SONELASTIC
Advanced Impulse Excitation Technique

Installation and operation manual

Sonelastic® Software

6.0

Sonelastic® Division, ATCP Physical Engineering

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Software for elastic moduli and damping
determination of materials by the
Impulse Excitation Technique

Developed by:

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Brazilian Industry

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1. Introduction

ATCP Physical Engineering equipment and products were projected and manufactured to provide a long-lasting and top-rated performance. This Installation and Operation Manual contains all necessary information regarding the use and maintenance of Software Sonelastic®.

Read this manual carefully before using the software. Improper use may damage it and affect its performance.

2. Definitions

Impulse Excitation Technique: The Impulse Excitation Technique is a non-destructive technique to determine the elastic moduli and damping of materials by the resonance frequencies of the test specimens. ASTM E1876 is the main standards related to the Impulse Excitation Technique.

Resonance frequencies: Specimen natural frequencies of vibration.

Elastic modulus: Elastic modulus or Young's modulus is defined as the slope of the stress-strain curve at the elastic region, as described by Hooke's Law. The elastic modulus determined by Impulse Excitation Technique is termed as dynamic elastic modulus.

Damping: Damping is the phenomenon by which mechanical energy is dissipated in dynamic systems. It is directly linked to the presence of defects and to the material microstructure.

3. Applications and features

Sonelastic® Software is dedicated to non-destructive characterizations of materials' elastic moduli and damping by Impulse Excitation Technique, according to the ASTM E1876 and correlated standards. Sonelastic® Software was developed to be used alongside Sonelastic® Systems.

Sonelastic® Software is a transient vibrations' analyzer from which it extracts the frequencies for elastic moduli calculation and the respective decay rate for damping calculation. The software identifies the resonance frequencies and respective damping ratios by processing the specimens' acoustic response to a mechanical impulse excitation.

To be used, the software should be installed on a computer (desktop or laptop) with the Windows 11 operating system.

4. Specifications

Frequency range .... 20 Hz - 96 kHz

Elastic moduli measurement range .... 0.1 - 1000 GPa

5. System requirements

Compatible operating system .... Windows 11

Sound card sampling rate[1] .... 48 kHz (minimum) - 192 kHz (maximum)

Free HD space.. 4 Gigabytes

Available USB ports .... 01 port

Available audio inputs .... 01 TRS P2 / 3.5 mm

Supported screen resolutions[2] 1280x720, 1280x1024, 1366x768
1600x900 e 1920x1080 (Full HD)

[1] Sonelastic® Software digitizes the acoustic response using the Signal acquisition PCIe card XONAR or the signal acquisition USB module ADAC. The maximum measurable frequency is equal to half of the sampling rate.

[2] Sonelastic® Software features window automatic fitting for the listed screen resolutions. For resolutions not listed, the software will fit the largest possible resolution from the supported list.

Before installing the software, verify the followings items:

- The computer must be connected to a grounded three-pin AC plug in good conditions;

- The Sonelastic® Software should be used in lab and office environments with moderate ambient noise (≤ 60 dBA). Intense noises may affect the acoustic response analysis;

- For the measurements as a function of time or temperature, it is advisable to use a laptop or a PC connected to a no-break to avoid data losses in the case of power outage.

6. Software and accessories installation

6.1 Installing the software for the first time

The following sub-items describe in details Sonelastic® Software installation and updating processes for compatible operating systems (see item *5. System requirements*), including the installation process of Sonelastic® accessories. *Note: Sonelastic® Systems are usually supplied with a DELL desktop computer with Sonelastic® Software already installed.*

6.1.1 Step-by-step Installation (Windows 10&11):

Step 01 – Run the installation flash drive or request the link to download the installer by email to info@sonelastic.com.

Step 02 – Find the "Sonelastic 6.0 Installer" folder, right-click on "setup.exe" and select "Run as administrator".

It is advisable to close all programs before beginning the installation process.

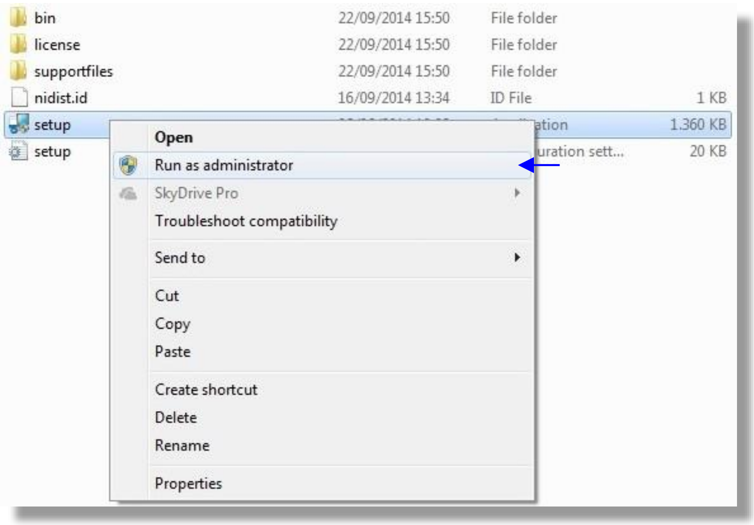


Figure 1 - Run the installer as administrator.

Step 03 – Select "Yes" on the "User Account Control" window.

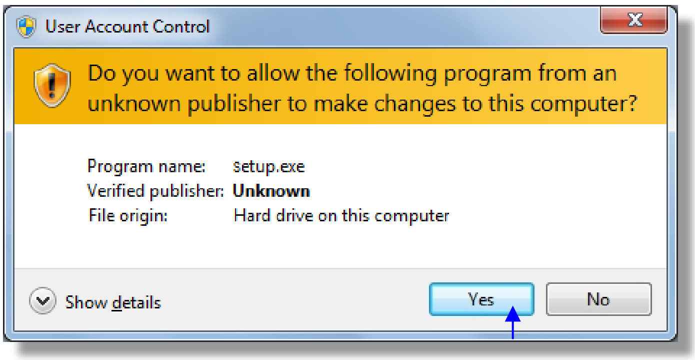


Figure 2 - Accept to install the software.

Step 04 – Wait for the window below and click "Next."

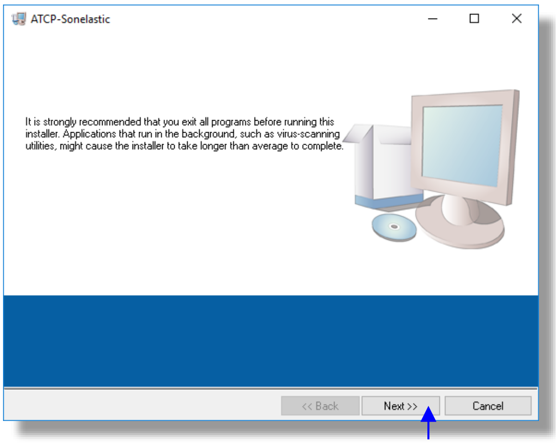


Figure 3 – Click "Next" to advance.

Step 05 – Select the destination directory folders where you wish to save the installation files. It is advisable to maintain the pre-selected directories. Click on "Next".

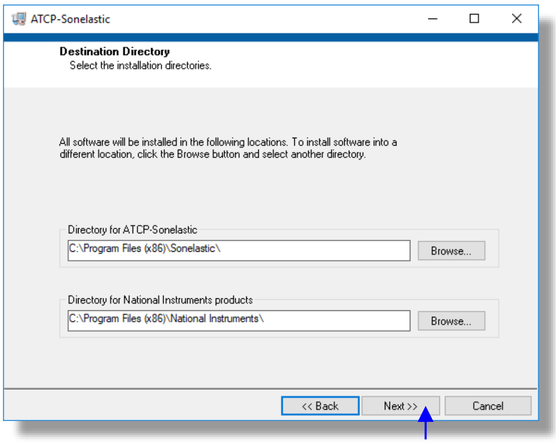


Figure 4 – Click "Next" to advance.

Step 06 – Read the National Instruments Software License Agreement regarding the *plug-ins* used by Sonelastic® Software. Accept the License agreement by selecting "I accept the above 2 License Agreement(s)", then click on "Next".

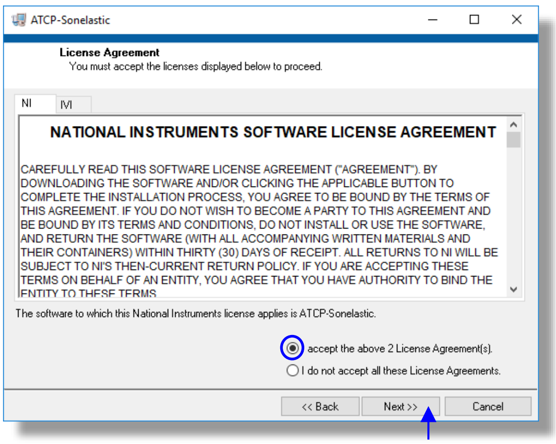


Figure 5 – Accept and click "Next" to install the software.

Step 07 – Click on the “Next” button to begin the installation.

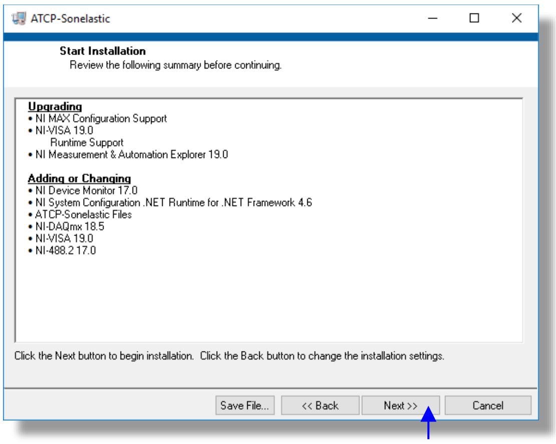


Figure 6 – Click “Next” to begin installation.

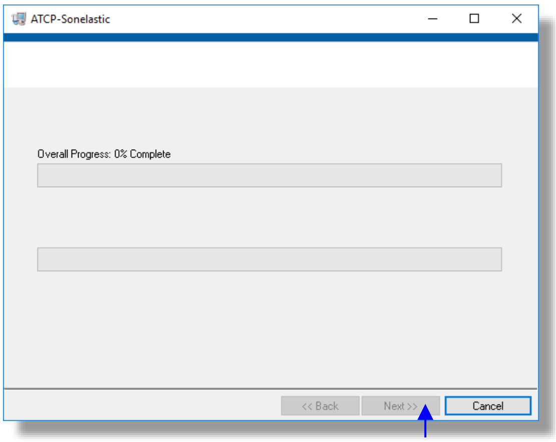


Figure 7 – After installation progress, click "Next" to finalize.

Step 08 – After installation, click on “Finish” and restart the computer.

Step 09 – Attribute administrator privileges to Sonelastic® Software. To do this, right-click on the Sonelastic® icon presented on the Desktop, then select “Properties”.

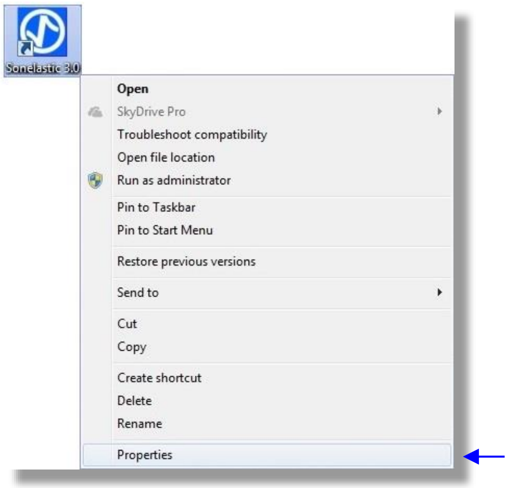


Figure 8 – Right click on the Sonelastic® icon and then click on “Properties”.

Step 10 – Select the "Compatibility" tab and activate the option "Run this program as an administrator". For the cases of operating systems with more than one user, click on "Show settings for all users" and select the option "Run this program as an administrator". Click on "OK" to accept the changes.

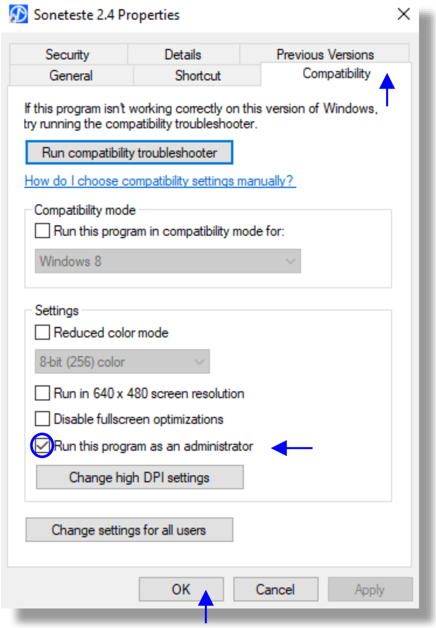


Figure 9 – Verify to have the Software run as administrator.

Step 11 – Authorize file saving and modification. Select the "Security" tab and enable permissions for all users (use the Edit button). Click the "OK" button to confirm the changes.

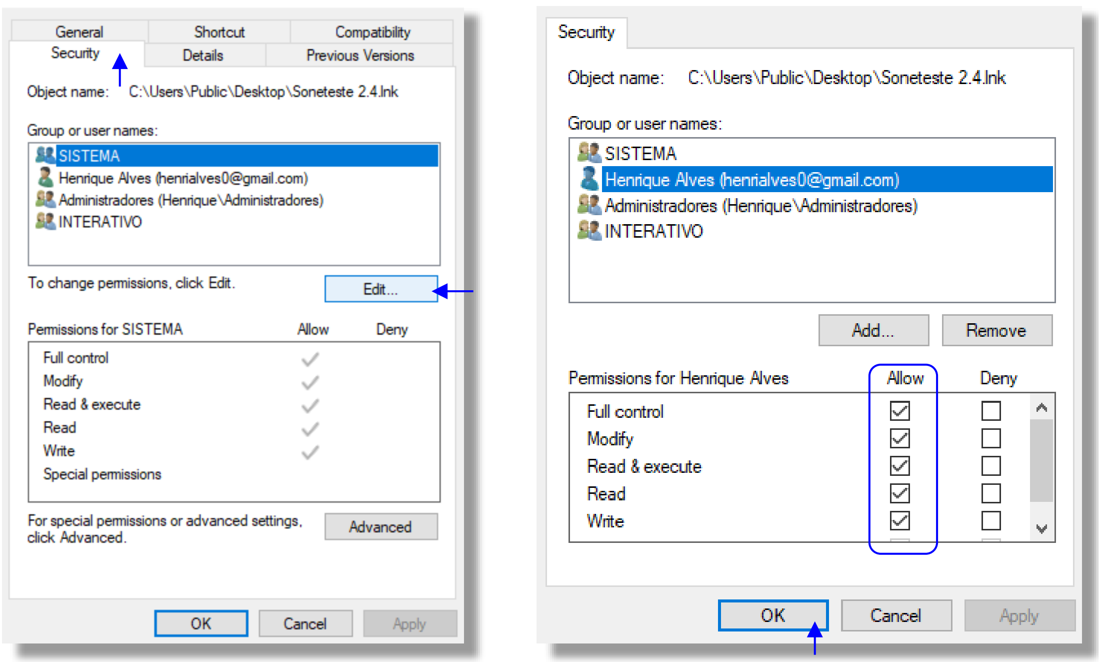


Figure 10 – Allow the software to perform file changes for all users and groups.

