bd. infrastructure machineries mentioned above) or as amplification effects of the soil motion because of the structural resonances of the Bd., or a combination of both. Provided that a measurement with two synchronous probes inside and outside the Bd. would give a deeper insight on this issue, I derive some indications on the nature of the observed "peak structures" by studying the noise behavior in presence of intense wind, in the next section.

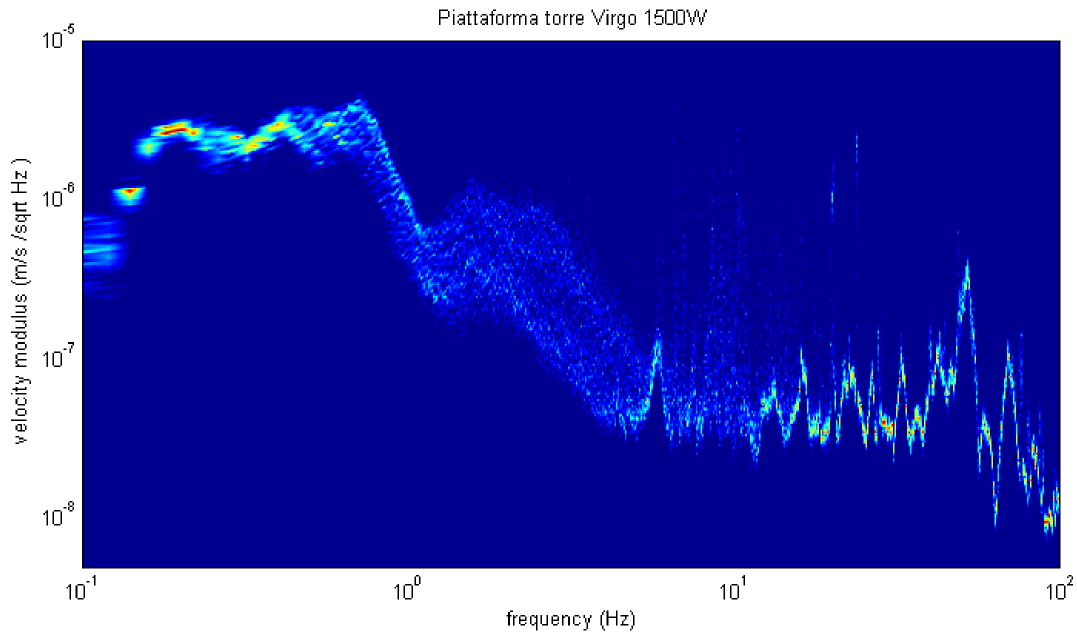


***Figure 2**. Spectral amplitude of velocity modulus measured in pos. 1 (pit SW corner). The graph is made with 6 hours of data. Data are sliced in 5minutes segments and FFT is computed over each segment with 0.02Hz resolution. The color scale indicates the persistency of the spectral amplitude over the 6 hours. The spectral amplitude of the velocity modulus is computed from the spectral amplitude of the three axis components as: $v = \mathrm{sqrt}(v_{NS}^2 + v_{EW}^2 + v_{vert}^2)$.*

