TINY VIBER

USER'S MANUAL

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*Note: some features of the software may
have been changed in recent versions;
the basic functions described in the manual still apply.*

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Introduction

The structural vibrations can annoy their occupants, determine the malfunction of the contained equipment contained and compromise their stability[1]. The criteria for measuring and assessing the effects of vibrations on buildings and acceptable threshold values are **not** currently regulated by national laws. However, there are technical standards which define these criteria both nationally and internationally[2]. Some used standards are summarized in the documents:

ISO 4866	"Guidelines for the measurement of vibrations and their effects on structures"
DIN 4150-3	"Structural vibration: effects of vibration on structures"
UNI 9916	"Criteria for the measurement of vibrations and the assessment of their effect on buildings"
UNI 9614	"Vibration measurement in buildings and annoyance evaluation"

The ISO 4866 standard establishes the methodology for signal testing and analysis. It classifies the different types of buildings based on their structure, foundations and soil. Furthermore, it classifies some factors that affect the degree of tolerance to vibration of the structure.

The DIN 4150-3 is the reference regarding the limits of the vibration which may be imposed to a building. It establishes a procedure for the assessment of the effects induced by vibration on structures, indicating the reference values to avoid the building damage. The appendix B of this standard describes the actions needed to reduce or completely remove the vibration effects. There are different evaluation methods depending on the type of vibration (continuous, not constant and/or impulsive) and the building type (home, office, factory, vibration sensitive structure).

The UNI 9916 does not provide well defined limits but a guide on the measurement methods, data processing and evaluation of the vibration phenomena in order to enable the analysis of the vibration effects on buildings. It refers to the DIN 4150-3 as a standard reference for the execution of the on-site measures. It also differentiates the velocity type between PPV (Peak Particle Velocity) and PCPV (Peak Component Particle Velocity).

The UNI 9614 regulates the conditions of physical wellness of the occupants of a building subject to vibrations. It prescribes to evaluate the acceleration comparing it to reference values according to the three dimensional axes. It differentiates the measurement period between day and night and the vibration type among continuous, not continuous and/or impulsive. This standard is supported by the UNI 11048 standard, for which it defines the measurement methods.

1 Damage: effect that the vibration causes to the buildings. The damage can be classified following the terminology used in seismology as:

- * *aesthetic damage*: cracks on the surfaces of drywalls or growth of existing cracks on plaster surfaces or on surfaces of dry stone walls; cracks in the mortar joints of brick or concrete buildings.
- * *minor damage*: open cracks, detachment and fall of pieces of plaster; cracks in blocks of brick or concrete surfaces.
- * *major damage*: damage of structural elements; cracks in the support columns; opening of joints.

2 Other standards related to vibrations phenomena are: UNI 10985, bridges and viaducts; UNI 10815 concerning the classification of tunnels; UNI 9942 concerning railroad galleries.

Warning!
This document is not intended to provide guidance or interpretations on the use of the indicated standards, for this purpose please refer to the texts in the Appendix and those mentioned above. It has been also tried to respect the terminology defined by these standards but it is possible that this was not done in a full and consistent way. Therefore, the reader is invited to pay attention and critically evaluate the reading.
In addition, many of the practical indications in this manual not always closely follow the standards. It is then essential to gather information by themselves and to carefully compare the standards with the given hints, especially when the measures are executed in safety sensitive contexts.

The software Tiny Viber
This document describes how the Tiny Viber software works. It is especially oriented to measure the buildings vibrations for the purpose of damage assessment, and only partially to describe the vibration annoyance

Before continuing with the description of the program it could be useful to describe the methods of measurement and calculation used by the software.

The text is therefore articulated in the following way:

- Information on methods for coupling the transducer
- Data types
- Information on the acquisition of the measure: length and sampling
- Method of data elaboration (from the samples time series to the seismogram in the final measure unit) in velocity (m/s) and acceleration (m/s^2), single component motion and particle motion
- Damage evaluation
- Annoyance evaluation
- Appendix

Coupling of the transducer

The fixing of the transducer should take place in order to ensure that it has the same motion of the structure. This can be achieved when its three tips never detach from the support base. In other words, the sensor mass should make it able to follow the movement of the base, thanks to its weight. The ISO 4866 indicates that the transducer should have a mass less than 1% of the vibrating structure and/or be fixed to it, for example, with expansion plugs, masonry, plaster, or adhesives (for accelerations of less than 1 m/s^2), resins, glues or even magnetic couplings (if your transducer allows it).

The ISO 4866 states that to fix the transducer to the ground is useful to bury the sensor down at a depth that is at least three times the largest dimension of the sensor, or to attach it to a rigid plate of proper mass (see the standard for details). However, even in this case the weight of the sensor may be sufficient, provided that the expected acceleration is modest (< 1 m/s^2).

It is strongly advised to not lean or glue the transducer on coating surfaces.

The orientation of the horizontal sensors should usually follow the major and minor axes of the structure. If the purpose is to measure the action to the ground by a source located at a certain distance, it is probably better to point one of the horizontal axes toward the source.

Data types

The collected data can contain different types of information depending on its type. The ISO 4866 standard refers to the classification listed on the ISO 2041 standard, with this tree structure:

- Deterministic signals
  - Periodic
    - Sinusoidal
    - Complex
  - Non periodic
    - Transient
    - Shock

- Random signals (white / white-pink noise)
  - Stationary
  - Non stationary

Measure acquisition: length and sampling

There is a classification on the duration of signals which implies the choice of the recording length.

This classification will not be shown here but generally defines a distinction between *continuous signals*, *intermittent signals* and *individual signals*, such as respectively heavy traffic on road, railroad and blasts. Depending on the classification of signal it will evidently be advantageous to record for several hours or tens of hours, for a few tens of minutes, or for a few tens of seconds.

The sampling of the vibration requires that the signal is generated by transducers capable of appropriately detect (or with sufficient resolution capability) the frequency band of interest. Consequently, the system must digitize the signal inside the same band.
The frequency ranges specified by the ISO 4866 standard are shown as reference.

Source	Frequency band Hz	Typical amplitude m	Typical velocity m/s	Typical acceleration m/s/s
Traffic on road and rail	1 -- 100	0.000001 -- 0.0002	0.000200 -- 0.050000	0.02 -- 1
Explosions (from the ground)	1 -- 300	0.0001 -- 0.0025	0.0002 -- 0.1	0.02 -- 50
Pile driving	1 -- 100	0.00001 -- 0.00005	0.0002 -- 0.1	0.02 -- 2
Earthquakes	0.1 -- 30	0.000001 -- 0.0002	0.0002 -- 0.4	0.02 - 20
Wind	0.1 -- 10	0.000001 -- 0.0002	< 0.000001	< 0.0000001
Industrial activity (from the ground)	1 -- 100	0.000001 -- 0.0001* (0.000001 -- 0.001)	0.0002 -- 0.1	0.02 -- 1
Industrial activity (inside the same structure)	1 -- 300	0.00001 -- 0.001* (0.000001 -- 0.0001)	0.0002 -- 0.1	0.02 -- 1

Notes
* The values given in parentheses are those indicated by the standard, at least in the edition that we viewed. These values are believed to be unrealistic or maybe subject to printing error as reported (quote) between 10 and 1000 micrometers for industrial activity outside the building and transmitted through the ground while between 1 and 100 micrometers for industrial activities inside the structure.

Note that it is also not plausible to calculate typical velocities and accelerations peaks (IV and V column) from the maximum amplitudes of displacement (column III) using the extreme values and/or point in the middle of the frequency band. In fact, the peak values of velocity and acceleration come from the sum of the various frequency components, with different results from time to time even within a single class of vibration source.

These frequency ranges don't expressly require the use of a particular type of sensor. The ISO 4866 standard indicates that the transducer can be accelerometric or velocimetric, of the piezoelectric type, electrodynamic type or other types (force-balance, MEMS, etc …). The sensor has obviously to properly resolve the signal of interest.

The rule discourages using digital processes of integration or derivation to move from one domain to another (velocity → acceleration and vice versa). Although the reasons are not highlighted, the literature (see the bibliography) shows that measurement errors can be avoided using the proper signal deconvolution methods.