Step 12 – Activate the software license. Before running the software, it is necessary to activate its license. For this, open Sonelastic® Software and complete the following fields: "Name", "Enterprise", and "Contact" (e-mail address). After that, click on "Save File" to create an identification file. This file must be sent by email to ATCP Physical Engineering (info@sonelastic.com) in order to create the license file. License will only be valid for the computer related to this file.

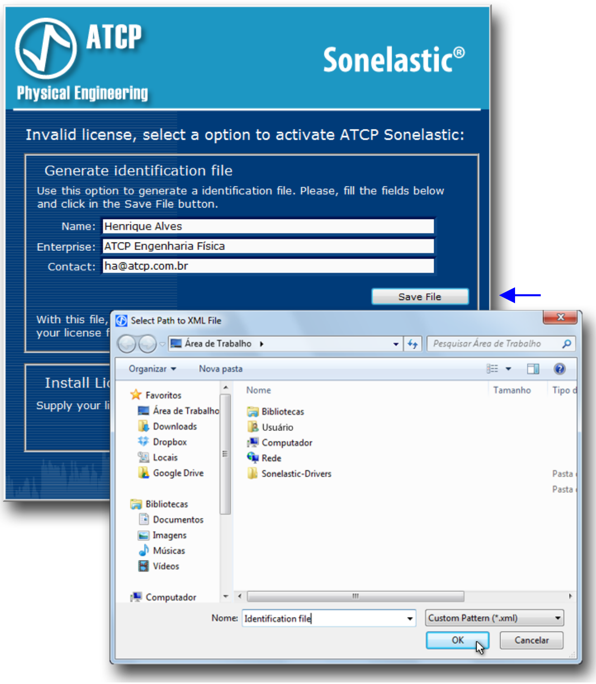


Figure 11 – Generating the identification file.

Step 13 - After receiving the license file, run the software and load the license file by clicking on "Activate Sonelastic". The installation process is completed. Close Sonelastic® Software and run it again, the program will be ready for use.

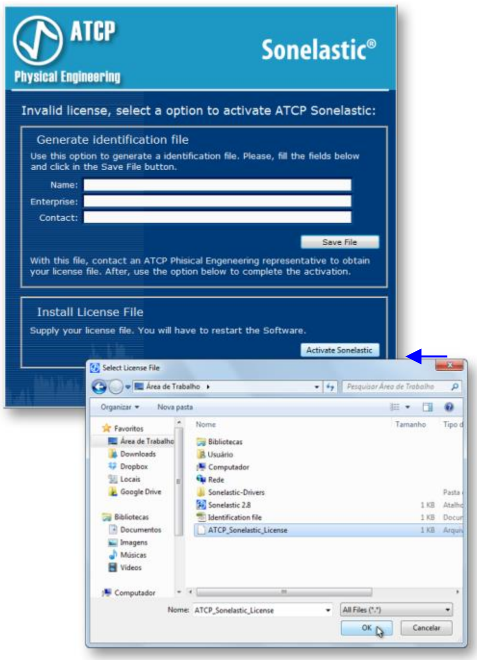


Figure 12 – Activating the software after receiving the license file.

6.1.2 MSXML dll Installation

The software needs the MSXML dll to work. After software installation, locate and open the "Sonelastic-Drivers" folder on the Desktop. Locate the msxml.msi executable and install it.

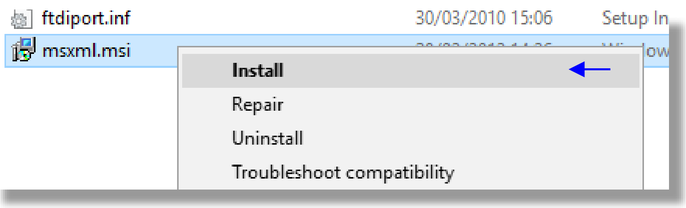


Figure 13 – Install the MSXML dll.

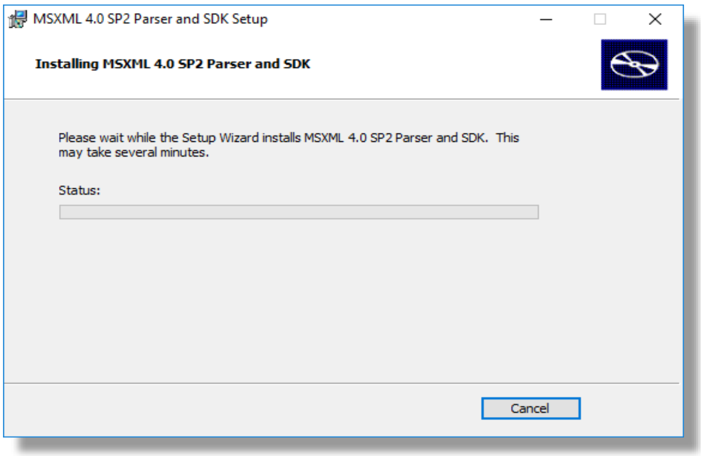


Figure 14 – MSXML dll installation progress.

After the installation is complete, click "Finish".

6.2 Updating the software (for users who already have the license)

To update the Sonelastic® Software, please follow the steps:

Step 01 – Open "Control Panel" and click on the link "Remove a program" under the option "Programs".

Step 02 – Find "ATCP-Sonelastic" on the system programs and features list.

Step 03 – Right-click on the "ATCP-Sonelastic" icon and select "Uninstall". Follow the instructions to uninstall the software.

Step 04 – Install the new version of Sonelastic® Software as described in *item 6.1 Installing the software for the first time*.

6.3 Connecting the acoustic sensor and configuring audio options

Step 01 – Connect the CA-PD or CA-DP-S Acoustic Sensor to the signal acquisition card or USB acquisition module.

Figure 15 – Acoustic sensor TRS P2 / 3,5 mm plug.

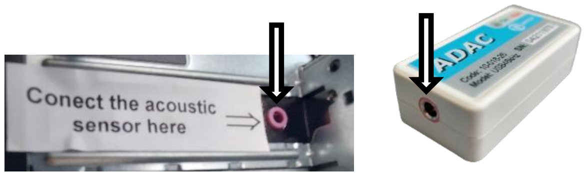


Figure 16 - Audio input from a XONAR acquisition board installed on the rear panel of a DELL computer, and audio input from the ADAC acquisition module. The audio input is always a P2 connector.

Step 02 – Configure the audio options. To avoid any distortions to the acoustic response signal, it is necessary for both operating system and sound manager software to do not optimize nor enhance the signal. In the Windows Notification Area, right-click on the Speakers/headsets icon.

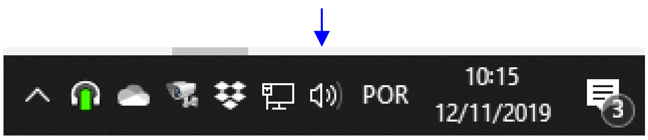


Figure 17 – Speakers/headsets icon.

Note: If this icon is not shown in the Windows notification area, it is possible to verify the sound configuration options by the Control Panel. For that, click on "Hardware and Sound", and then on "Sound", identified by the speaker icon.

Step 03 – Select "Sounds" on the menu.

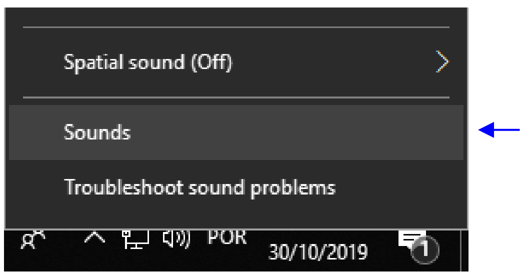


Figure 18 – "Sounds" menu.

Step 04 – In the "Sound" screen, select the "Recording" tab, then left-click on "Microphone" showing the ✅ symbol. After that, click on "Properties", such as shown below:

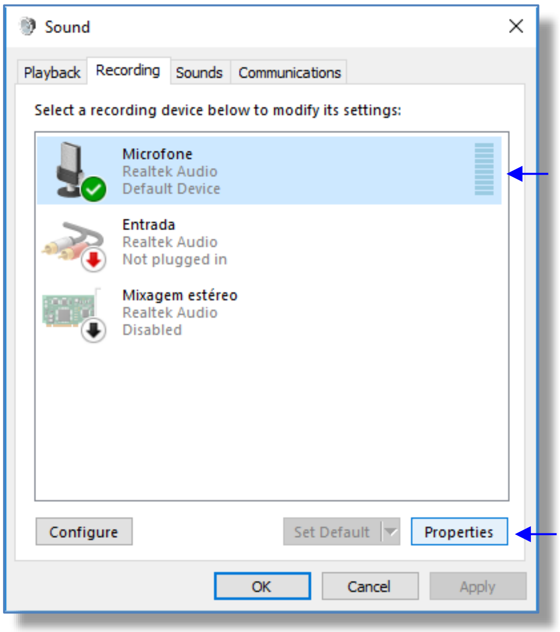


Figure 19 - Accessing the microphone settings.

Step 05 - Two types of sound configuration may appear, follow the instructions below to perform all necessary changes for both cases. In the new window, select the "Advanced" tab or the "Enhancements" tab as described below. Unmark the "Enable audio enhancements" option or mark the "Disable all sound effects" option. Apply the changes by pressing "OK".

Step 06 – In the "Default Format" or equivalent field, select the mode with the highest available sampling rate (192000 Hz for XONAR and 48000 Hz for ADAC module).

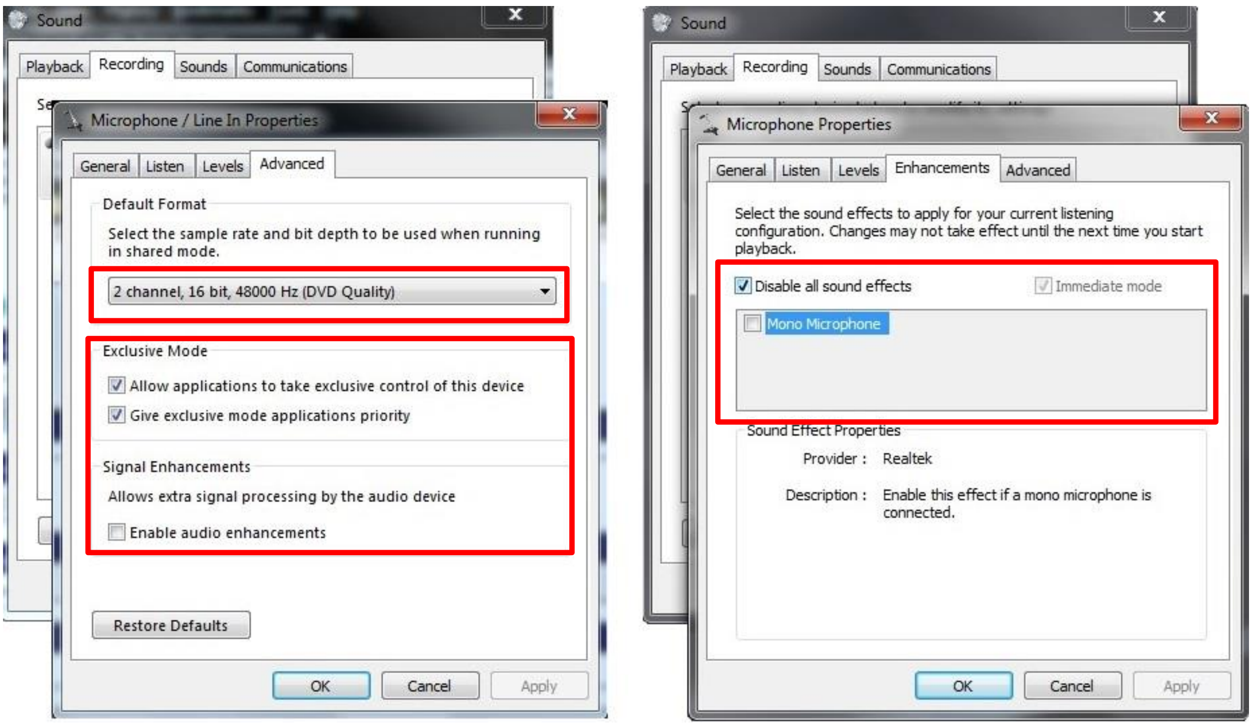


Figure 20 - Recording settings.

6.4 Installing the IED Automatic Impulse Device

Information regarding the installation and operation of the IED Automatic Impulse Device may be found on the Installation and Operation Manual supplied with the device.

6.5 Installing the specimen support

Information regarding the installation and operation of supports manufactured by ATCP Physical Engineering to be used with Sonelastic® Software can be found on the Installation and Operation Manual of each support a (SB-AP, SA-BC, SX-PD and SA-AG).

Attention! The best support choice depends on the specimen dimensions. For further information, visit our website www.sonelastic.com or contact us (info@sonelastic.com).

7. Specimens

7.1 Recommended aspect ratios and typical dimensions

Minimum aspect ratios must be observed to avoid coupling between specimen's vibration modes. In addition, aspect ratio determines the pattern of frequency spectrum of the acoustic response.

Table 1 - Recommended aspect ratios and typical dimensions.

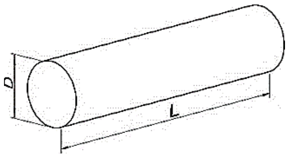
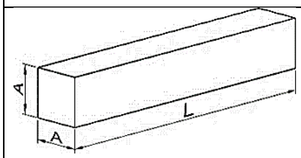
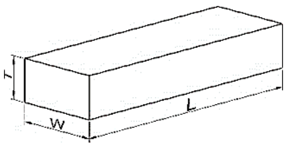
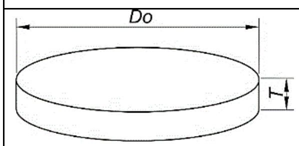
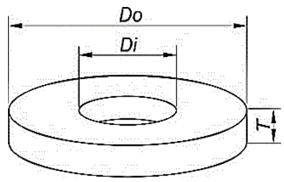
Geometry	Recommended aspect ratios	Typical dimensions
 Cylinder	$\frac{L}{D} \geq 2$ The ratio between length (L) and diameter (D) must be greater than or equal to 2.	(L x D) - 50 x 5 mm - 50 x 10 mm - 100 x 50 mm - 200 x 100 mm - 300 x 150 mm - 500 x 50 mm
 Square section bar	$\frac{L}{A} \geq 3$ The ratio between length (L) and edge (A) must be greater than or equal to 3.	(L x A x A) - 30 x 5 x 5 mm - 100 x 15 x 15 mm - 150 x 25 x 25 mm - 150 x 35 x 35 mm - 150 x 40 x 40 mm - 500 x 50 x 50 mm
 Rectangular section bar	$\frac{L}{W} \geq 4$ The ratio between length (L) and width (W) must be greater than or equal to 4. $\frac{W}{T} \leq 8$ The ratio between width (W) and thickness (T) must be less than or equal to 8.	(L x W x T) - 30 x 6 x 2 mm - 40 x 10 x 4 mm - 60 x 12 x 4 mm - 100 x 15 x 2 mm - 150 x 30 x 10 mm - 150 x 37,5 x 5 mm - 300 x 60 x 20 mm - 500 x 100 x 35 mm
 Discs	$\frac{D_o}{T} \geq 10$ The ratio between diameter (D_o) and thickness (T) must be greater than or equal to 10.	(D_o x T) - 10 x 1 mm - 20 x 2 mm - 30 x 2 mm - 25,4 x 2,5 mm - 50,8 x 2,54 mm
 Rings	$\frac{D_o}{T} \geq 10$ The ratio between diameter (D_o) and thickness (T) must be greater than or equal to 10. $\frac{D_o}{D_i} \geq 2$ The ratio between outer diameter (D_o) and inner diameter (D_i) must be greater than or equal to 2.	