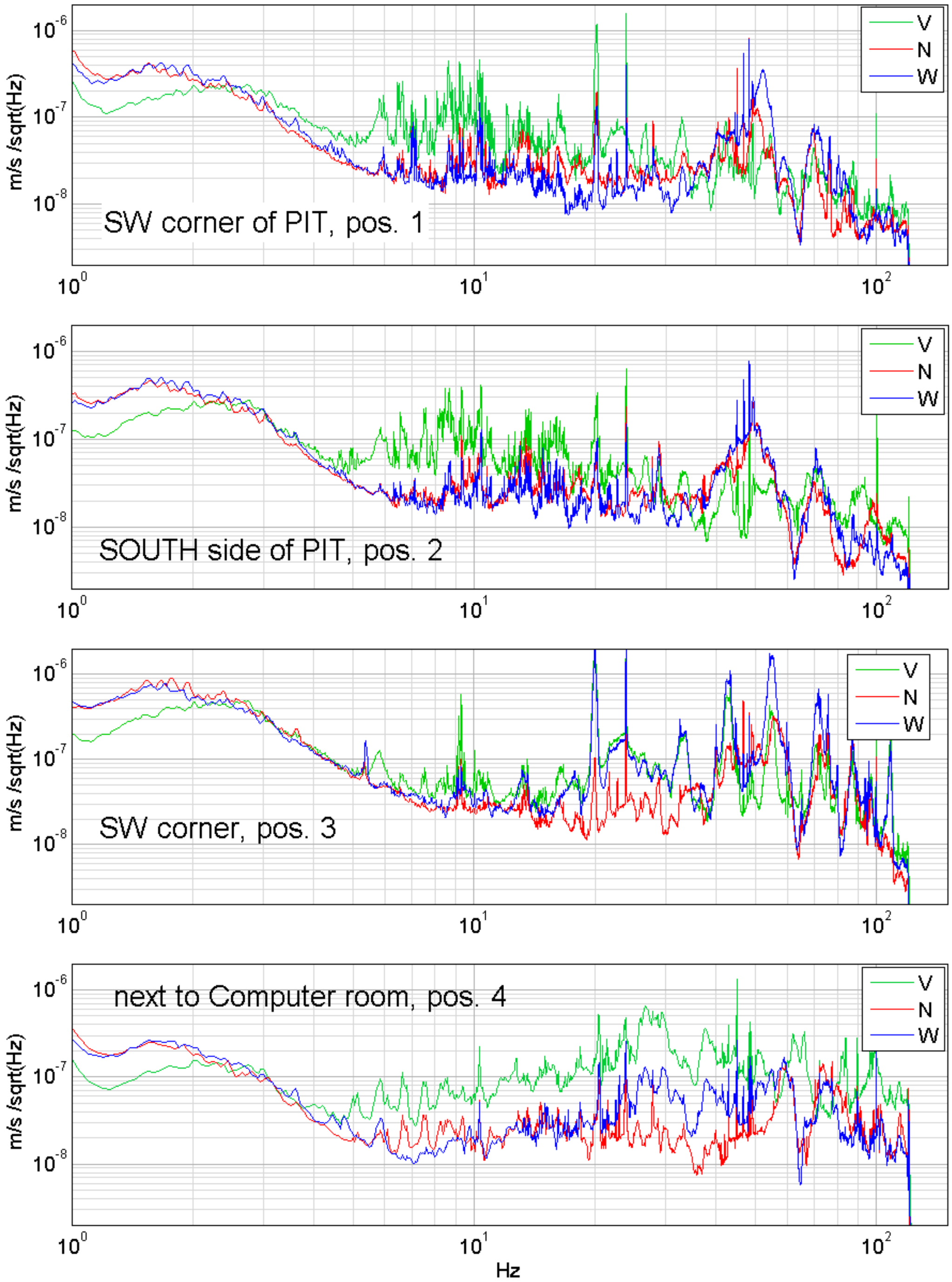


Figure 3. Spectral amplitude of 1500WA floor velocity measured at the four locations. From top we have: pos. 1 (inside pit SW corner), pos 2 (inside pit SOUTH side), pos 3 (SW corner of Building), pos 4 (outside of computer room). Are shown separately the three velocity components along the vertical (V), the horizontal direction along the Virgo west vacuum pipe (W) and the horizontal direction perpendicular to the Virgo west vacuum pipe (N). All four are averaged over 2hours time selected in similar conditions of anthropogenic noise (day-time) and winds (low wind).