The Tiny Viber software uses the frequency domain deconvolution method, accurately characterizing the measurement chain, allowing to use relatively cheap and high sensitivity sensors (electrodynamic geophones). These sensors may also don't strictly follow the standard requirements; this methodology preserves and improves the results reliability.

For example, in the paragraph 8.4.2.g the standard states that the minimum measurable amplitude of the recording system should be 10 micrometers/second. With our systems, normally used in seismology, you can reach resolutions of one nanometer/second (10000 times better than what required by the standard), even with geophones of 4.5 Hz natural frequency. These levels are often not achievable using most of the piezoelectric accelerometers commonly used for this type of measures.

The output files from Tiny Viber (as the final output of the measuring system) will therefore be adjusted according to the requirements of the ISO 4866 within the band of interest.

A further indication of the ISO 4866 standard is given in the paragraph 8.3. It states that to consider the registration meaningful the signal to noise ratio should be better than 5 dB, or that the transient signal to be analyzed must be 5 dB greater than the background environmental noise present in the absence of the transient.

Signal processing

The resolution capability of sensors used in seismometry is pushed to the limit, trying to detect signals in the frequency band from 0.001 Hz (1000 seconds) to 100 Hz, and with noise levels that should be lower than 1 nanometer/second (1×10^{-9} m) between 0.1 and 10 Hz.

The majority of the sensors is of inertial type (velocimeters and accelerometers), so it is also essential to correct the errors introduced by the measuring system to obtain acceleration from the velocity, the velocity from the acceleration and the displacement from one of the two inertial transducers.

The correction must include the proper phase corrections of the various frequency components of the recorded signal, both of the transducer and the measuring system.

Tiny Viber uses a deconvolution method (also known as instrumental correction) applied in the frequency domain, in order to obtain the original signal from the raw detected signal as closely as possible.

In general, when we have a motion x measured by the instrument g, we get the digitized signal y, ie:

$$y(t) = x(t) * g(t)$$

this is equivalent to convolve the signal x with the transfer function g of the instrument.

Therefore, if we want to go back to the signal of motion $x(t)$ we will need to take in account the convolution theorem. The theorem states the equality between the Fourier transform of a convolution of two functions and the product of the Fourier transforms of the functions

$$Y(f) = F[x(t) * g(t)] = X(f)\, G(f),$$

with $X(f) = F[x(t)]$ and $G(f) = F[g(t)]$

so that we can easily express both the transfer function and the recorded signal in the frequency domain, and perform a simple division

$$X(f) = Y(f) / G(f).$$

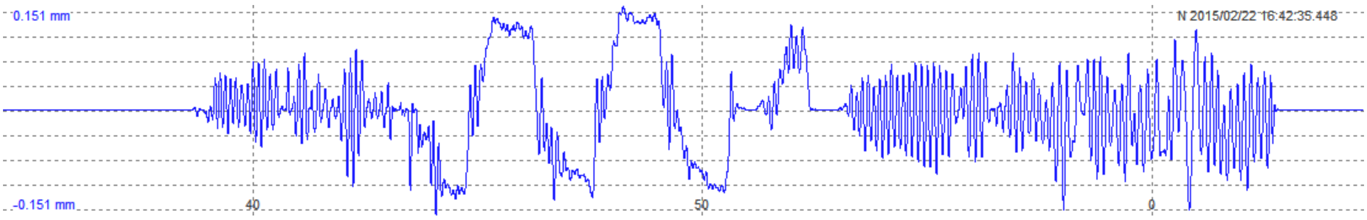
Then, through the operation of inverse transform we will have:

$$x(t) = F^{-1}[X(f)].$$

We can also perform other operations on the signal before the inverse transform. It is quite simple if we properly describe the transfer function using its poles and zeros. For example, you can integrate or derivate the signal respectively simply adding or removing a zero at the origin from the transfer function.

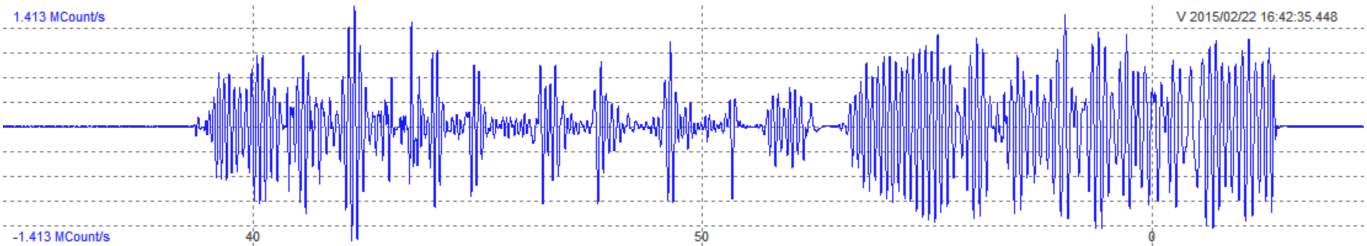
In the above calculations, the signal to noise ratio of our system must be very low and the function *G(f)* well described, otherwise the result will be altered by significant errors. In addition, the frequency band must be limited in the range of interest, otherwise may be introduced signals that have nothing to do with the sampled signal.

In the example below we see a raw signal recorded on a vibrating table with a capacitive position transducer.