Table 1 presents the recommended aspect ratio and typical dimensions for bars, cylinders discs and rings.

Important observations for preparing and finishing the specimens:
- The recommended dimensional tolerance and flatness are 0.1%;
- Faces should be flat and parallel;
- Corners must not be chamfered.

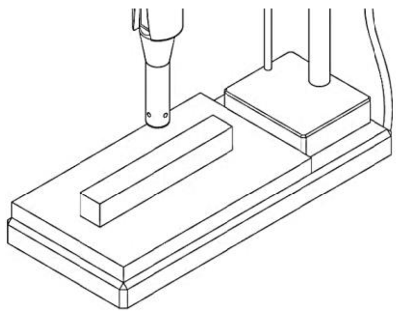
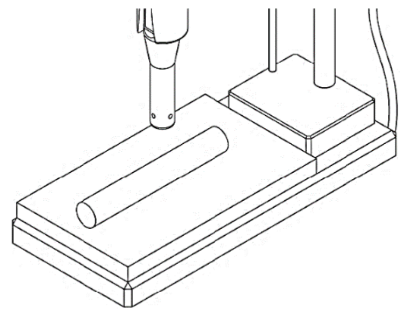
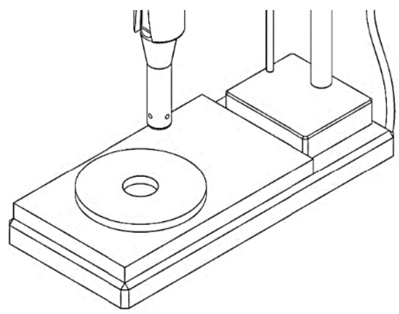
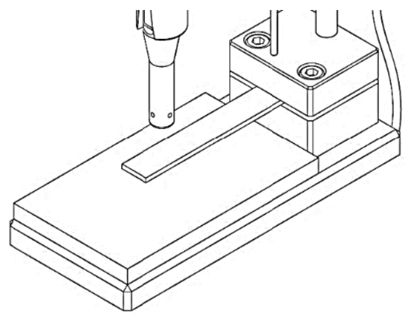
7.2 Specimen positioning and dimensions

ATCP Physical Engineering, Sonelastic® Division, offers many specimens supports. Next, find out our support's basic information and maximum and minimum dimensions for each model.

SB-AP - Support for small specimens and cantilever beams
Maximum dimensions for cylindrical specimens (L x D) .... 120 x 60 mm
Minimum dimensions for cylindrical specimens (L x D) .... 20 x 2 mm
Maximum dimensions for rectangular specimens (L x W x T) .... 120 x 40 x 40 mm
Minimum dimensions for rectangular specimens (L x W x T) .... 20 x 2 x 2 mm
Maximum dimensions for cantilever beams (L x W x T) .... 200 x 25 x 5 mm
Minimum dimensions for cantilever beams (L x W x T) .... 120 x 10 x 0.5 mm
Maximum dimensions for discs and rings (D x T) .... 80 x 8 mm
Minimum dimensions for discs and rings (D x T) .... 15 x 1 mm

In the SB-AP Support, the specimen is supported on a foam block and positioned according to the vibration mode of interest. For more information, see the SB-AP operation manual.

Table 2 – SB-AP support with compatible geometries.

 Rectangular specimen.	 Cylindrical specimen.
 Ring-shaped specimen.	 Ruler-shaped specimen (cantilever beam).

SA-BC - Adjustable support for bars and cylinders
Maximum dimensions for cylindrical specimens (L x D) .... 450 x 200 mm
Minimum dimensions for cylindrical specimens (L x D) .... 100 x 5 mm
Maximum dimensions for rectangular specimens (L x W x T) .... 450 x 170 x 170 mm
Minimum dimensions for rectangular specimens (L x W x T) .... 100 x 5 x 5 mm

The specimen is placed over the support-cables at a distance of 0.224L from the ends, where L is the specimen length. The supporting distance calculation is automatically performed and informed by Sonelastic® Software.

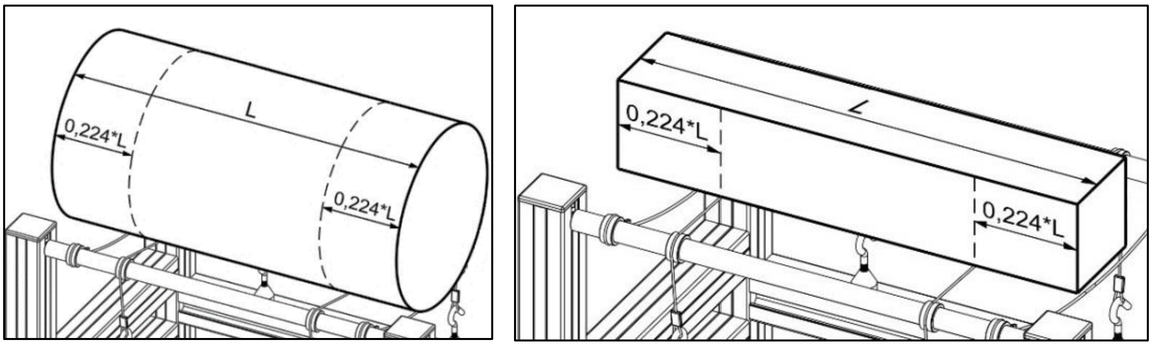


Figure 21 – SA-BC support with cylindrical and prismatic specimens.

For further information, verify the SA-BC installation and operation manual.

SX-PD - Adjustable support for discs and rings
Maximum dimensions for circular specimens (D x T) .... 380 x 60 mm
Minimum dimensions for circular specimens (D x T) .... 80 x 5 mm
Maximum dimensions for rectangular specimens (L x W x T) .... 380 x 380 x 60 mm
Minimum dimensions for rectangular specimens (L x W x T) .... 60 x 60 x 5 mm

The specimen is placed on the support so its center is aligned with the support center, as shown below.

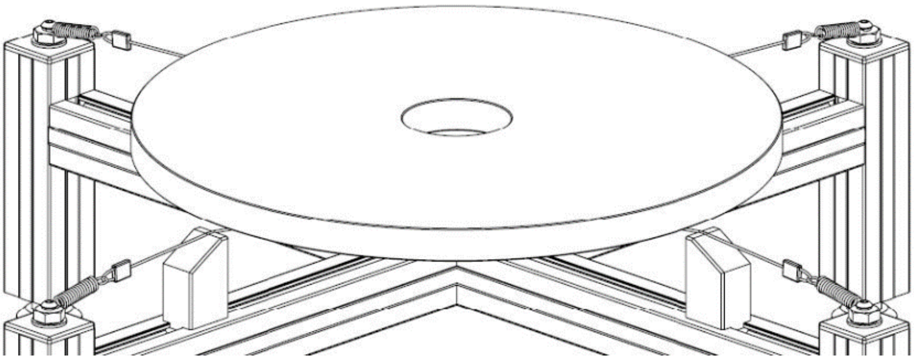


Figure 22 – SX-PD support with a ring-shaped specimen.

For further information, verify the SX-PD installation and operation manual**.**

SA-AG - Adjustable support for large specimens

Maximum dimensions for rectangular specimens (L x W x T) .... 5,300 x 200 x 200mm
Minimum dimensions for rectangular specimens (L x W x T) .... 120 x 20 x 20 mm
Maximum dimensions for cylindrical specimens (L x D) .... 5,300 x 200 mm
Minimum dimensions for cylindrical specimens (L x D) .... 120 x 30 mm

The specimen is symmetrically supported and placed at a distance of 0.224L from the ends, where L is the specimen length. The supporting distance calculation is automatically performed and informed by Sonelastic® Software.

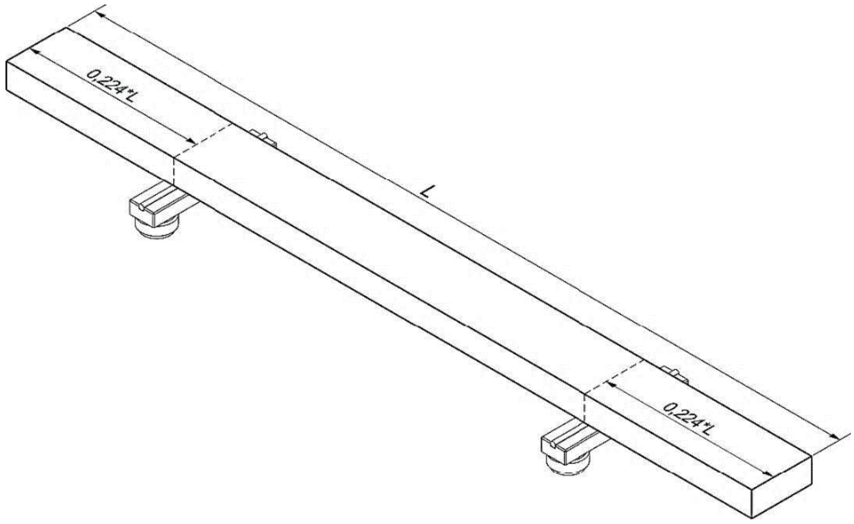


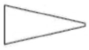
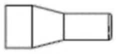
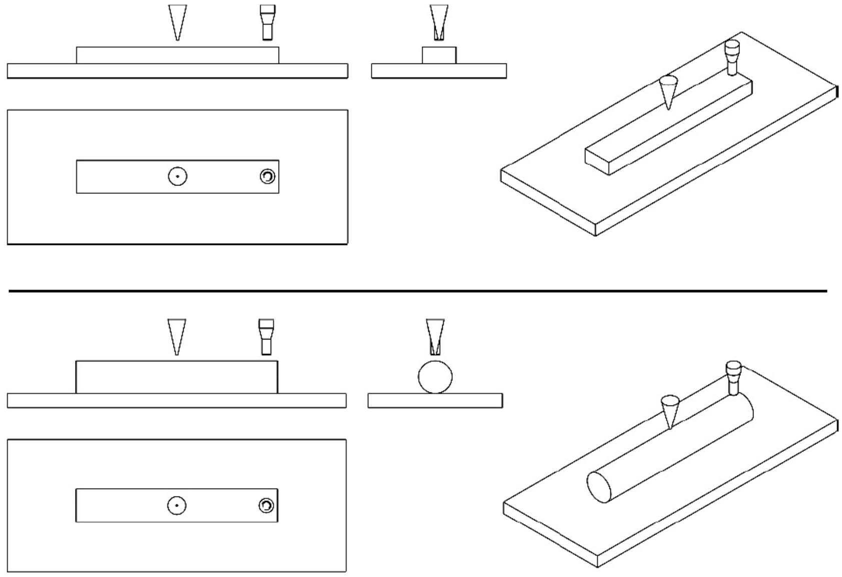
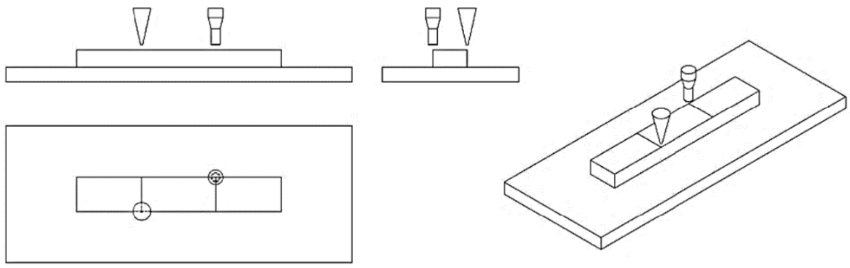
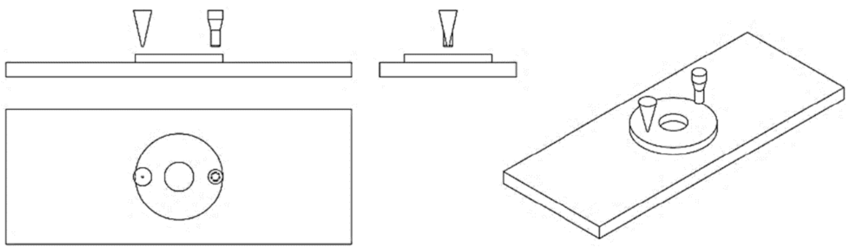
Figure 23 – SA-AG support prismatic specimen.

For further information, verify the SA-AG installation and operation manual.

7.3 Excitation and acquisition modes

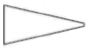
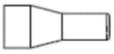
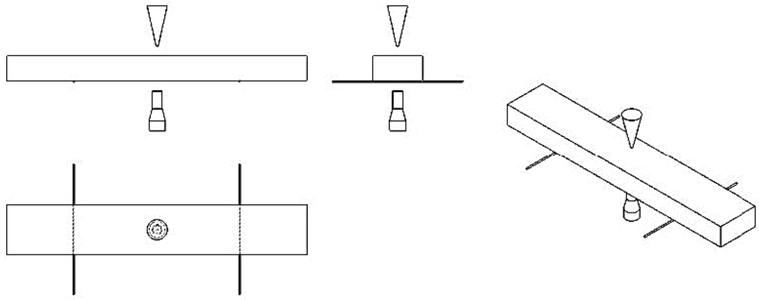
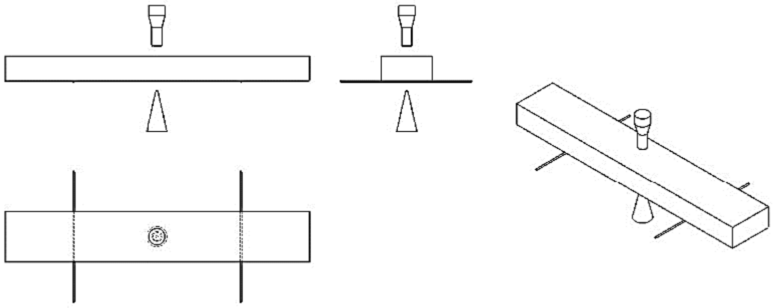
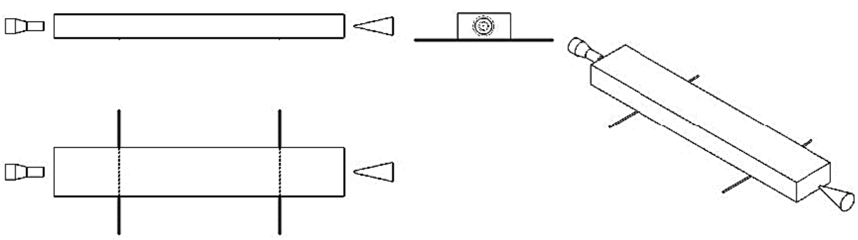
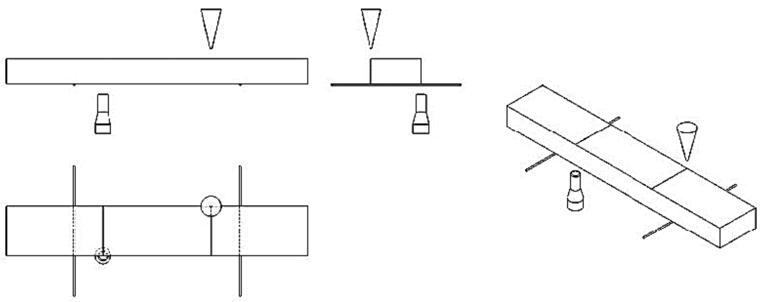
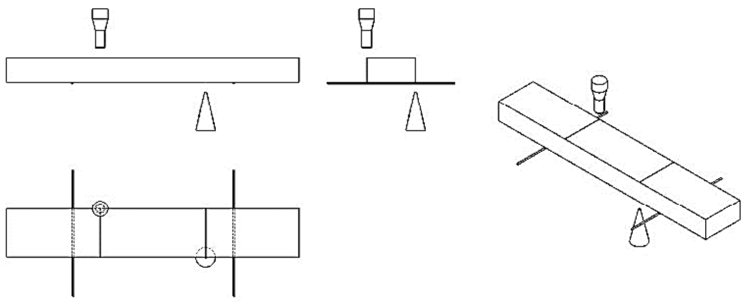
SB-AP Support