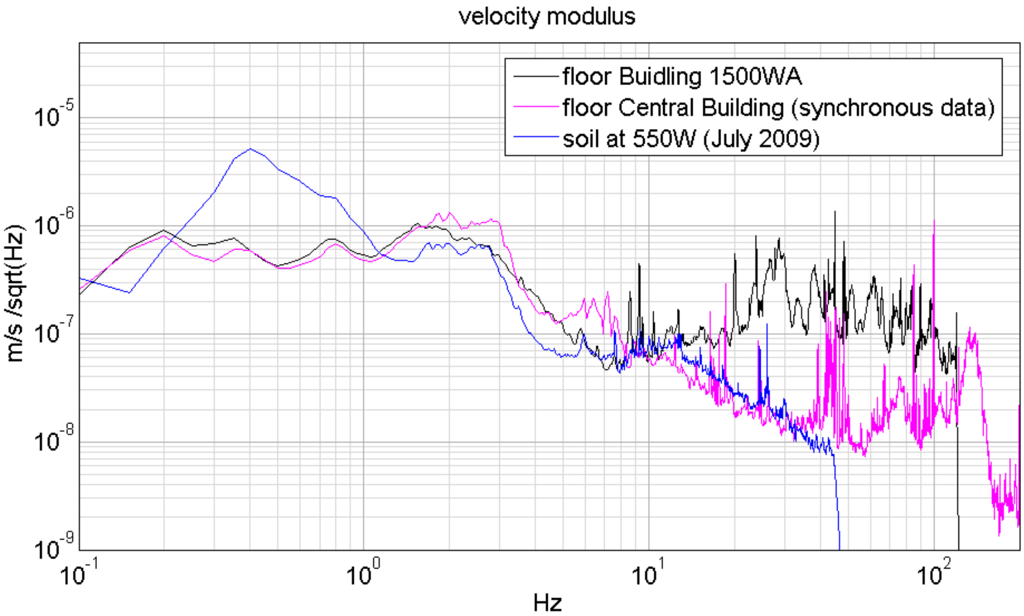


***Figure 4**. Spectrum of velocity modulus of 1500WA (FRI Nov 5 2010 3-5pm in Pos. 1, BLACK) is compared to the same quantity measured at the Central Building (FRI Nov 5 2010 3-5pm, MAGENTA color) and in the soil (seismometer dip in ground at 550W, data of FRI July 10 2009 9-11pm, BLUE color).*

4. Analysis of data in presence of intense wind

Figure 5 shows the evolution of velocity noise of 1500WA floor during a four-day long acquisition, starting at 15:00 UTC of Thursday November 4th 2010. In the first morning hours of Monday Nov. 8th winds from West increased in speed from less than 20 km/h to 50 km/h. Wind gusts reaching up to 70 km/h were as well present. Wind graphs are shown at top of **Figure 5**. As evidenced in magnified spectrograms of **Figure 5**, high winds correspond to an increase in amplitude of the 1500WA floor seismic noise in the entire measured bandwidth. In particular, noise amplifies at the above noted "peaks": the 5 Hz to 10 Hz peaks show a more marked amplification, the 10 Hz to 80 Hz bumps amplify less but definitely do. Spectrograms also show the "discrete" nature of the peaks amplification which occurs in short events lasting less than 100s (our spectrograms time resolution) and plausibly are due to the action of wind gusts (an exact time correlation with measured wind speed maxima is indeed not expected being the anemometer probe located on top of Virgo Control Bd. that is about 1.5km far from 1500WA).

These facts seem to us to demonstrate that seismic "peaks" of 1500WA floor cannot be due to noise generated by infrastructure machineries, but instead are structural resonances of the Building as a whole and/or of individual Bd. components.