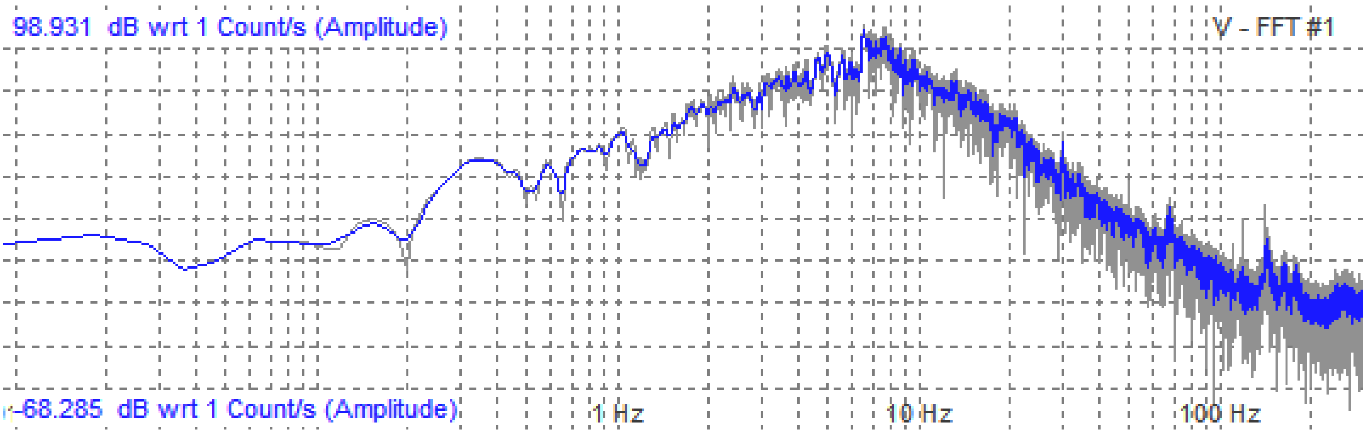


oscillogram in absolute displacement of the vibrating table

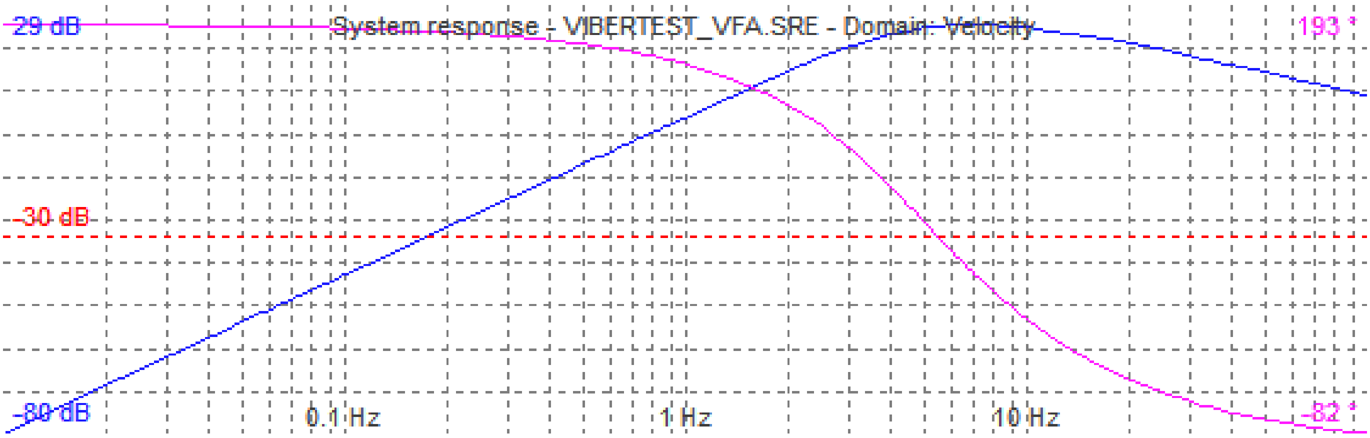
An oscillogram in velocity (*y(t)*) is detected by a geophone placed on the same table. The signal recorded by the geophone results to be:



which shows the following amplitude spectrum *Y(f)*:

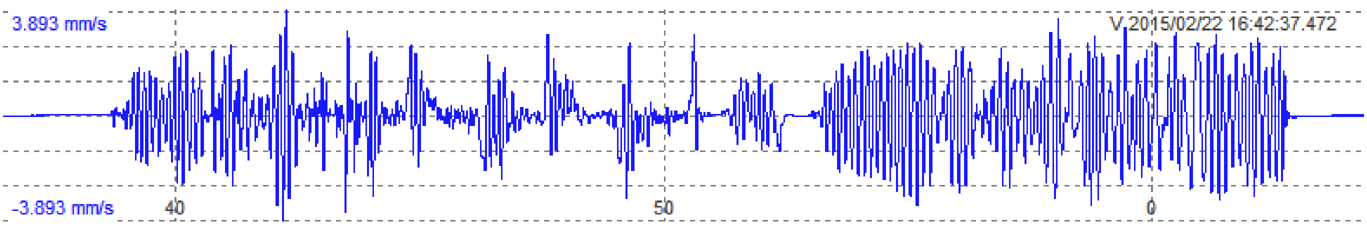


The geophone with its recording system are described as a transfer function *G(f)* by the following Bode plot:

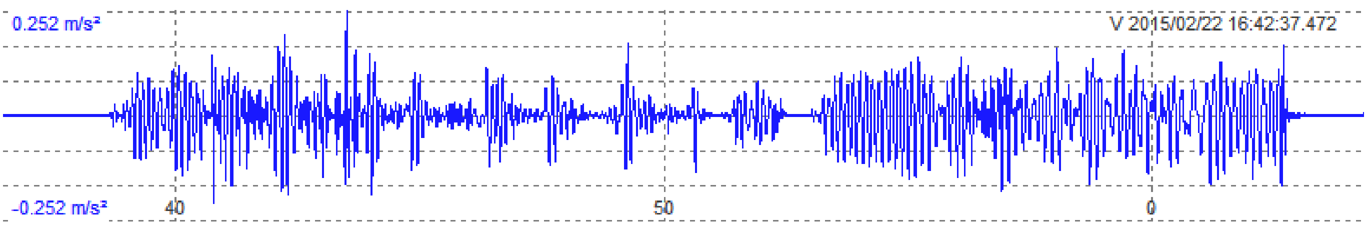


where the dotted red line (ref. -30 dB) is the limit of amplitude correction that will be applied to the signal.

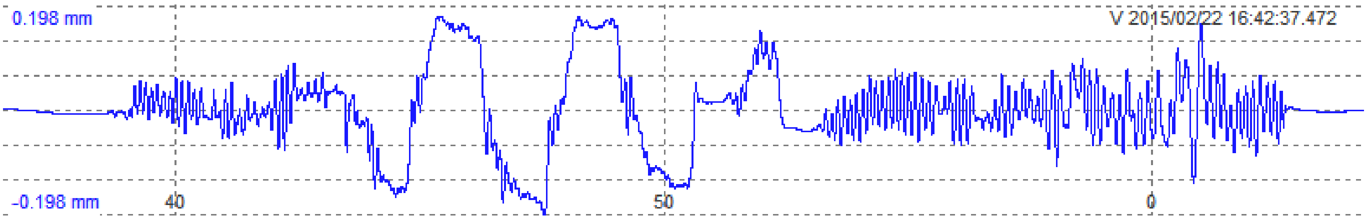
With the above described methodology we can reconstruct the signal in velocity *x(t)*:



and, through the subtraction of a zero from the transfer function, reconstruct the acceleration signal:

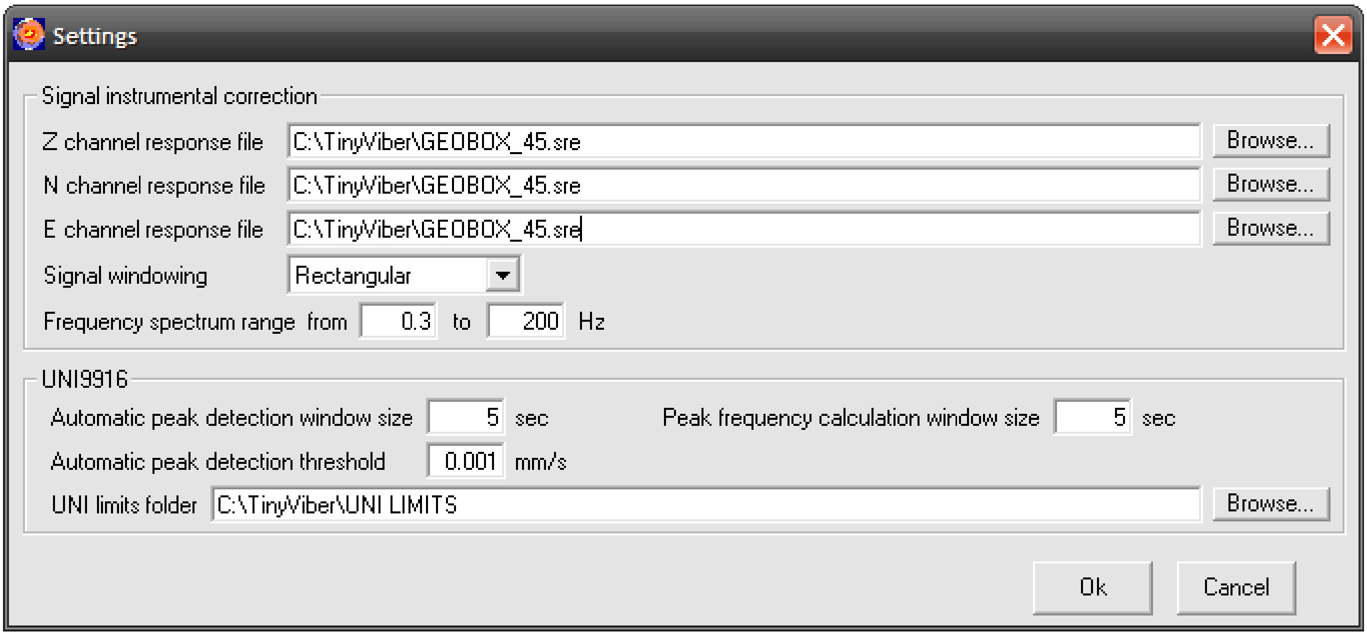


or, adding a zero to the transfer function, reconstruct the displacement signal:



Parameters that control the signal calculation

From the *Settings* menu of the main window you can control some parameters that control the instrumental correction process through the calibration, or response, files.



[Z – N – E] response file

These fields allow defining the instrumental correction channel by channel, although it is not always necessary to set a different response file for each channel because the sensors are usually quite homogeneous. However, it is important to differentiate the calibration file at least as a class of sensors or prepare an ad hoc file, depending on the recording system used. The creation of a calibration file can be a delicate operation so feel free to ask us how to do it without improvising.