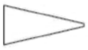
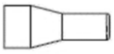
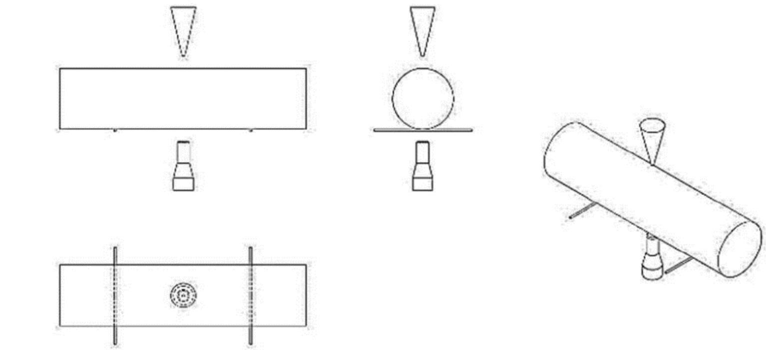
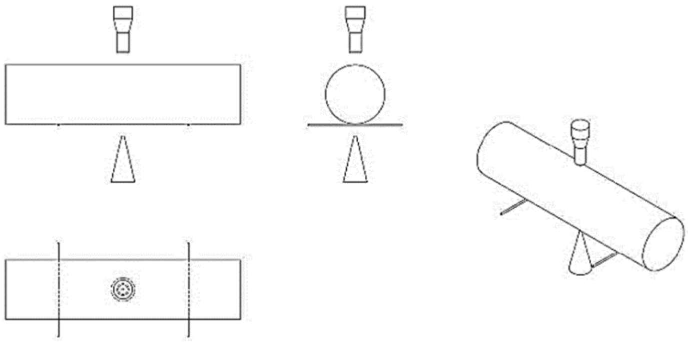
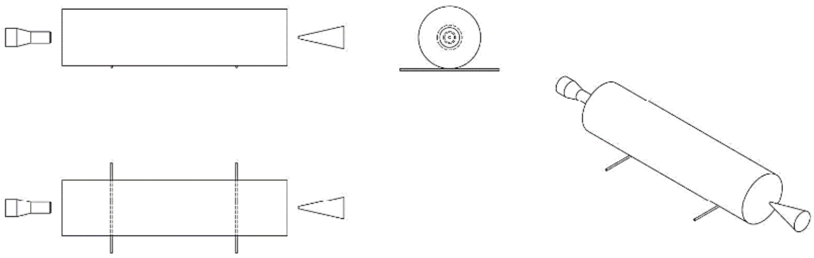
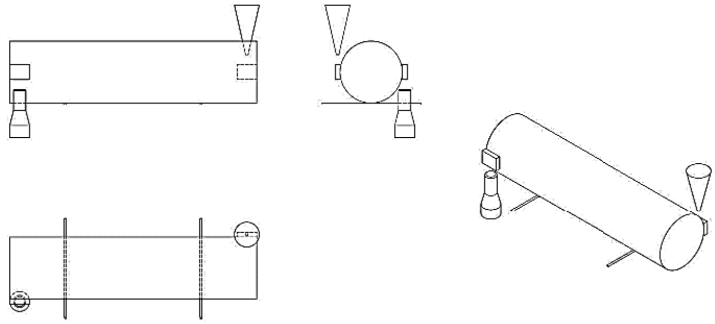
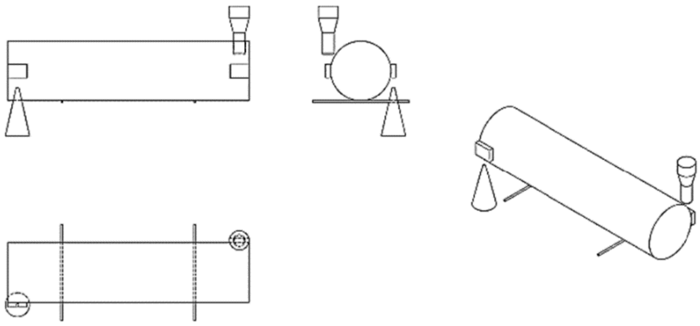
Table 3 - Excitation and acquisition modes for SB-AP support.

Impulse:  Acoustic sensor: 	
Flexural mode *Excitation at the center and acquisition at the end, both width-centered. Allows the Young's modulus (E) characterization.*	
Flexural + torsional mode *Excitation and acquisition from opposed edges at 0.32 L (L = length). Allows E, G and μ characterization. Applicable only to rectangular bars.*	
Planar mode (anti-flexural) *Excitation and acquisition diametrically opposed one another. Allows the Young's modulus (E) characterization. Applicable only to discs and rings.*	

SA-BC Support

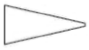
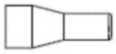
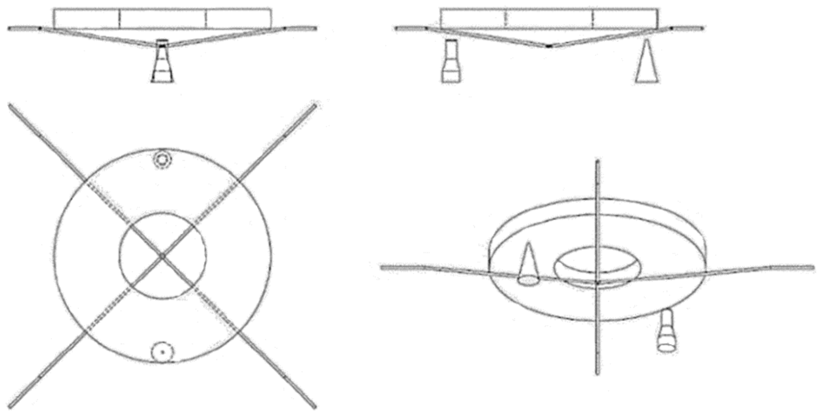
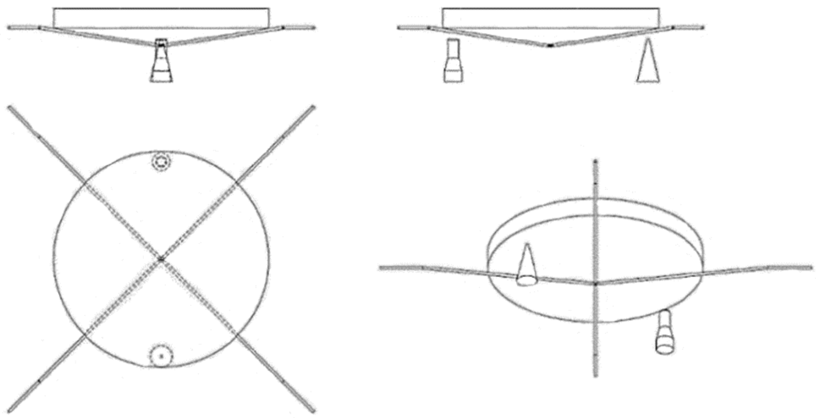
Table 4 - Excitation and acquisition modes for SA-BC support.

Impulse:  Acoustic sensor: 	
Flexural mode - I *Excitation from above and signal acquisition from below, both aligned with the center of the specimen.* *Cables at 0.224L.*	
Flexural mode - II *Excitation from below and signal acquisition from above, both aligned with the center of the specimen.* *Cables at 0.224L.*	
Longitudinal mode *Top-centered excitation and signal acquisition from opposite sides of the specimen.* *Cables at 0.224L.*	
Flexural + torsional modes - I *Excitation from above and signal acquisition from below, positioned at 0.32L from opposed edges.* *Cables at 0.224L.*	
Flexural + torsional modes - II *Excitation from below and signal acquisition from above, positioned at 0.32L from opposed edges.* *Cables at 0.224L.*	

Impulse:  Acoustic sensor: 	
Flexural mode - I *Excitation from above and signal acquisition from below, both aligned with the center of the specimen.* *Cables positioned at 0.224 L.*	
Flexural mode - II *Excitation from below and signal acquisition from above both aligned with the center of the specimen.* *Cables positioned at 0.224 L.*	
Longitudinal Mode *Top-centered excitation and signal acquisition from opposite sides of the specimen.* *Cables positioned at 0.224 L.*	
Flexural + torsional modes - I *Excitation from above and signal acquisition from below from opposite sides and ends.* *Cables positioned at 0.224 L.*	
Flexural + torsional modes - II *Excitation from below and acquisition from above from opposite sides and ends.* *Cables positioned at 0.224 L.*	

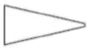
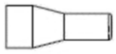
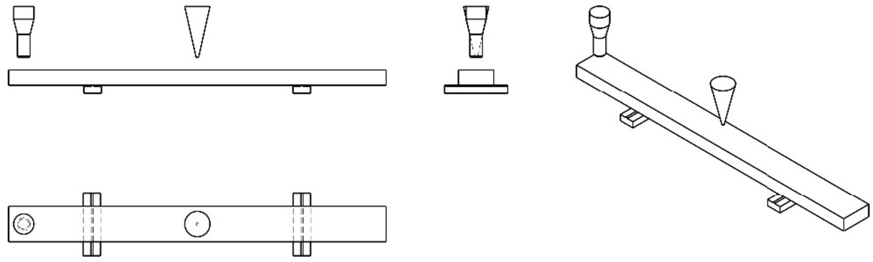
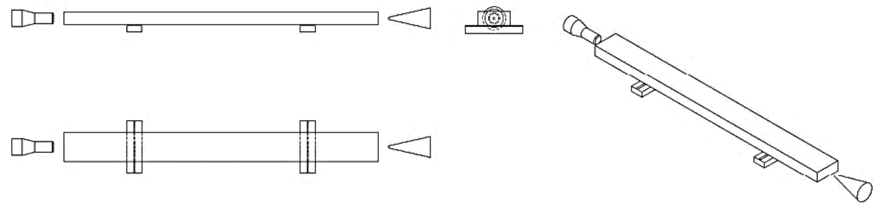
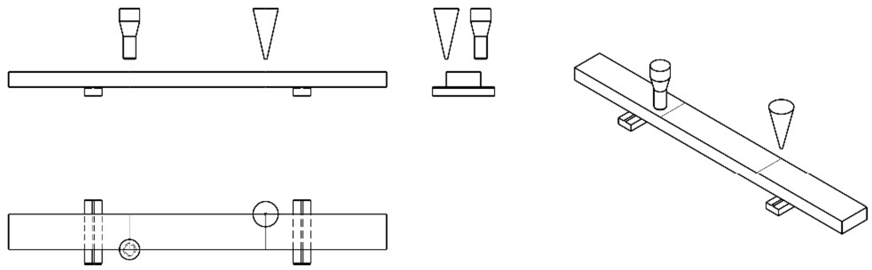
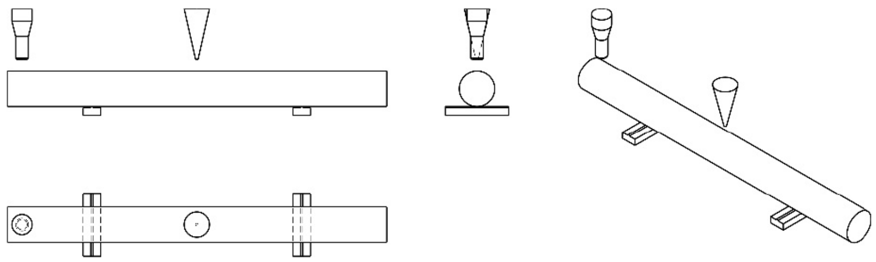
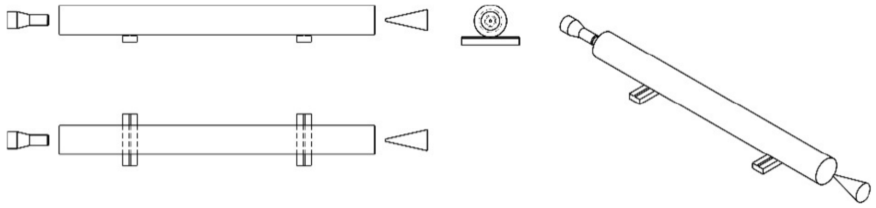
SX-PD Support

Table 5 - Excitation and acquisition modes for SX-PD support.

Impulse:  Acoustic sensor: 	
Planar mode for rings *Diametrically opposed excitation and acquisition, on the inferior face.* *Allows Young's Modulus (E) characterization.* *Applicable only to discs and rings.*	
Planar mode for discs *Diametrically opposed excitation and acquisition, on the inferior face.* *Allows Young's Modulus (E) characterization.* *Applicable only to discs and rings.*	

SA-AG Support

Table 6 - Excitation and acquisition modes for SA-AG support.

Impulse:  Acoustic sensor: 	
Flexural mode for bars *Excitation at the center and acquisition at the end of the specimen, both from above and width-centered. Supports positioned at 0.224 L.*	
Longitudinal mode for bars *Top-centered excitation and signal acquisition from opposite sides of the specimen. Supports positioned at 0.224L.*	
Flexural + torsional modes *Excitation and signal acquisition from above, positioned at 0.32L from opposed edges. Supports positioned at 0.224 L.*	
Flexural mode for cylinders *Excitation at the center and acquisition at the end of the specimen, both from above and width-centered. Supports positioned at 0.224 L.*	
Longitudinal mode for cylinders *Top-centered excitation and signal acquisition from opposite sides of the specimen. Supports positioned at 0.224 L.*	

8. Operating the software

Before start operating the software, verify the followings:

- The Sonelastic® Software 6.0 version is installed;

- The specimen and Sonelastic® System items are positioned as described in item *7. Specimens*;

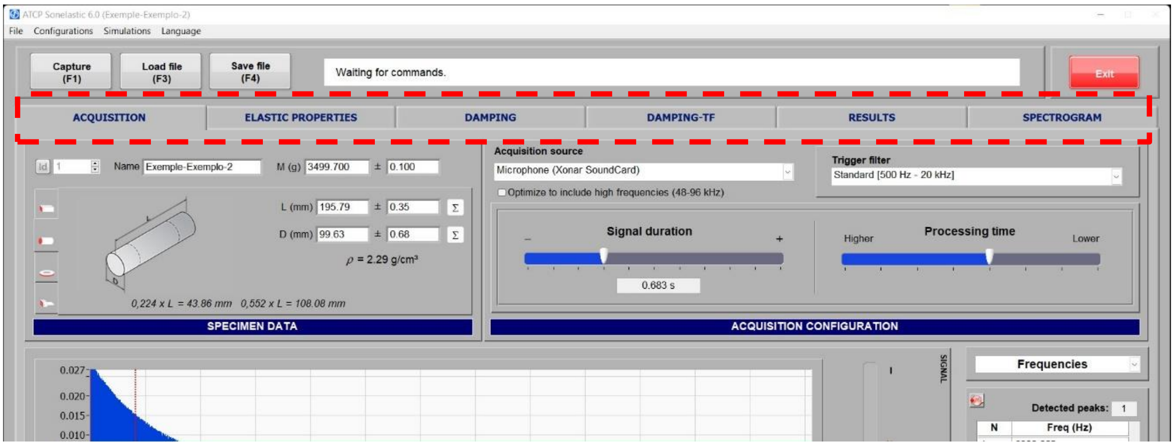
- The IED Automatic Impulse Device is ON and correctly installed (if applicable).