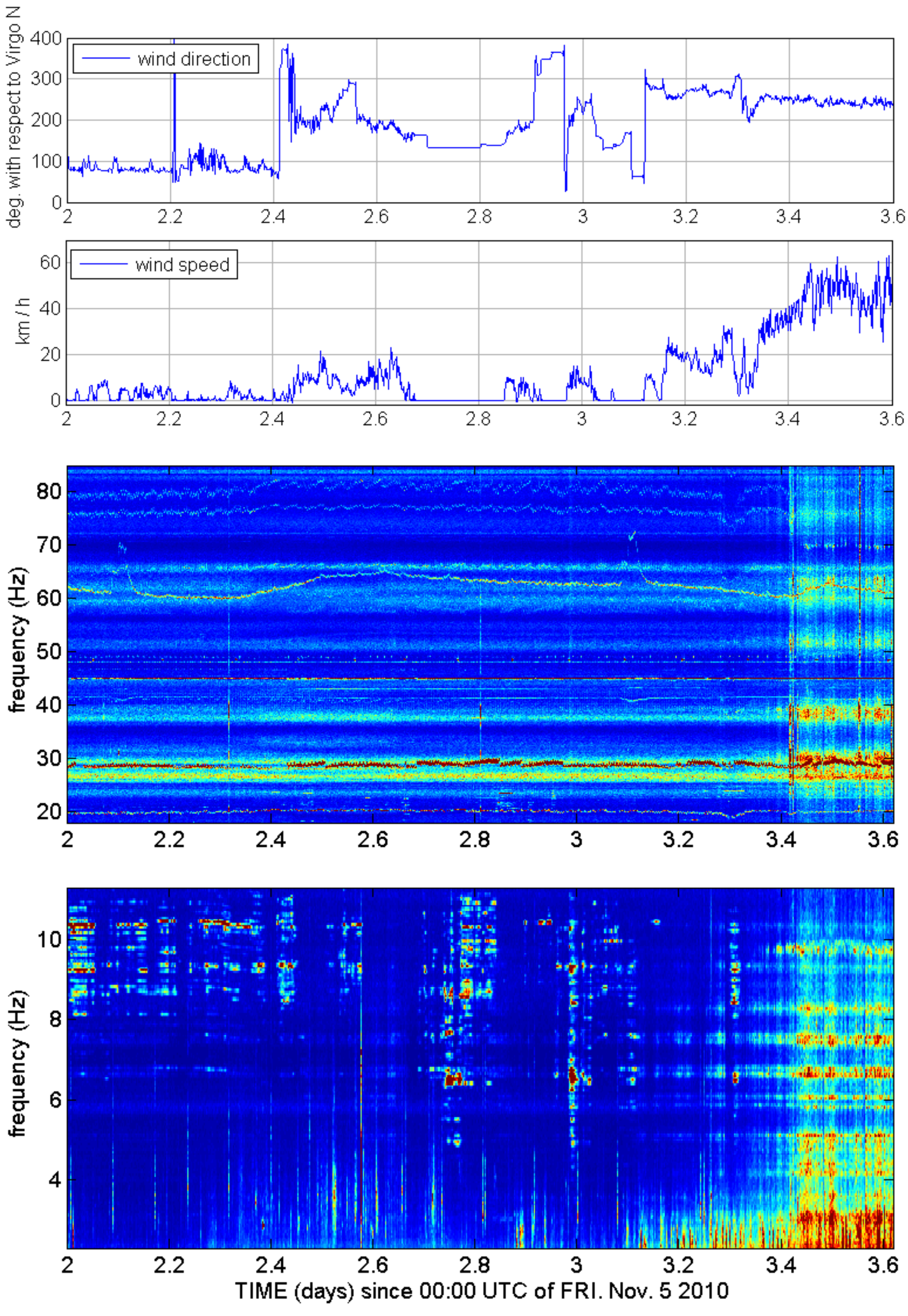
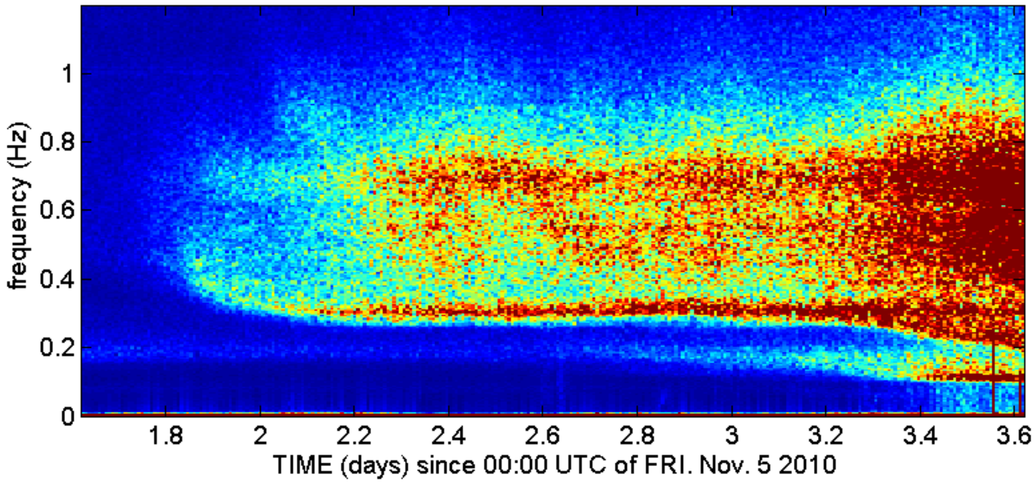