Frequency spectrum range from - to

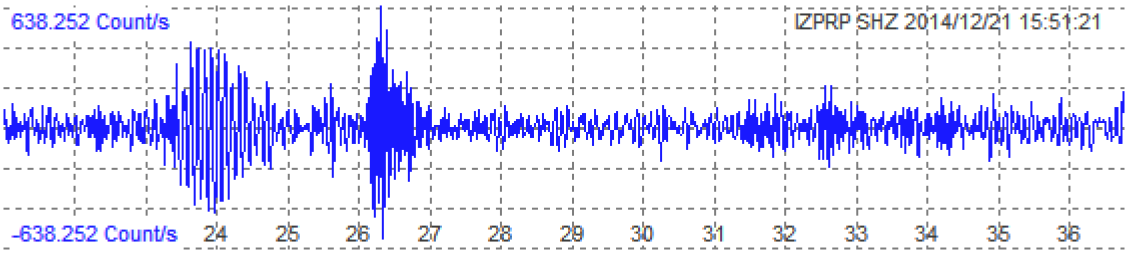
It is important to define the frequency range to be examined. Usually, when working with artificial vibration the frequency range of interest is higher than 1 Hz.

Sometimes it can be useful to examine frequencies of less than 1 Hz. In these cases it is necessary caution and knowledge of the instrumental limits of the seismograph. Each velocimetric sensor or accelerometer lowers the signal outside of his work frequency band but it is almost always possible to extend at least twice the explorable frequency range. For example, you can easily read signals around 2 Hz using a 4.5 Hz geophone (in this case half the base frequency) performing the appropriate instrumental correction. If the acquisition system is sufficiently powerful, the sensor has a good sensitivity and the detected signal is of considerable magnitude, you can

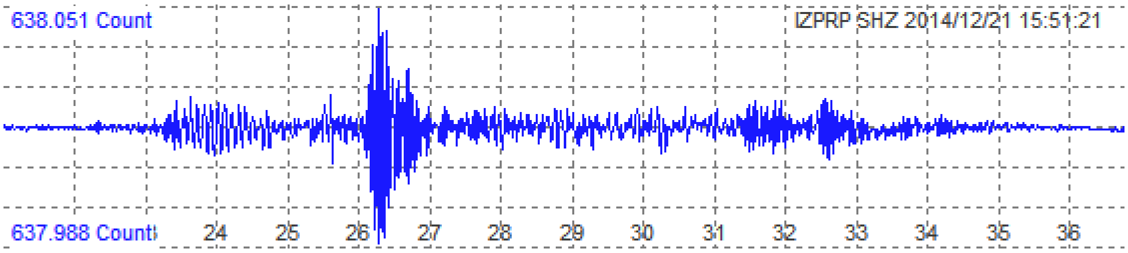
measure up to 10 or 20 times over the sensor frequency range (eg resolve up to 0.2 Hz using a 4.5 Hz geophone).
In these cases, however, are required caution and experience in evaluating the signal levels.

Signal windowing
You can define the windowing type to apply before performing the Fourier transform.
In fact, the Fourier transform is perfectly valid only for periodic signals (for example a sinusoid that origins and ends at the zero point of the ordinate axis). When the signals does not originate and/or terminate with periodicity (the transient signals or noise are not periodic by nature) there is a phenomenon of “loss” (*leakage*): the signal energy results distributed on frequencies different from the real ones. You cannot completely avoid the leakage especially in the DFT (Discrete Fourier Transform), used in the numerical treatment of signals.
The windowing tries to artificially recreate a kind of periodic nature of the time series, reducing to zero the intensity of the analyzed signal at the beginning and at the end of the series of samples.

For example the signal:

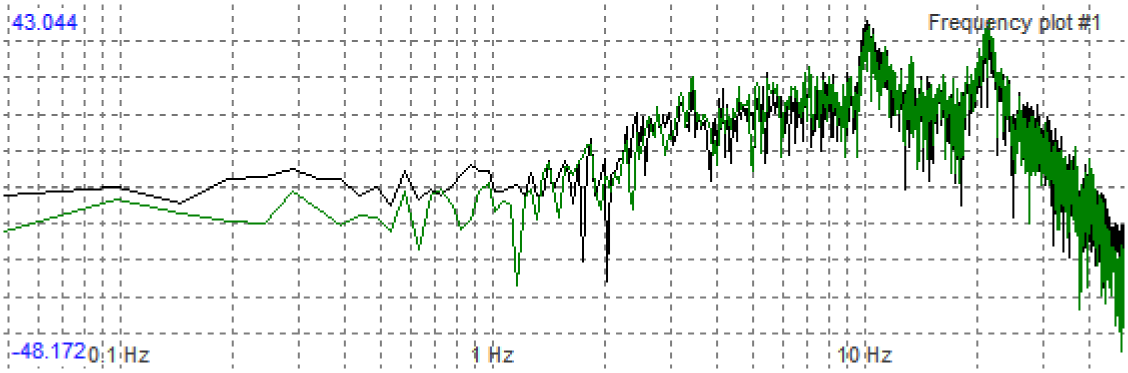


after Hamming windowing becomes:



with an amplitude reduction at both ends of the time series.

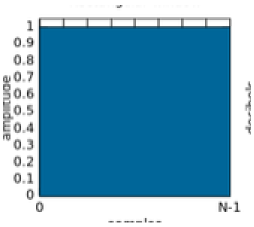
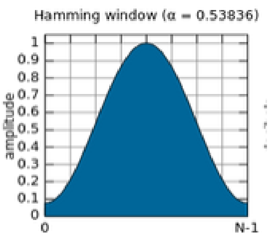
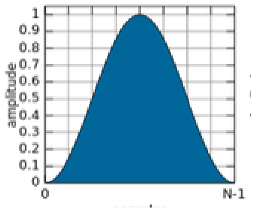
Here the spectra (green with windowing and black without windowing) of the signal above.

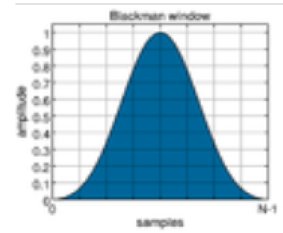
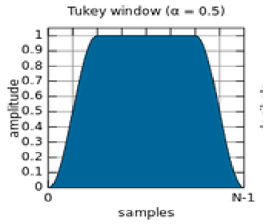


The results are not so different because the signal energy of the source was prevalent in the central part of the seismogram. In the neighborhood of 1 Hz some level differences became apparent.

Through the choice of the windowing type the measurement error is reduced; the choice should therefore be guided by a qualitative assessment of the type of signal.

The following table lists the available windowing types and their characteristics.

Signal Type	Recommended windowing type	Graphic of the treatment
Short-term transient which are concentrated in the central part of the seismogram.	Rectangular (no windowing). All samples are treated without any alteration in their amplitude for the entire duration of the time series.	
Transients or signals longer than the total time of the seismogram or that overflow before the beginning or after the end of the seismogram.	Hamming.	
Signals generally constant but of unknown origin.	Hann (or Hanning). If in doubt whether to use Hamming or Blackman may be preferable to use this windows.	

Continuous and mainly periodic signals	Blackman. It increases the accuracy of the peak level of the signal, useful for the definition of the signal level in the annoyance evaluation.	
Constant background noise or pink-white noise.	Tukey. This windowing modifies the signal with a gradual increase and a symmetrical “fade” ending, without altering the amplitude in the central part of the seismogram.	

Automatic peak detection window size and *Automatic peak detection threshold*
According to the UNI 9916 standard all the most significant peaks of the signal have to be analyzed. Tiny Viber searches and automatically selects the local peaks using an algorithm with a sliding window of fixed size.
The first parameter controls the size of that window in seconds; the second parameter indicates to discard the peaks whose amplitude is below the inserted threshold.