After verifying the items above, the system is ready.

Sonelastic® Software was developed to provide an easy, quick and interactive way to characterize materials elastic moduli. Next, it is presented all the information regarding the Sonelastic® Software configuration and operation.

Note: A quick guide for measurements using Sonelastic® Software is on Appendix A.

Sonelastic® Software is structured in modules (tabs) which perform the sequential processing of the acoustic response, as shown in Figure 24 and following fragments.



Module for signal acquisition.

Module for the damping ratio determination on time-frequency domain.

Module for the Elastic Moduli determination.

Module for storing the results.

Module for the Damping ratio determination on time domain.

Module for the visualization of the spectrogram.

Figure 24 - Sonelastic® Software tabs.

8.1. ACQUISITION tab

8.1.1 Entering the specimen dimensions

Acquisition tab (Sonelastic® Software main screen):

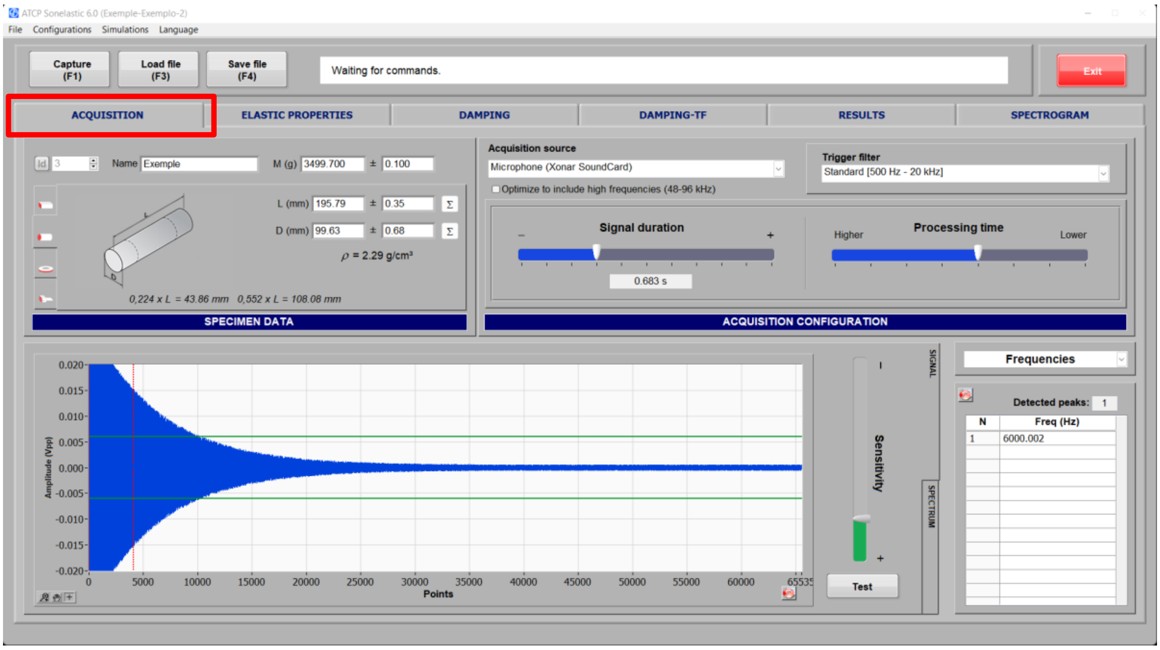


Figure 25 - Sonelastic® Software main screen, highlighting the ACQUISITION tab.

Step 01 - In the field "Specimen data": 

choose the specimen's geometry: rectangular bar, cylinder, ring/disc or cantilever beam, as shown on Fig. 26 below.

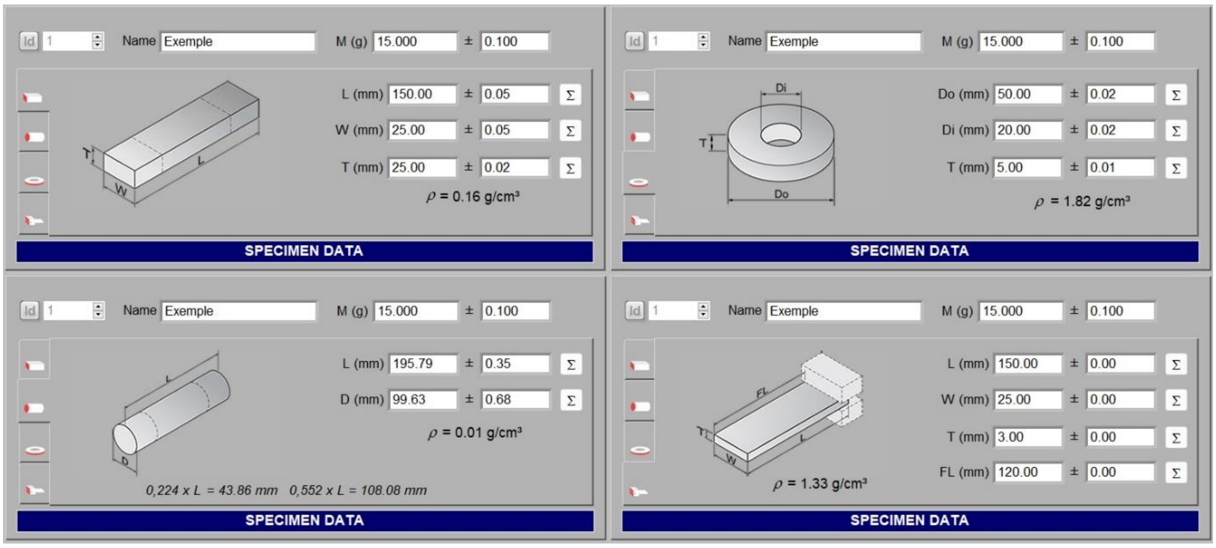


Figure 26 - Options for geometry and specimen data.

Meaning of the parameters shown in Fig. 26:
"Name": Specimen name/reference;
"Mass (g)": Specimen mass (g);
"L (mm)": Length of the bar, cylinder or cantilever beam (mm);

"W (mm)": Width of the bar or cantilever beam (mm);
"T (mm)": Thickness of the bar, ring or cantilever beam (mm);
"D (mm)": Diameter of the cylinder (mm);
"Do (mm)": Outer diameter of the ring/disc (mm);
"Di (mm)": Inner diameter of the ring/disc (mm). *Note: For a disc, this value is equal to zero;*
"FL (mm)": Cantilever beam free length (mm);
"Id": Selector of pre-registered specimens.

Step 02 – Insert the specimen name / designation.

Step 03 – Insert the specimen dimensions by following the instructions below.

Use the most precise apparatus available to determine the dimensions and a high-precision scale to obtain the mass value. The length, width, thickness and diameter should be measured at three different points for average calculation.

To calculate automatically the average and the deviation of the measurements, click on the auxiliary button next to the uncertainty value for each dimension: 

Insert the instrument used precision and the measured values in the respective fields of the new window. It is advisable to perform three measurements for each dimension at different and equidistant points of the specimen. As the values are inserted, the software will automatically calculate "Average (mm)" and "Uncertainty (mm)". To update the values on the "Specimen data" field, click on "Export".

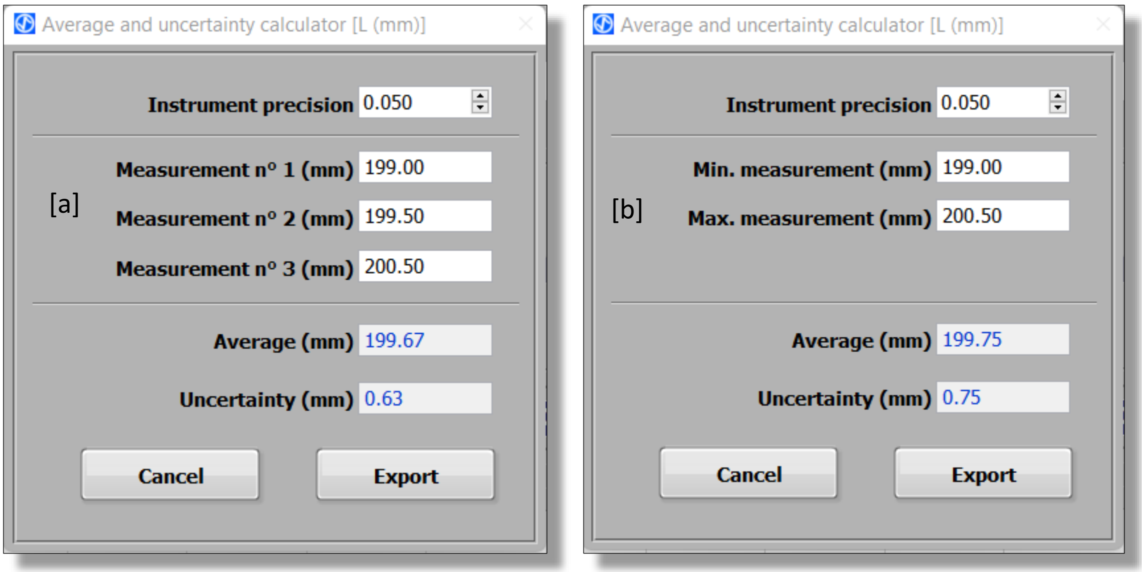


Figure 27 – [a]: Average and uncertainty calculator; [b]: Average and uncertainty calculator for the length and diameter of cylinders when the option "Cylinder dimensions by ABNT NBR 8522-2:2021" is activated.

If the average value and deviation have been previously calculated, it is possible to type the values directly in the respective fields for each dimension or import from the specimen register.

Note: It is possible to configure the software to accept uncertainties values equal to zero ("Allow null values for the uncertainty of mass and dimensions"), verify item "8.9 Configurations Menu" *in this manual. If the option "Cylinder dimensions by ABNT NBR 8522-2:2021" is activated (Settings/Options menu), the calculator interface for the length and diameter of cylinders will be different and with fields for only two measurements input.*

After insert all dimensions, the software will automatically calculate the apparent density (ρ) and show the localization of the nodal lines for bars and cylinders (where the specimen should be placed over). Figure 26 shows where this information. Always check if the calculated apparent density is consistent with the material under test.

Always check if the apparent density (ρ) calculated by the Sonelastic® Software is coherent with the material under test. Dimensions and mass errors are detectable in this way.

8.1.2 Performing a preliminary signal acquisition

It is necessary to take preliminary measurements to verify if the software parameters and configurations are adequate for the specimen and material under test.

To start an acquisition, click on "Capture (F1)", on the screen left corner.

The software will start a continuous acquisition and be ready to perform the capture of an acoustic response. If the IED Automatic Impulse Device is connected to the computer, it will impulse continuously until the signal curve in blue reaches the green line (if the impulse device is not reaching the specimen, modify the intensity as shown in *8.1.5. Spectrum and pre-processing of the acquired signal*). If the IED Automatic Impulse Device System is not available, perform the impulse excitation by using a manual impulse device.

The acquired acoustic response will be shown in the interface (amplitude graph as a function of time/points). Verify the obtained graph and perform the necessary adjustments according to item *8.1.3 Adjusting the signal acquisition.*

8.1.3 Adjusting the signal acquisition

In the field "Acquisition source" (Fig. 28), it is possible to select the signal source. Click the arrow on the right to access the options. If a new source is connected with the software already open, it may be necessary to restart it for it to appear in the list.

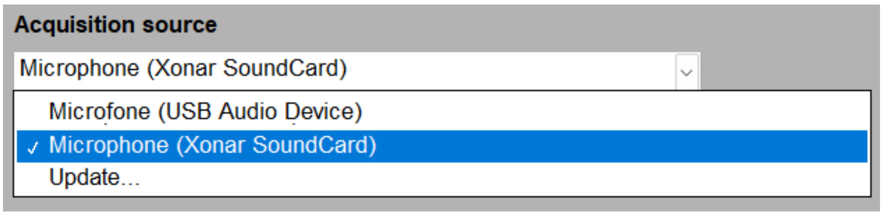


Figure 28 - Control for selecting the signal acquisition source.

Depending on the specimen characteristics, it may be necessary to enable the option "Optimize to include high frequencies (48-96 kHz)" (Fig. 29). This may occur for high-moduli and small-size specimens (length of a few millimeters). This option increases the detectable frequency range; however, it is advisable to enable this option only when the resonance frequency expected is higher than 48 kHz. If it is not necessary, disable this option. To estimate a specimen resonance frequency, use the "Frequency simulator" feature (specified in *8.10 Simulations Menu*). *Note: To signal acquisition within the 48-96 kHz range, the signal acquisition card or module must have the 192 kHz sample rate option or higher.*

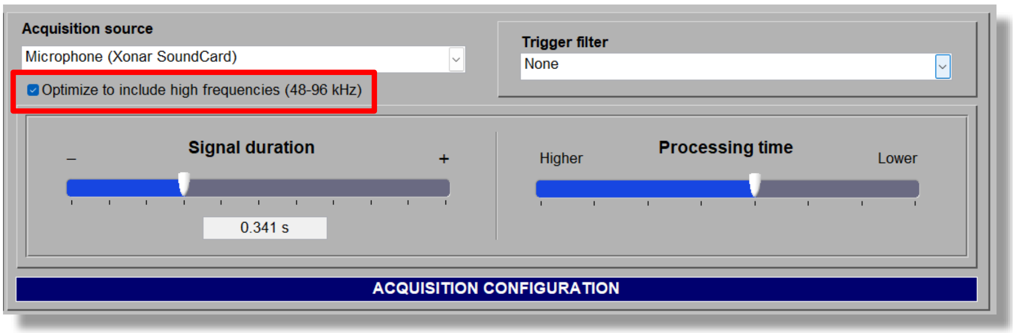


Figure 29 - Enabling the option to increase the detectable frequencies range.

In the "Trigger filter" field (Figure 30) it is possible to reduce the influence of environment noise and other interferences. This filter activation is by choosing a frequency range. The filtering is applied only to the signal preceding the acquisition beginning, so that the triggering signal to begin the acquisition is not influenced by surrounding noises. The detection filter is disabled as soon as the signal exceeds the green line.

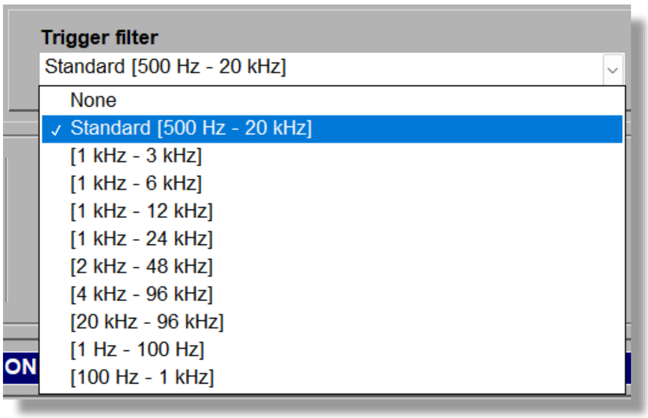


Figure 30 - Selecting the frequency range to trigger the acquisition.