***Figure 5. Top**: wind speed and direction; **Middle**: spectrogram of 1500WA floor velocity between 15 Hz and 85 Hz; **Bottom**: spectrogram of 1500WA floor velocity between 1 Hz and 15 Hz. Around 6:00 UTC of Monday Nov 8th (TIME=3.4 days) the wind speed increased rapidly from 20 km/h to 50 km/h and wind gusts were present.*

We also inspected the frequency region below 1 Hz, looking for very low frequency modes of the building which might move “as a whole” with very long time period. Look at **Figure 6**. A general slow rise of micro-seism amplitude occurs starting from midnight of Nov. 7. One narrow peak at 0.12 Hz rises much later and apparently in correspondence to the wind increase. This peak could thus be suspected to be a building resonance. But, we drop this suspect as we realize that the same peak with similar characteristics is detected also at the CB floor. This 0.12 Hz peak should instead be interpreted as a seismic wave in the soil, whose origin does not concern us at the moment.



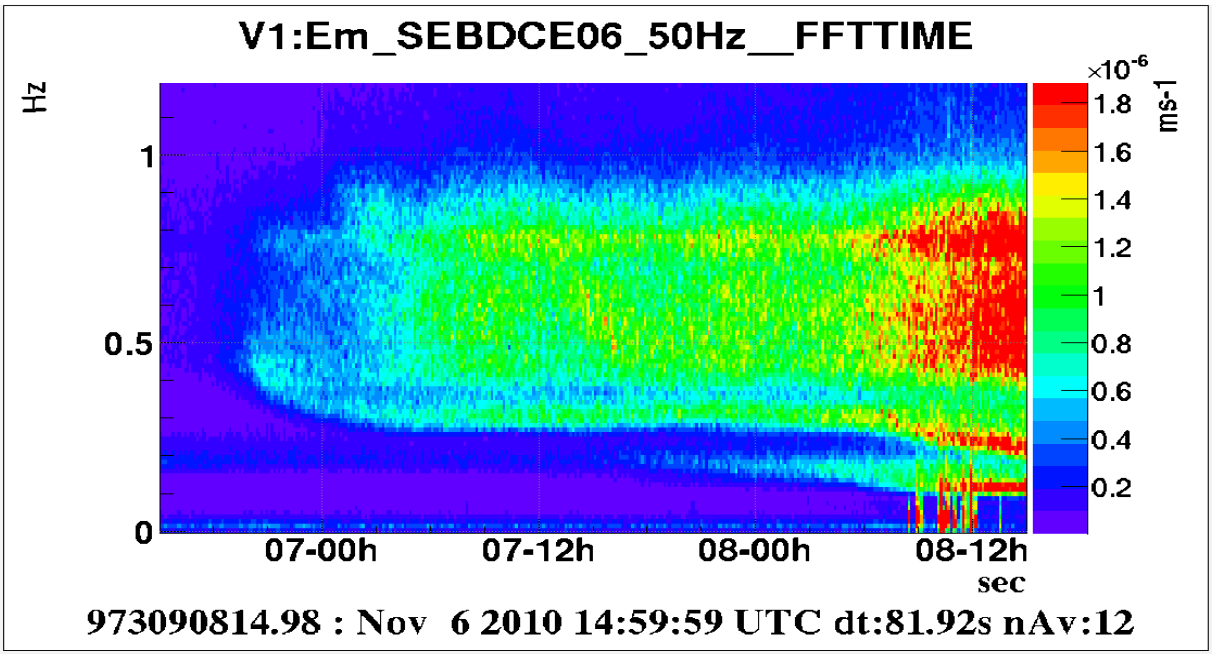


Figure 6*. Spectrogram of floor velocity in the microseism frequency band during the last two days of recording in position 4.* ***Top****: 1500WA building floor in pos.4;* **Bottom**: *Central Building floor. Synchronous times.*