Peak frequency calculation window size
The DIN 4150 standard, referred by the UNI 9916 standard, states that the dominant frequency of each examined peak has to be calculated taking into account a portion, or window, of the signal centered on the peak.
This parameter defines the size of that window. Just as reference, the example provided in the standard uses a window size of 1.28 seconds. As Tiny Viber does not allow indicating fractional lengths, the default value is 2 seconds. Expanding the size of the window allows a better definition of the frequency, but involves the risk of including signal that has no direct relationship with the transient under analysis.

Damage assessment

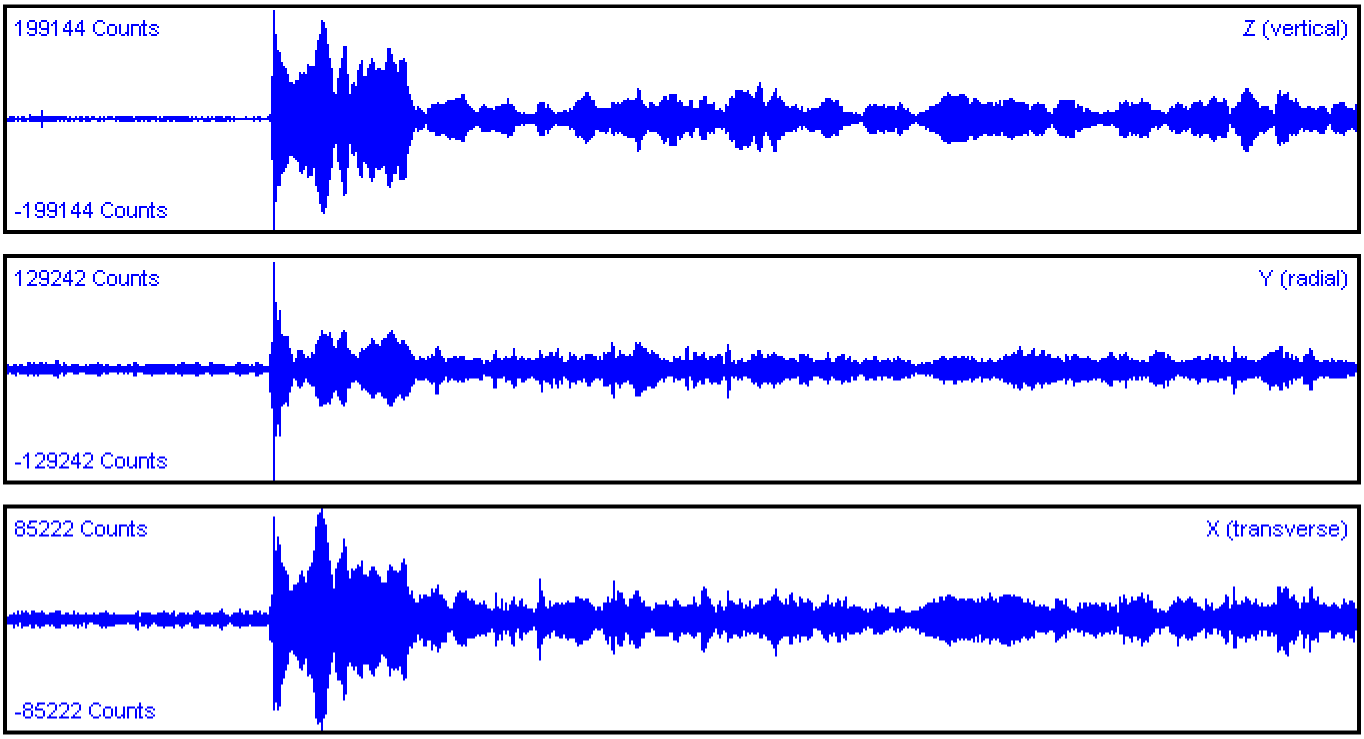
Here is an example of the assessment of damage threshold for a recording made during a ground compaction, about 300 meters away from a residential building (bricks and stones building of 3 floors).

The raw acquisition has been made with a set of 4.5 Hz velocimetric sensors; the instrument was placed on the third floor (attic) because we wanted to examine the likelihood of damage to the roof elements (brick tiles).

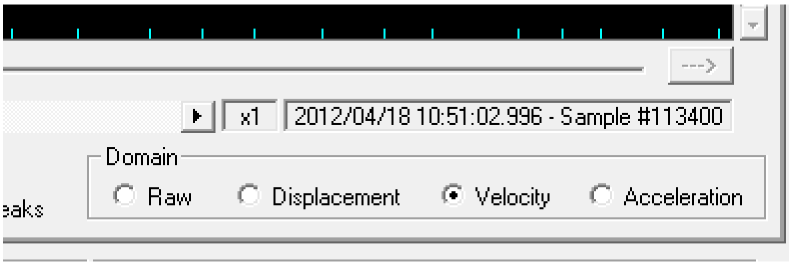
After loading the proper calibration files, settings have been adjusted as follows:

- frequency range: 1 - 180 Hz;
- peaks search window: 10 second;
- peaks detection threshold: 500 micrometers/second (0.0005 mm/s);
- peaks frequency calculation window: 10 second.

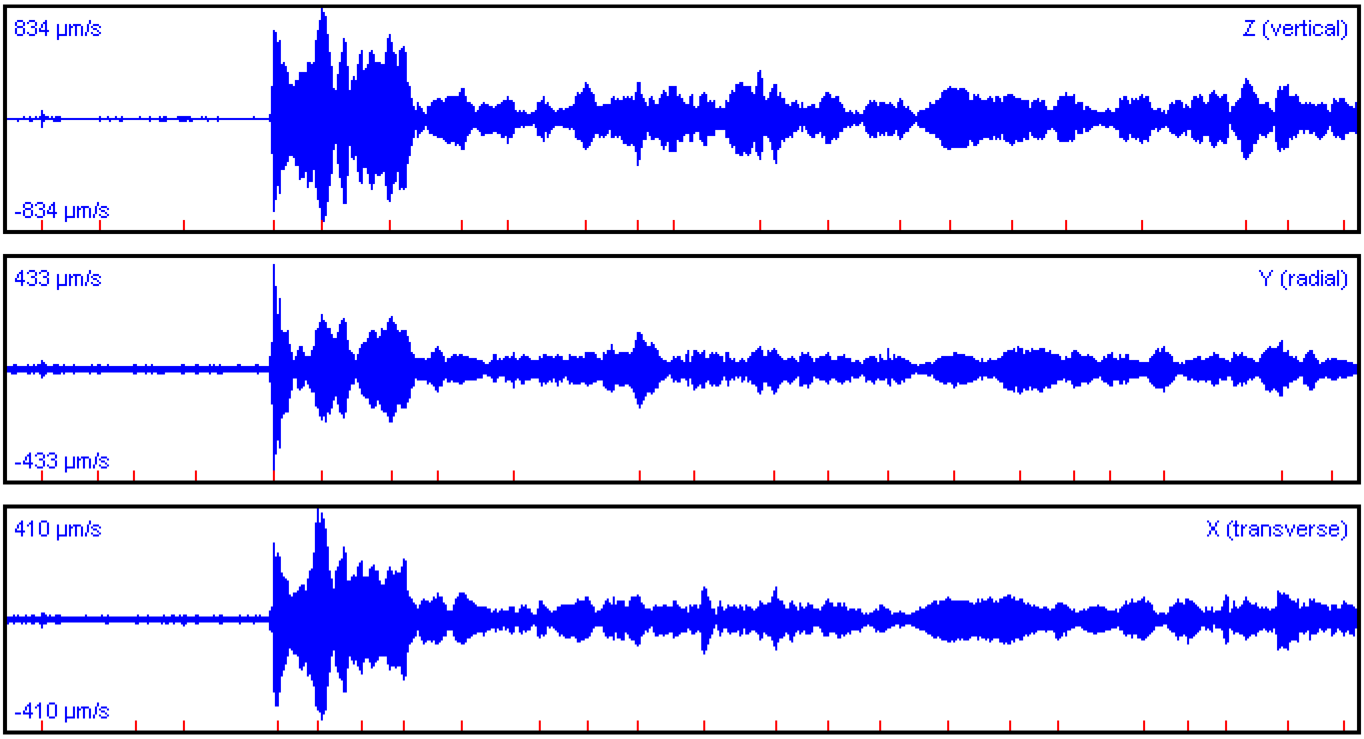
The acquisition file is loaded using the *File → Load signal* menu.
The selected file is loaded, and the raw data is shown in the figure:



Acting on the *Domain* box, you can view the signal in displacement (*Displacement*), velocity (*Velocity*) or acceleration (*Acceleration*). If the options are not active, it means that the system response files are missing.