If a specimen is small and presents high frequencies, then select higher ranges of frequencies, for instance, "4 kHz - 96 kHz". In that case, only the frequencies within this range will trigger the acquisition. *Note: After acquisition, all frequencies will be shown in the spectrum, even the ones that were not previously considered to trigger the acquisition.*

The controllers shown in Fig. 31 allows the adjustment of the "Signal duration" and "Processing time".

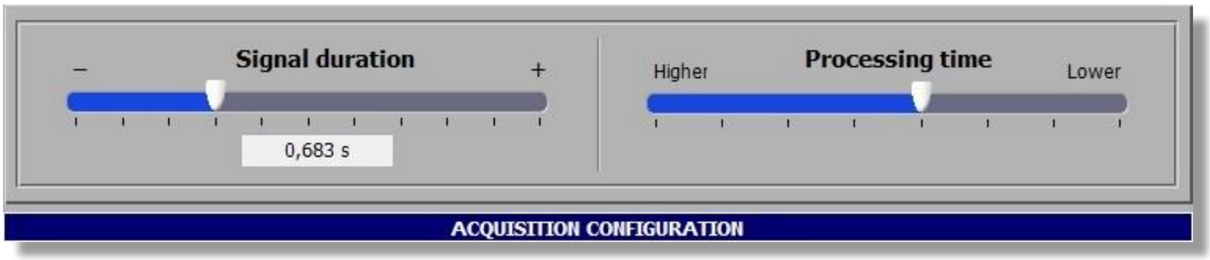


Figure 31 - "Signal duration" and the "Processing time" controllers.

The "Signal duration" controls the software signal acquisition after acquisition trigger, it ranges from 0.0853 to 14.6 seconds. The signal duration must be 4 to 8 times greater than the apparent duration of the acoustic response (Fig. 32).

The "Processing time" selects the signal interval to be processed for obtaining the frequency spectrum. This region is indicated by the vertical red dashed lines, as shown in Fig. 32. Processing time reduction allows detecting frequencies with lower amplitude what is necessary for high damping materials. However, processing time reduction also causes frequency peaks enlargement, resolution decreasing and even merging nearby peaks. Additionally, if the processing time is longer than the acoustic response duration, it is possible that there is only noise processing what may cause the frequency peaks to disappear due to the moving average.

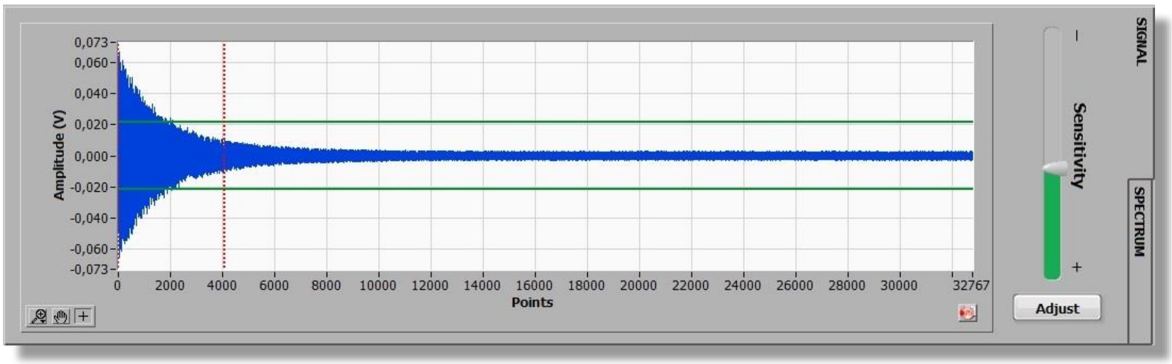
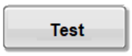


Figure 32 - Graph and control to adjust the scale ("Sensitivity").

The "Sensitivity" parameter, under the "Signal" tab, allows adjusting the graph scale and the acquisition triggering level (the green lines shown in the acquisition graph / Fig. 32). This adjustment is also important to optimize the signal visualization.

The Signal duration, Processing time and Sensitivity adjusting should be carried out by the user in agreement with the material and specimen dimensions. When in doubt, start with the "Signal duration" of 0.683 seconds and "Processing time" in position 5 (Fig. 31) and Sensitivity at 0.025 (Fig.32). This set up is usually the ideal one for ceramics and low-damping materials.

Note: the acquisition time is divided in half if the option "Optimize to include high frequencies (48-96 kHz)" is enabled (Figure 29).

The "Test" button 

allows the user to perform tests before taking measurements, verifying the peak intensity and the suitable scale. When this button is pressed, all other commands are deactivated and the software goes into a continuous acquisition mode. To interrupt this mode, click on the same button, which will turn to "Stop" instead of "Adjust":

Sonelastic® Software may request offset adjustment on the amplitude scale. This adjustment is necessary for the acoustic response to be acquired without a DC level (Fig. 33).

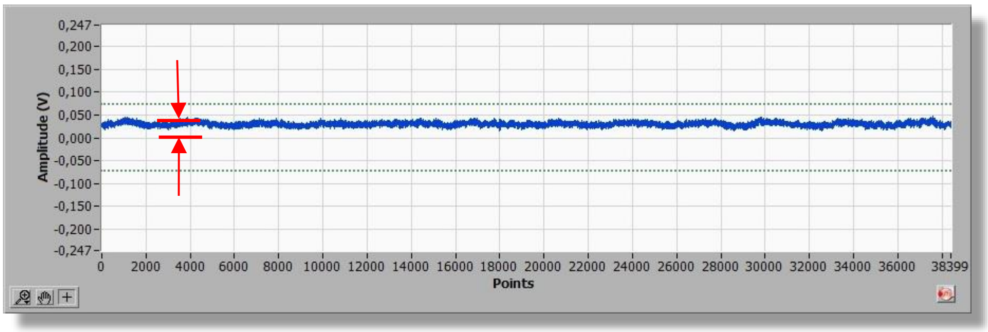


Figure 33 - Graph for the visualization of the signal, indicating an offset of approximately "+0,023 Volt".

If the blue line is on the zero-amplitude line (0,000), it is not necessary to perform the steps described next. Otherwise, follow the instructions after these steps.

Offset adjustment procedure:

Step 01 – Click on the "Test" button and the blue line (regarding the signal) will activate and continuously updated. Verify if the signal average value coincides with the x-axis (y = 0.000). Fig. 33 shows an example in which the blue line does not coincide with the x-axis, being necessary an *offset* correction.

Step 02 – Click on "Stop" to perform the adjustment.

Step 03 – In the "Configurations" menu (Fig. 34), select the "Advanced acquisition".

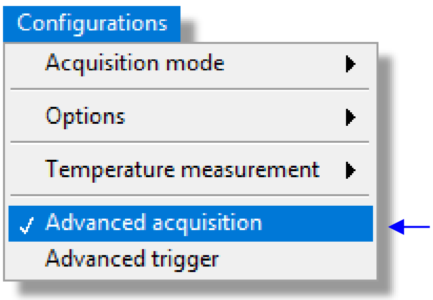


Figure 34 - Menu to select the advanced acquisition mode.

New settings will be presented in "Acquisition configuration" and will allow the fine adjustment using the  button, under the "*Offset*" field (Fig. 35).

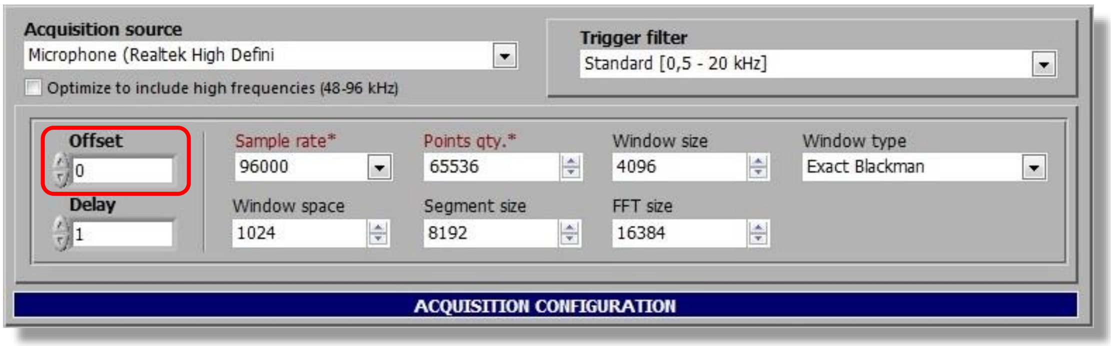


Figure 35 - “Offset” adjustment section.

Step 04 – Perform successive adjustments changing the “*Offset*” and visualizing the result using the “Test” button, until the average blue line is on the zero amplitude (Fig. 36).

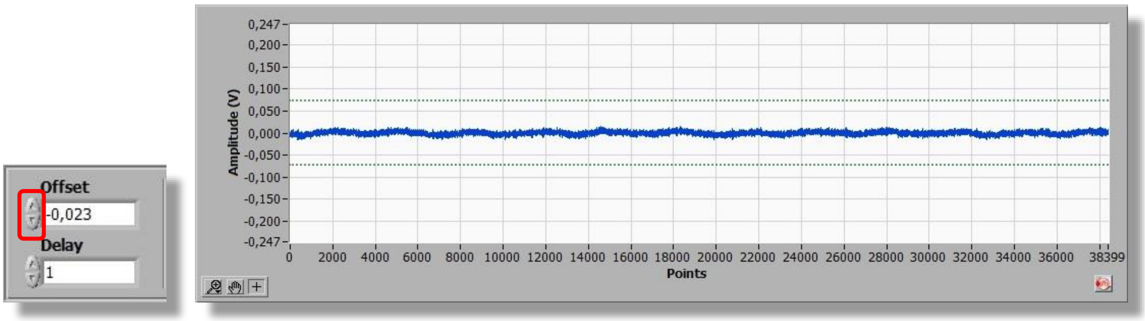


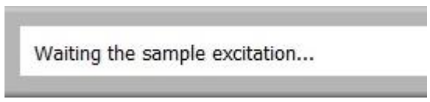
Figure 36 - Detailed image of the “Offset” configuration result.

Step 05 – In the “Configurations” menu, unmark the “Advanced acquisition” option. The “Acquisition configurations” screen will return to the simplified mode. Verify item *8.9.4 Advanced acquisition* for more information about the “Advanced acquisition” mode**.**

8.1.4 Software feedback during the signal acquisition

On the software interface top right corner, next to the “Exit” button, there is a status display. When the software is in waiting mode, the message displayed will be: “Waiting for commands”.

Immediately after clicking on “Capture”, whilst the software waits for the acquisition, the message displayed will be replaced for “Waiting the specimen excitation…”



As soon as the signal exceeds the triggering line, the message “Processing signal…” will appear, and in the following steps of measurement, the message will be “Detecting peaks…”

8.1.5 Spectrum and signal pre-processing

After the signal acquisition, it is possible to visualize the spectrum obtained from processing the acoustic response in the "Spectrum" tab (Fig. 37). The detected and selected frequencies are marked by a small red box and are listed on the side of the spectrum graph. The vertical red traced line corresponds to the frequency reader.

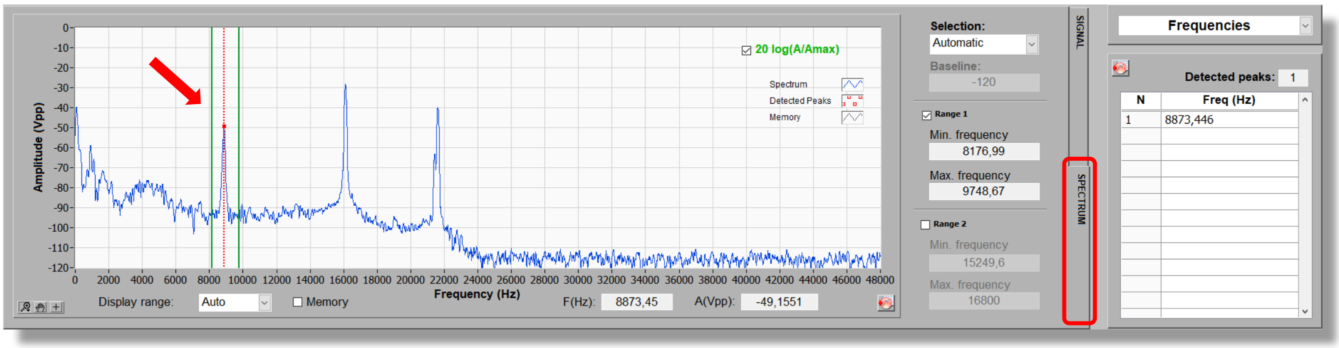


Figure 37 - Frequency spectrum tab and commands for the frequency selection.

It is possible to carry out manual pre-processing and specify the ranges of interest in the frequency spectrum (Range 1 and Range 2). Adjusts in both the minimum amplitude and frequency range will limit the software scan for frequencies.

At the "Selection" option (Fig. 38), it is possible to choose the method to detect the peaks: "Base Line", in which all peaks above a specific "Baseline" indicated by the horizontal red line are chosen; or "Automatic", in which an algorithm automatically detects the most relevant peaks.

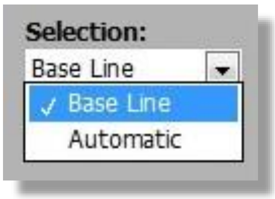


Figure 38 - Section for choosing the peak selection method: "Base Line" or "Automatic".

The frequency range to be analyzed is defined with the "Range 1" and "Range 2" options. For that, it is necessary to enable this function, indicating the minimum ("Min. frequency") and the maximum ("Max. frequency") frequencies moving the green and brown vertical lines.

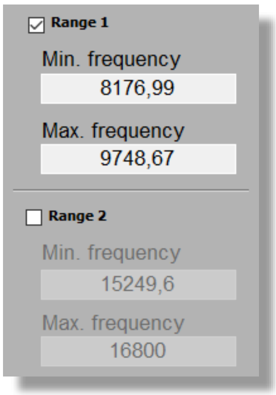


Figure 39 - Section for selecting the frequency ranges to be analyzed.

To set up the minimum amplitude, drag the horizontal red traced line to the required level (ensure the option "Base Line", at "Selection", is enabled).

If “Selection” is on “Automatic” and “Range 1” and “Range 1” are not enabled, the horizontal red line and the vertical lines will not appear. In this case, it will appear only the vertical red traced line, corresponding to the scroll reader, and it will be able to move from peak to peak (Fig. 40).