The 1500WA floor amplification in presence of strong winds is better described in **Figure 7** which compares average spectra “with strong wind” and “without wind”, and in **Figure 8** which shows their ratio. The two time periods are picked at markedly different average wind speeds (<20km/h and 50km/h) but at same solar day times (between 10:00 and 12:00 LT of a working day). Thus I expect effects of anthropogenic noise to be similar, and the measured amplification shall be attributed to just the effect of wind force pressure on the soil and on the building walls. I measure and amplification of noise of about a factor 5 between 1Hz and 10Hz, and a less pronounced increase, of about a factor 2, above 10Hz and up to 100Hz. The noise amplification is similar for the velocity components along the three axes.

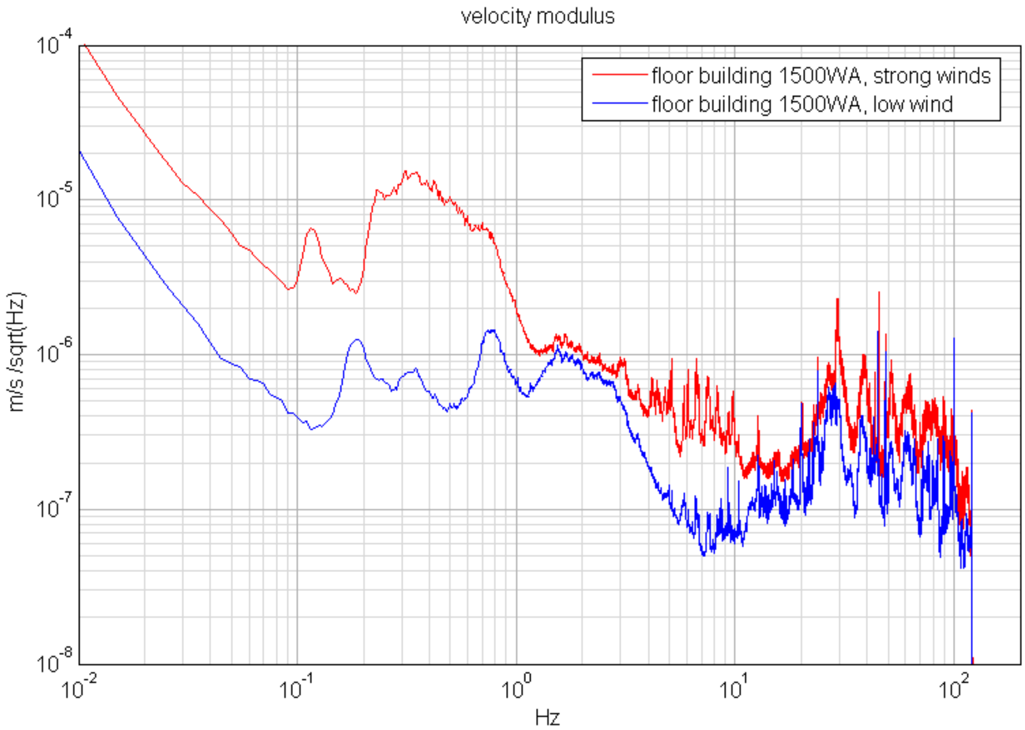


***Figure 7**. Spectral amplitude of velocity modulus of 1500WA (pos. 4) during a period of low wind and intense wind (see legend). Both spectra are averaged over the two hours period between 10am and 12am LT of a working day. Noise amplification below 1Hz is mainly due to increased sea activity.*