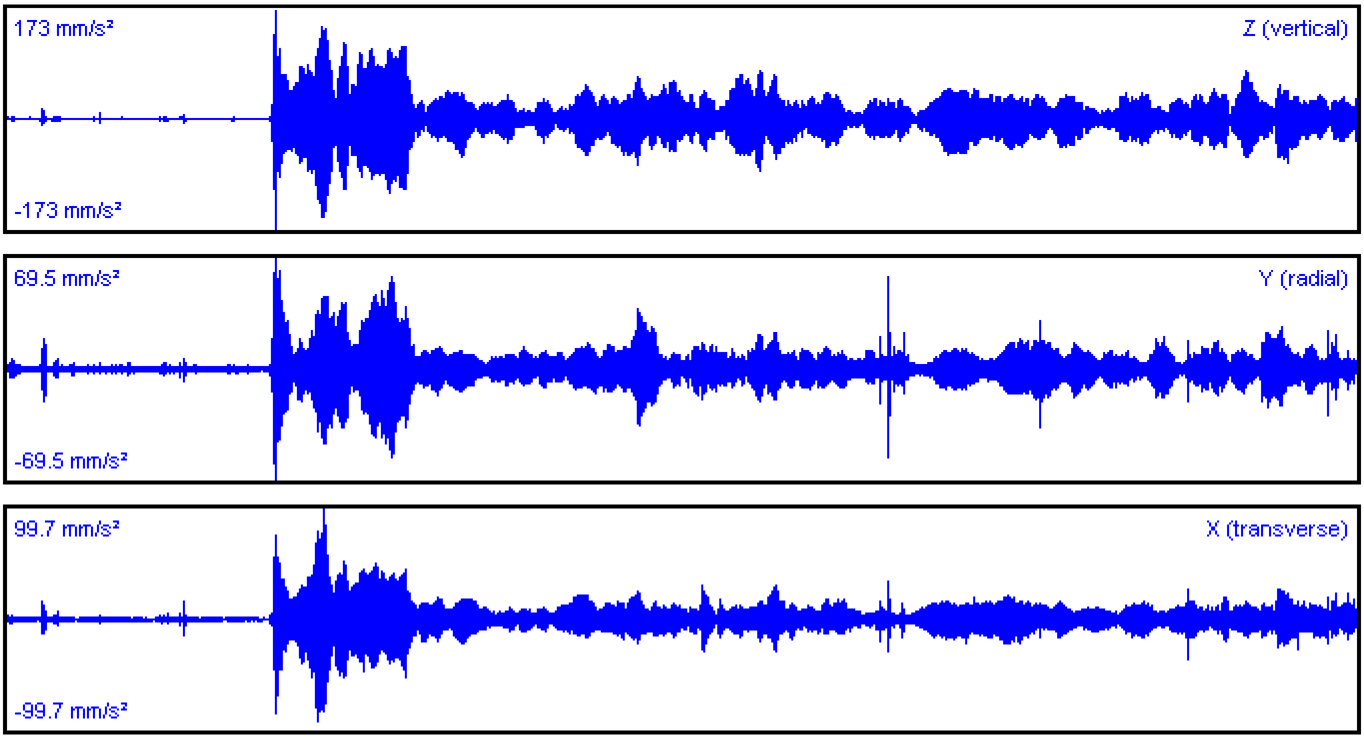


The velocity graph is the following:

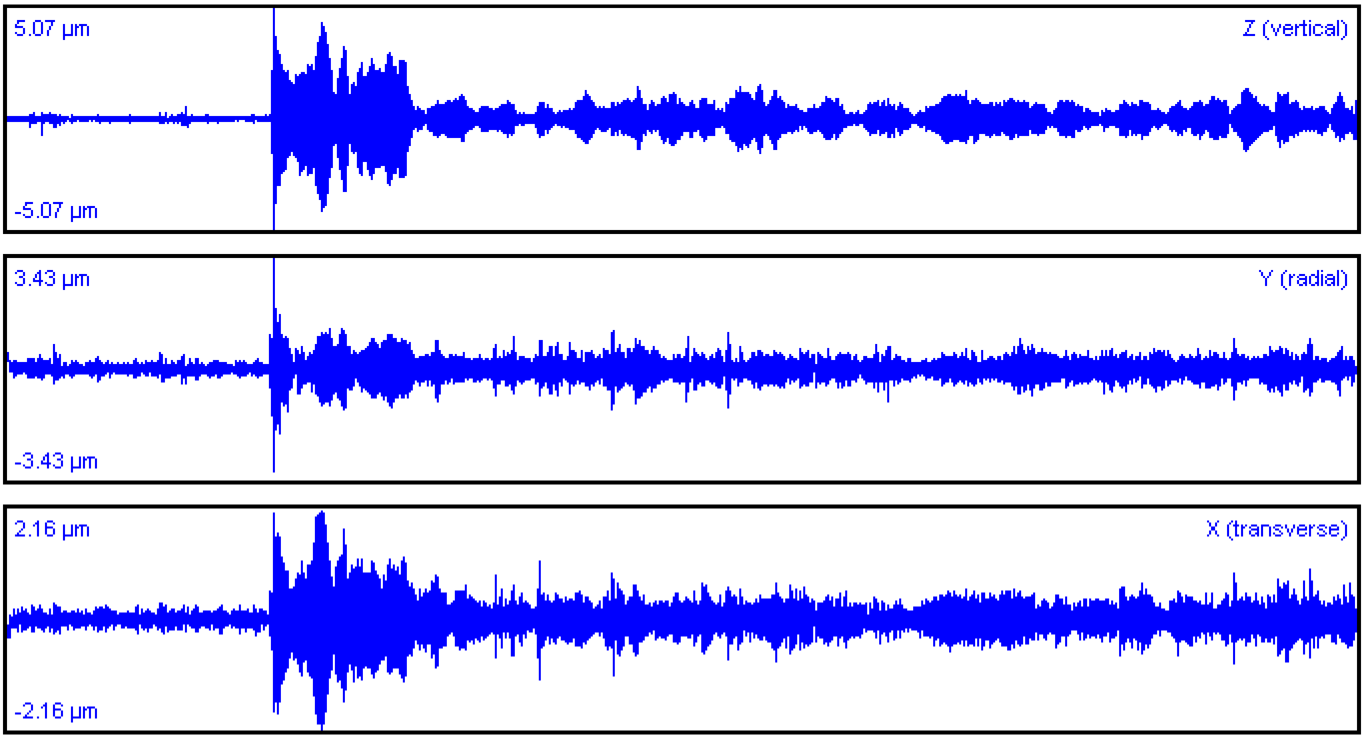


The red markers (in the program on the screen are blue) indicate the position of the local peaks of the signal, found according to the search parameters.