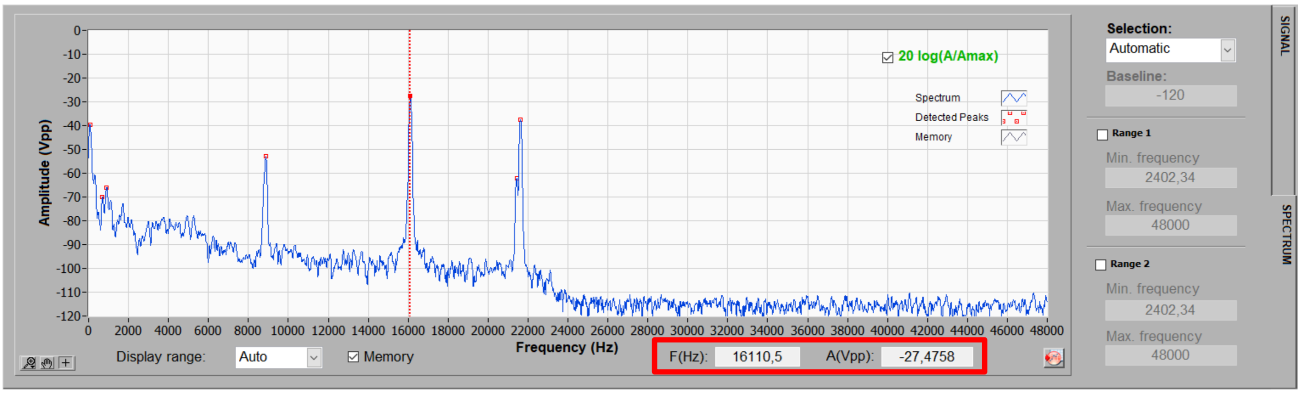


Figure 40 - Spectrum display when the option “Range” is disabled and “Selection” is on “Automatic”.

Figure 40 highlighted section shows the frequency and amplitude values of the peak selected by the screen reader (vertical traced line).

Next to the graph, in “Frequencies”, it is possible to choose the following options: “Actuator” or “Furnace”, when the IED Automatic Impulse Device and a furnace are available. These are optional items of Sonelastic® Systems.

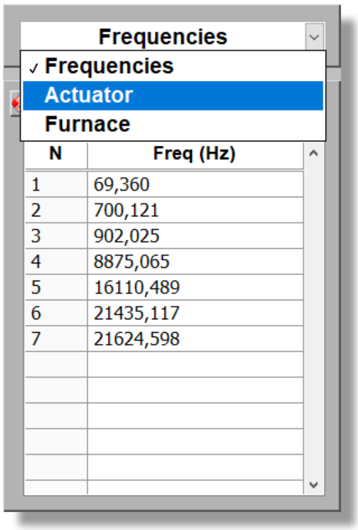


Figure 41 - Control for choosing between Frequencies, Actuator and Furnace.

Note: If “Range 1” and “Range 2” are on, the software will search for the torsional frequency in “Range 2” only.

8.1.6 Setting the automatic impulse device and furnace communication

If the option "Actuator" is enabled, the following screen will appear (Fig. 42).

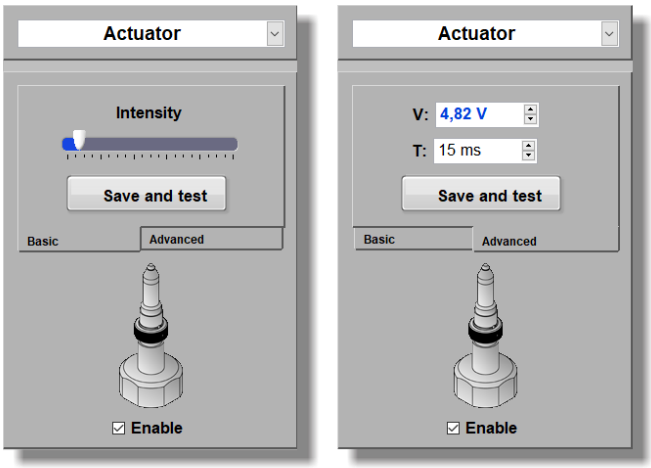


Figure 42 - Impulse device configuration screens.

On this screen it is possible to adjust the impulse excitation intensity. The basic interface allows "%" adjustment by using a the "Intensity" bar. In the advanced interface, the "V" parameter corresponds to the amplitude in Volts, and "T" to the duration of the electrical impulse applied on the impulse device, in milliseconds (ms). The higher the values, the higher the impulse intensity (in the basic interface, "V" and "T" parameters are automatically changed as the "Intensity" is adjusted). The "Save and test" button saves the configuration and applies an impulse to the user observe the changes effect on the impulse excitation intensity applied to the specimen.

Note: The impulse intensity should be adjusted by the user according to the specimen material and dimensions, always aiming a proper excitation without moving the specimen. The duration and intensity setting are usually customized around 3 V and 15 ms for the Light RT Impulse Device and around 35% for the Medium RT Impulse Device.

If the option "Furnace" is enabled, the following screen will appear (Fig. 43):

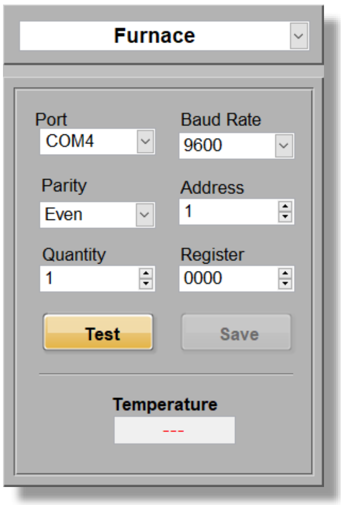


Figure 43 - Configuration tab for the communication of with the f instrumented furnace.

The option "Port" selects the serial port of the furnace, whilst the other parameters ("Baud Rate", "Parity", and "Address") configure the communication and must be synced with the specifications on the temperature transmitter.

The "Test" button enables to verify the communication between Sonelastic® Software and the Furnace, showing the temperature in that specific moment of time under the "Temperature" field. The memorization of this value is done by pressing the "Save" button.

If there is no characterization system as a function of the temperature (Furnace), disregard the need for these adjustments.

8.1.7 Spectrum view configuration and saving to file

Figure 44 shows an example of three frequency peaks detection. It is possible to change the scale by deactivating the "20 log (A/Amax)" option, on the top-right corner of the spectrum graph. The 0 dB level corresponds to the maximum amplitude measurable. Figure 44 images information are the same, nonetheless the logarithmic scale facilitates the visualization of smaller amplitude peaks.

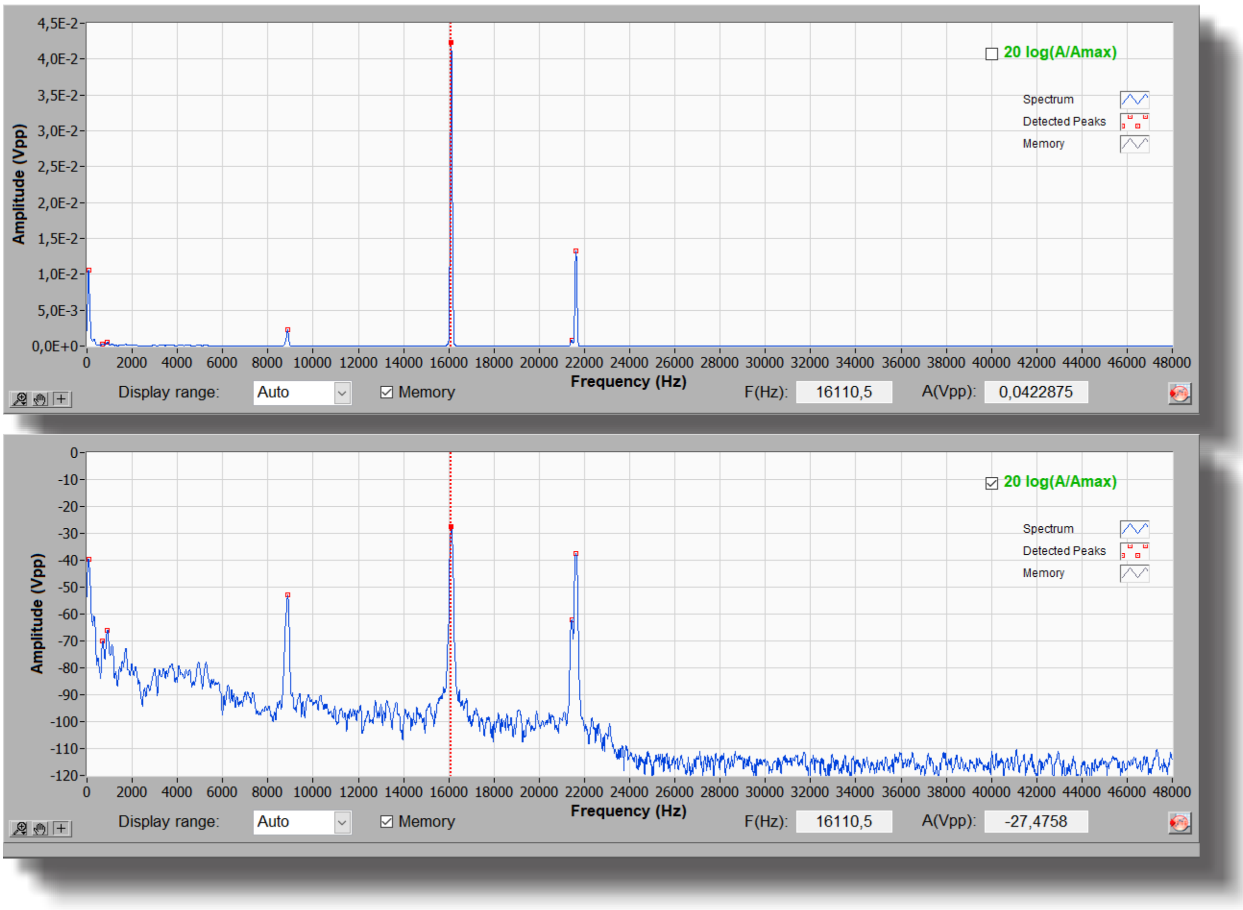


Figure 44 - Examples of a spectrum in the logarithm scale (above), and the same in linear scale (below).

On the next graph (Fig. 45), the option "Display range" allows selecting the maximum frequency to be displayed. In the "Auto" mode, Sonelastic® Software makes this selection automatically.

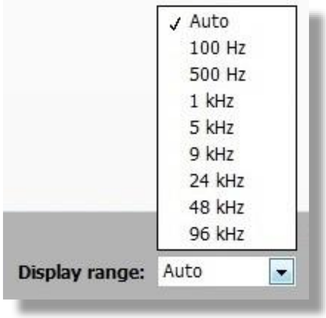
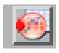


Figure 45 - Control for selecting the display range of interest.

The  buttons, on the corner of graphs and tables, allows to export the graph in ".xls", ".csv",".ogg". Click on this button and a window will pop up for the user to choose the folder to save the file. It is necessary to type/include the file extension at the file name end.

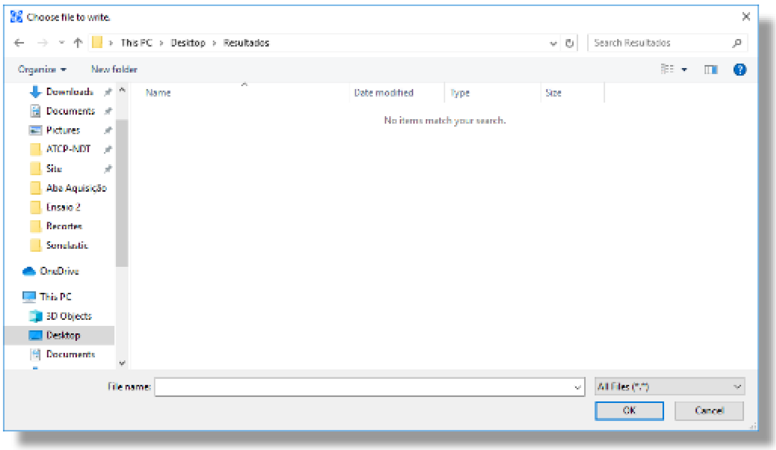


Figure 46 - Screen showing where the file will be saved in.

The graphics visualization may be adjusted by the button , on the graphs' bottom-left corner.

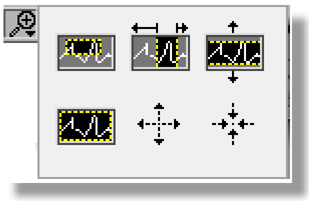
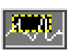
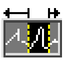
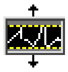


Figure 47 - Options for adjusting the spectrum.

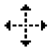
From the left to the right, the top to the bottom:

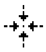
 Zoom in the selected area.

 Horizontal zoom into the selected area.

 Vertical zoom into the selected area.

 Automatic adjustment of the spectrum to the screen.

 Gradually increases the zoom when the user clicks on the graph or keeps the left-button of the mouse pressed.

 Gradually decreases the Zoom when the user clicks on the graph or keeps the left-button of the mouse pressed.

The  button allows the user to move the spectrum along the screen. Keeping the left button of the mouse clicked, it is possible to move the spectrum as desired.

To return to the initial model of Sonelastic® Software cursor, click on .

8.2 ELASTIC PROPERTIES tab

Tab for calculating the elastic properties:

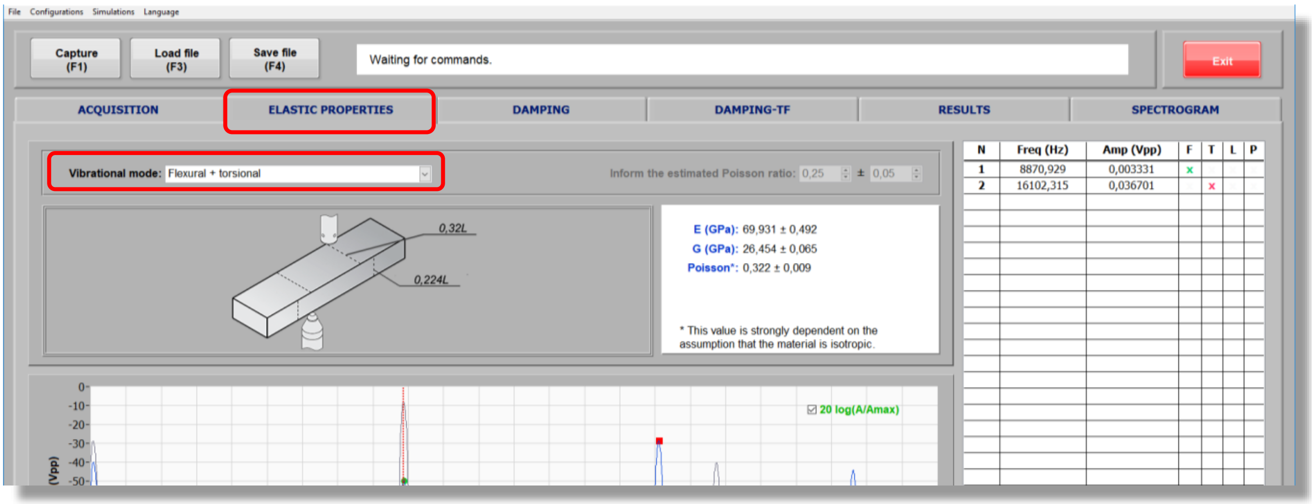


Figure 48 - Sonelastic® Software screen showing the module for elastic properties calculation.

This tab is used to perform the calculation of the elastic moduli according to the frequencies selected on the presented table. Based on these values, dimensions and mass of the specimen, it is calculated the elastic moduli (see item *7.2.2 Excitation and acquisition modes*).

The first step is to choose which type of analysis must be made, in “Vibrational mode”:

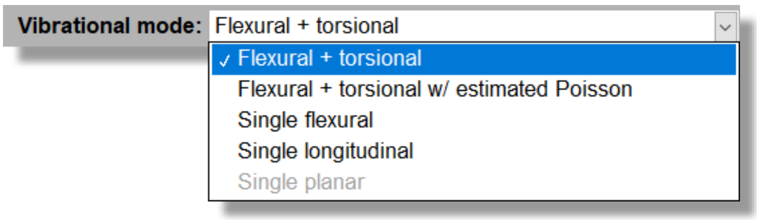


Figure 49 - Screen for choosing the analysis type.