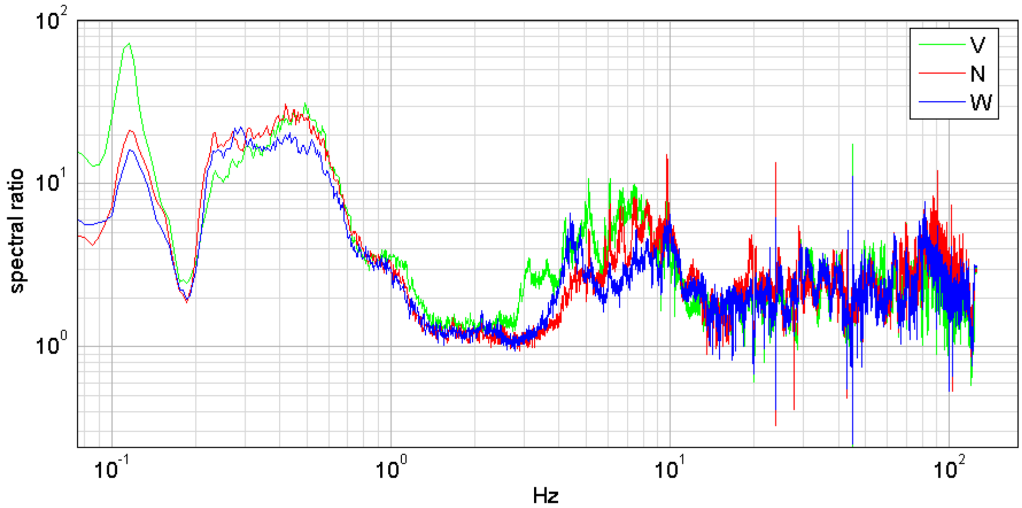


Figure 8. *Ratio of high-wind to low-wind spectra for the two selected periods in Figure 7. The ratio is computed for the individual velocity components along Vertical and orthogonal horizontal directions (N and W Virgo arms). This ratio measures the amplification of 1500WA building floor in presence of wind.*

5. Discussion and Conclusions

The 1500WA floor seismic noise is significantly amplified with respect to the external soil and it is significantly larger than Central Building floor. Amplification occurs at several peaks and bumps starting from 5 Hz and up to at least 100Hz. From the fact that peaks are excited by the action of winds we deduce they are mechanical modes of the Building structure. Seems that indeed a quite intense wind is needed to produce a significant amplitude increase; below 40 km/h wind speeds I could not evidence a correlation between wind and peaks amplitude. In conditions of “low” wind, I suppose these modes are excited either by the action of machineries inside the building or by the action of local traffic.

We examined 4 locations in the SW sector of the Bd. and found that peaks amplitude differs significantly. In particular floor in position 4 has a prevalent vertical motion, and I think this can be due to the fact that pos.4 is far from the foundation grid (see **Figure 1**) and it is thus sensing modes of the floor slab. On the contrary, position 3 corresponds to the position of a foundation beam and the measured seism shows less pronounced vertical amplification but a more pronounced horizontal motion along the Bd. long side (it might be a flexural mode of the foundation beam). Modes between 5Hz and 10Hz are present at all four locations and are more pronounced in the vertical direction. We do not evidence modes with frequency below 5 Hz.

The indication we derive is that the building moves not rigidly. It is interesting the comparison with the Central Building (CB) which from 10 to 100Hz moves much less (a factor up to 30) than 1500WA. The qualitative explanation is in the structural difference of the two buildings: the CB has been specifically designed to be massive and rigid and has a deep foundation (Section 2), while the 1500WA has a shallow foundation and a looser structure.

Having shown that windy periods help to evidence building structural resonances, it seems interesting to extend this type of investigation to Virgo experimental buildings. It is as well interesting to examine the soil motion in presence of winds. Studies in literature indicate that an increase in wind speed affects seismic noise over a wide frequency band (e.g., 1 Hz-50 Hz) [1]. It is interesting for us, in view of AdV buildings construction, understanding how much of the Bd. excitation occurs because of an increase of soil vibration, or because of the action of wind on the walls. A synchronous data taking with one internal and one external seismic probe could help investigating this topic. The Guralp 3TD is well suited for this application.

Bibliography

[1] Withers M.M., R.C. Aster, C.J. Young and Eric P. Chael (1996). "High-Frequency Analysis of Seismic Background Noise as a Function of Wind Speed and Shallow Depth". *Bull. Seism. Soc. Amer.*, 86, 1507-1515.

Acknowledgements

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