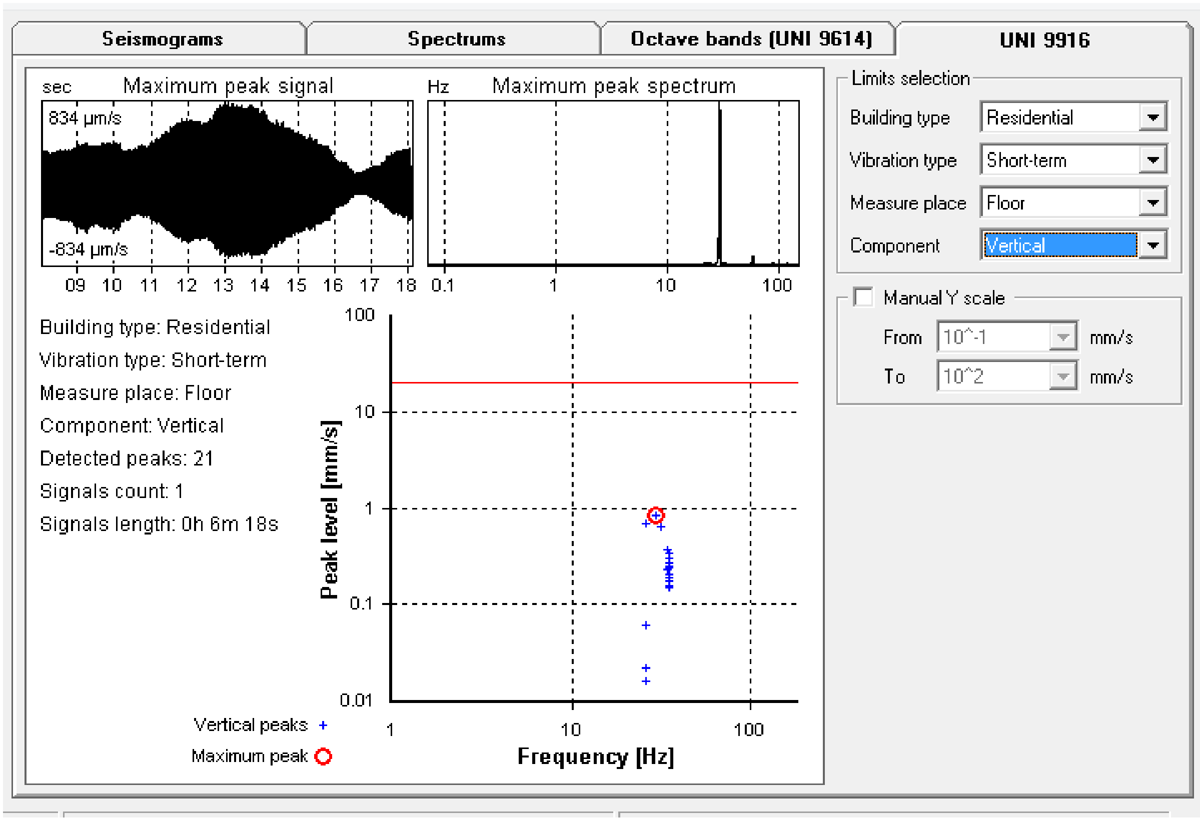
This is the diagram in acceleration:



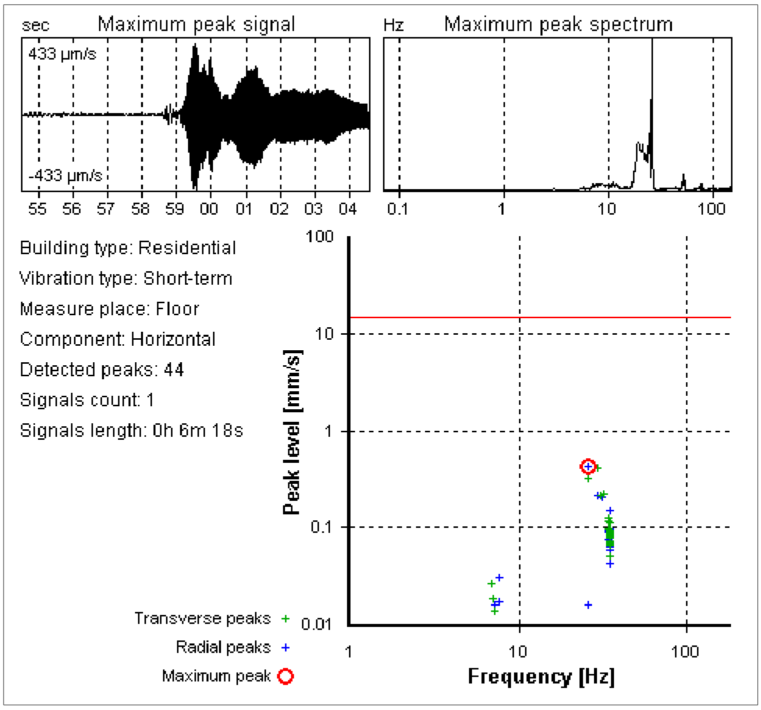
This is the diagram in displacement:



Clicking on the *UNI 9916* tab you will have to select the appropriate limit according to the acquisition conditions. In the example, the survey had been made on a residential building, with vibrations of short duration and placement of the sensor on a floor. In the figure below it is shown the examination of the vertical component.



Each blue marker shows the positioning of the peak of the signal based on its dominant frequency and on the peak level.

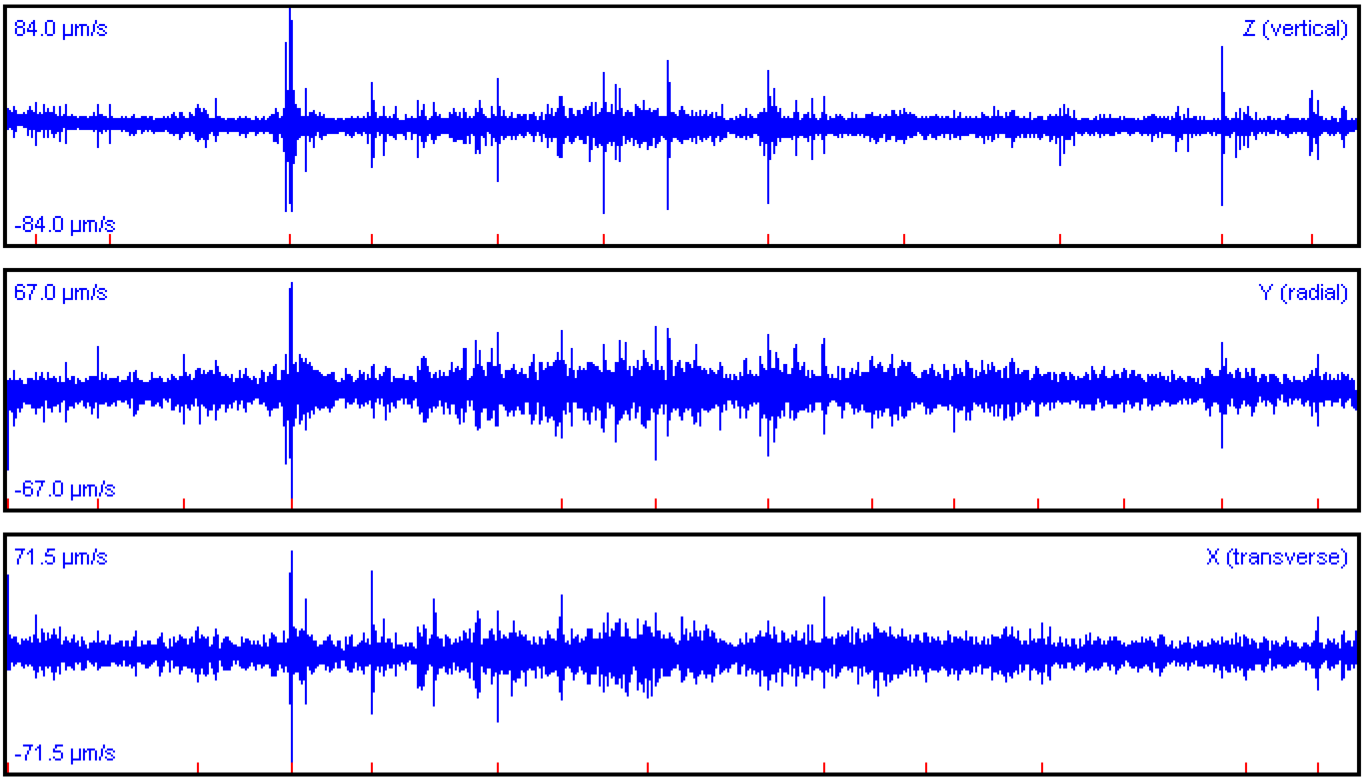


The figure on the left shows instead the peaks found for the horizontal components (green and blue).

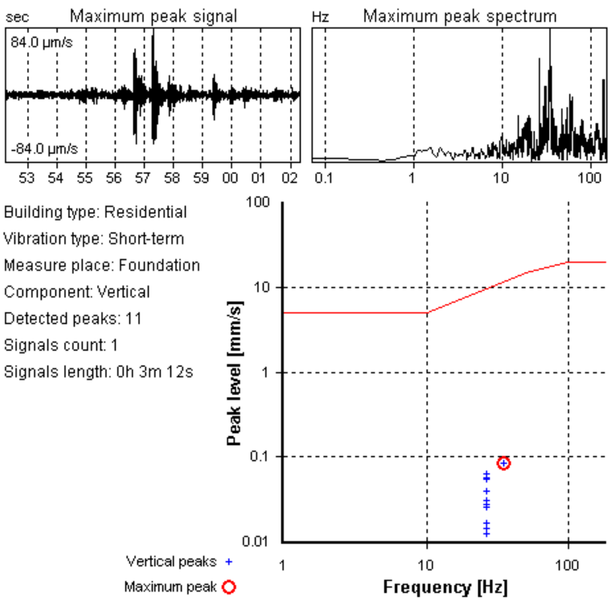
The red circle highlights the measure absolute maximum, which is also represented in the graphs above, the seismogram on the left and the spectrogram on the right.

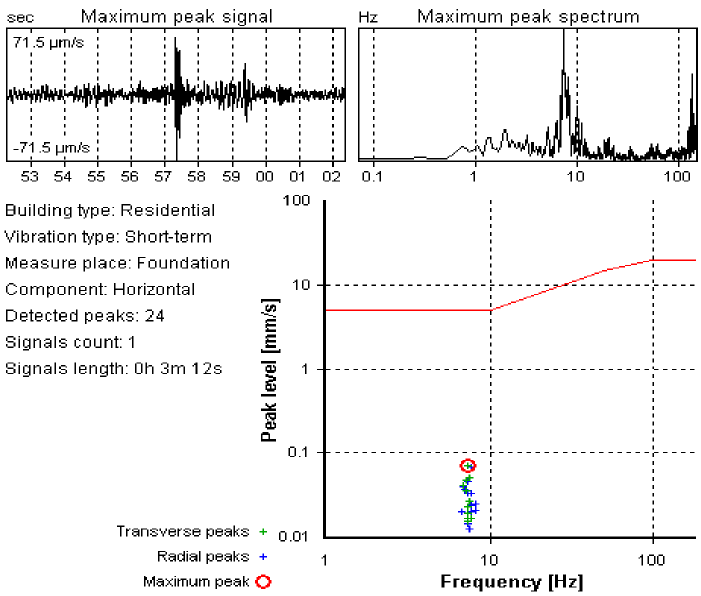
For this measure, and for the selected acquisition parameters, the limit expressed by the standard and indicated by the red line has not been exceeded, nor for the vertical component nor for the horizontal ones.

In this second example, regarding a measure of a completely different type, it was examined the behavior of the soil during the passage of some vehicles.



The representation of the detected velocity peaks is the following:



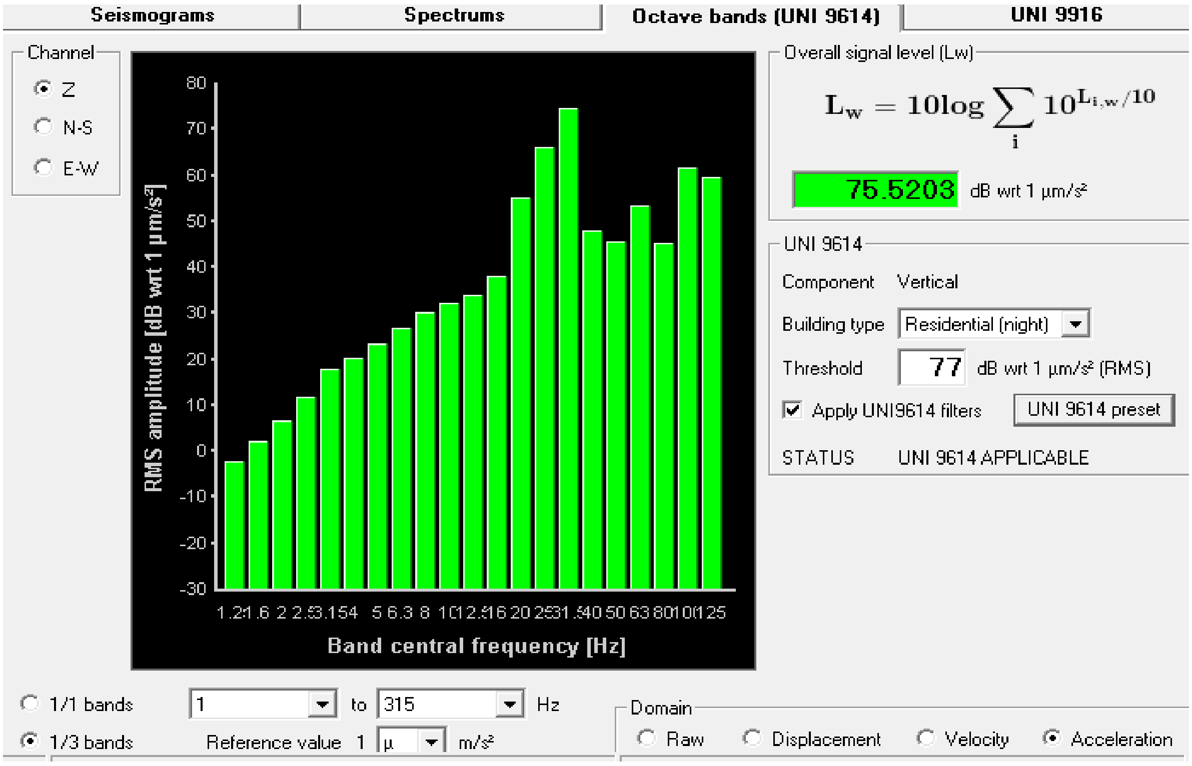


Also in this case, the limits indicated in the UNI 9916 were not exceeded. Furthermore, in this case the threshold is variable as expected for the measures on the ground, lower for low frequencies (<10 Hz) and more tolerant for frequencies higher than 10 Hz.

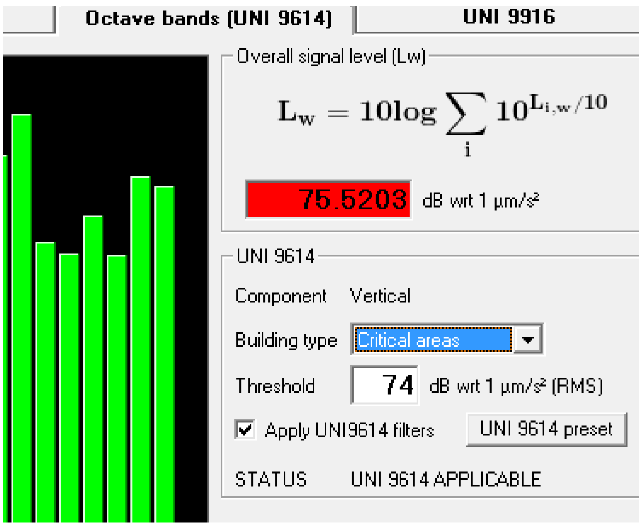
Annoyance evaluation

In the example above, the damage thresholds had not been overcome. However, the vibration sensation inside the building was remarkable. What would have happened examining the signal according to the UNI 9614?

The *Octave bands (UNI 9614)* tab must be activated. The reference settings for the UNI 9614 standard can be activated by pressing the button *UNI 9614 Preset*.



The limit for residential areas at night time, 77 dB wrt 1 μm/s^2, would have not been exceeded. If the building would have been considered a critical area (hospitals or buildings of particular historical or artistic importance) the limit (74 dB) would instead have been exceeded.



Appendix A

Below is a list of references regarding standards, articles and publications; if present on the Internet the last verified link is shown next.

- UNI 9916 - "Criteri di misura e valutazione degli effetti delle vibrazioni sugli edifici".
- DIN 4150-3 "Vibrazioni sulle costruzioni, effetti sui manufatti".
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