“Flexural + torsional” (Fig. 50): allows calculating the Young’s modulus (E), the shear modulus (G), and Poisson’s ratio. Flexural and torsional frequencies must be correctly selected from the frequency list*. Note: The specimen excitation and signal acquisition must be applied to points favoring such vibration modes (verify item 7.2.2 Excitation and acquisition modes).*

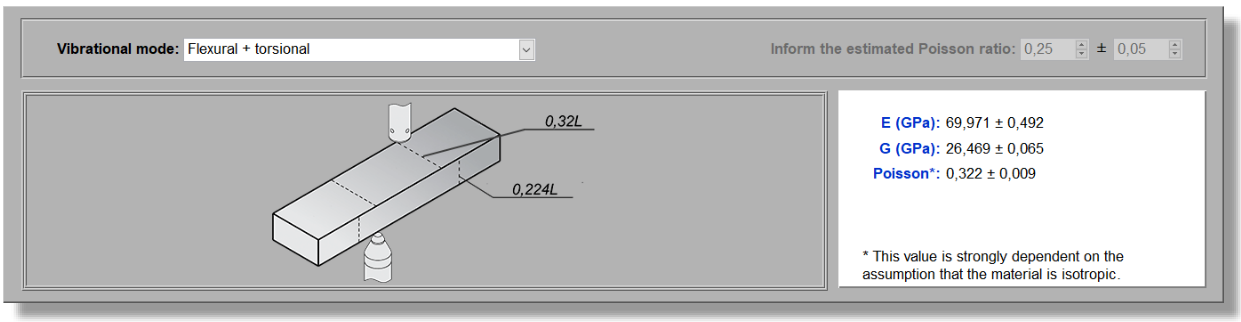


Figure 50 - Sonelastic® Software module showing the selection of the “Flexural + torsional” option.

"Flexural + torsional w/ estimated Poisson" (Fig. 52): allows calculating the Young's modulus (E) and the shear modulus (G). The Poisson's ratio value must be estimated by the user (Fig. 51).

Figure 51 - Field to fill with the approximated Poisson's ratio to be used in the calculations.

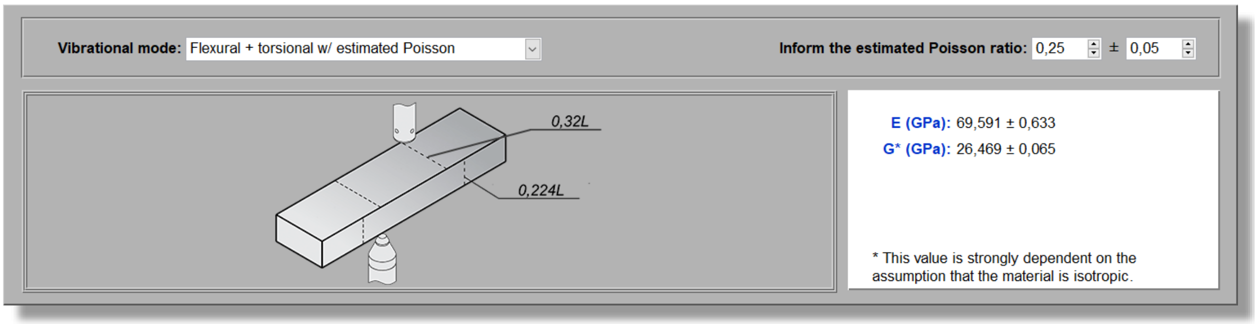


Figure 52 - Sonelastic® Software module showing the selection of the "Flexural + torsional w/ estimated Poisson" option.

"Single Flexural" (Fig. 53): allows calculating only the Young's modulus at flexural mode. In this case, only the flexural frequency must be selected.

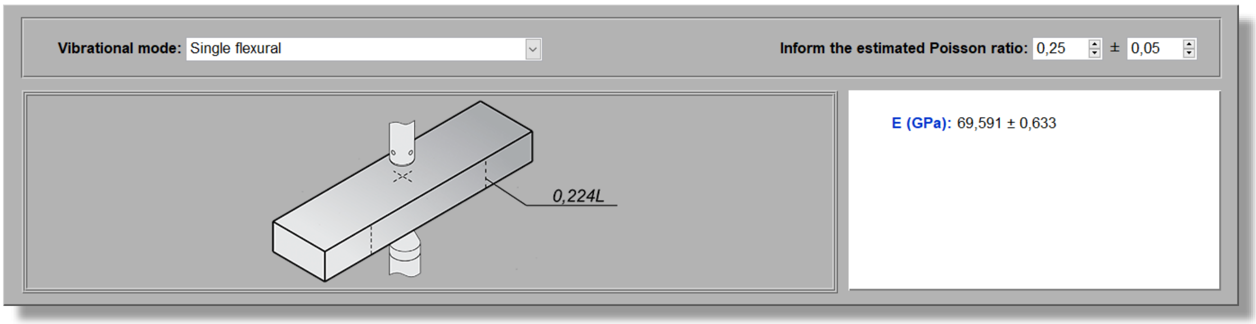


Figure 53 - Sonelastic® Software module showing the selection of the "Single Flexural" option.

"Single Longitudinal" (Fig. 54): allows calculating only the Young's modulus at longitudinal direction. In that case, only the longitudinal frequency must be selected.

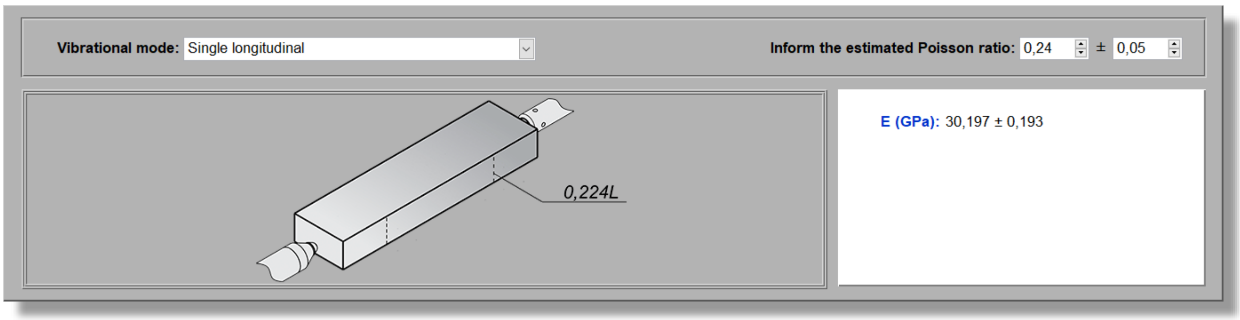


Figure 54 - Sonelastic® Software module showing the selection of the "Longitudinal" option.

"Single Planar" (Fig. 55): allows calculating the Young's modulus through the planar vibration mode. In that case, only the planar frequency must be selected.

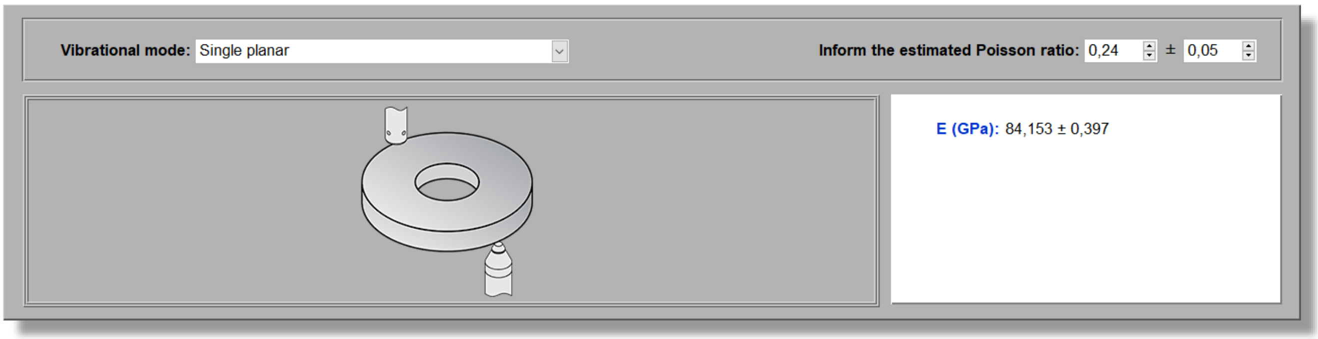


Figure 55 - Sonelastic® Software module showing the selection of the "Planar" option. Example of a grinding wheel measurement.

Note: The images, appearing as the "Vibrational mode" is changed, informs an example of the excitation and signal acquisition points depending on the vibration mode being measured.

The table on the Elastic Properties tab right (Fig. 56) displays the detected peaks. "N" represents the number of detected peaks; "Freq. (Hz)" corresponds to the frequencies; "Amp (Vpp)" corresponds to the amplitude of each frequency; "F" corresponds to the flexural frequency; "T", for the torsional; "L", to the longitudinal; and "P", to the planar one. For each vibration mode, only one frequency can be selected for the calculations.

N	Freq (Hz)	Amp (Vpp)	F	T	L	P
1	71,194	0,010237				
2	716,026	0,000292				
3	910,214	0,001145				
4	8873,446	0,003485	x			
5	16106,975	0,038673		x		
6	21429,696	0,000705				
7	21619,709	0,010190				

Figure 56 - Table listing the detected peaks, with the frequency's values, amplitude and mode selection.

Note that the frequency of 5000.089 Hz is marked with a green "x", and the frequency of 9999.848 Hz is marked with a red "x" (Fig. 56), which means that both were used for the calculations ("Flexural + torsional" vibration mode). To change the selected frequency, click on the cell related to the new frequency. The amplitude vs. frequency plot (Fig. 57) highlights the flexural frequency with a green circle the torsional one with a red square.

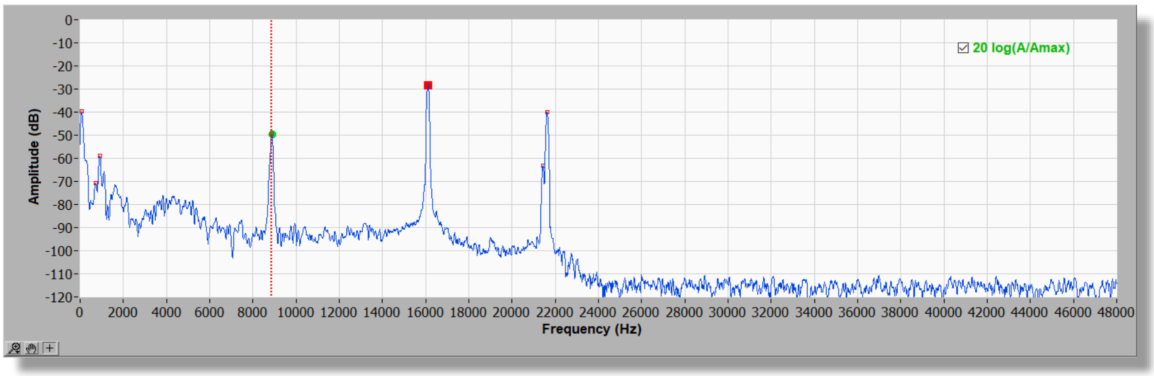


Figure 57 - Amplitude vs. frequency graph highlighting the one used to calculate the elastic moduli.

Elastic moduli values (E, G and Poisson's ratio) are shown in Figure 58-a.

If the option "Estimate the Eci by Popovics (ABNT NBR 8522-1:2021)" is enabled at "Settings/Options menu", the estimated secant/chord modulus of elasticity (Eci) will also be displayed as shown in Fig. 58-b. The Eci estimate is applicable and makes sense only for concrete and cementitious materials, in the example in Fig. 58-b the result of estimating the Eci of a cylindrical concrete specimen is presented.

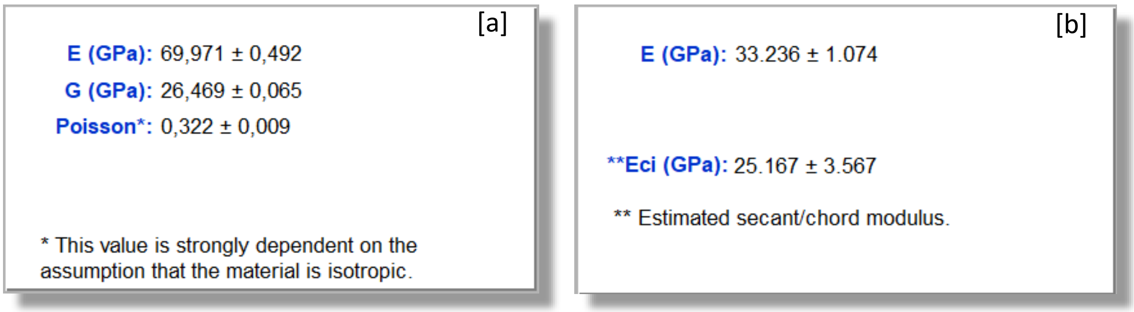


Figure 58 - Elastic moduli results ("E (GPa)", "G (GPa)", "Poisson" and estimated Eci (GPa).

The user may change the spectrum visualization between a linear and a logarithm scale marking the "20 log (A/ Amax)" option.

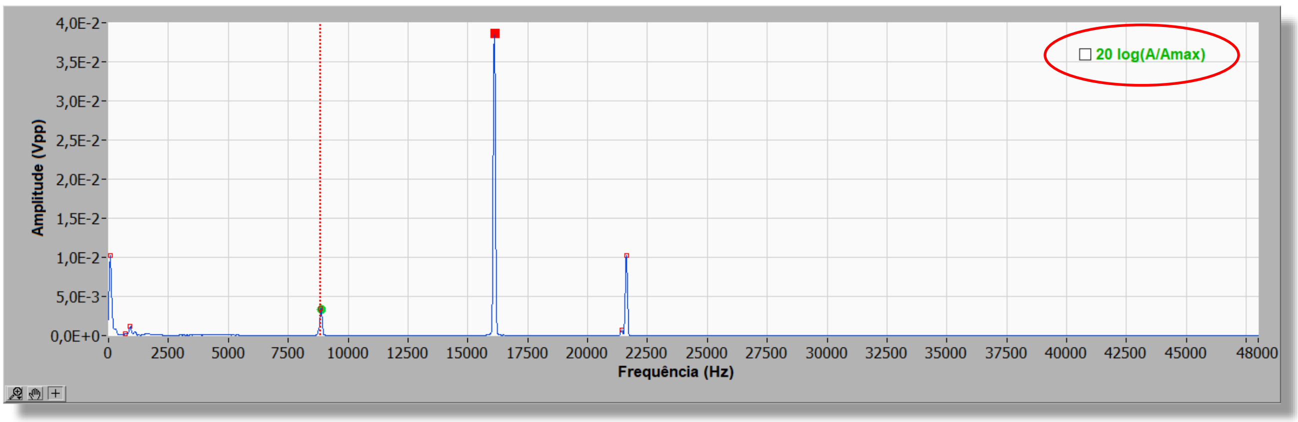


Figure 59 - Amplitude vs. frequency graph.

Note: The "Frequency simulator" helps discovering the frequencies pattern and assists on the detection and choice of fundamental frequencies of vibration (see item 8.10 Simulations Menu).

For further information about frequencies selection, visit our website www.sonelastic.com or contact us by email (info@sonelastic.com).

8.3 DAMPING tab

Tab for calculating time-domain damping ratio:

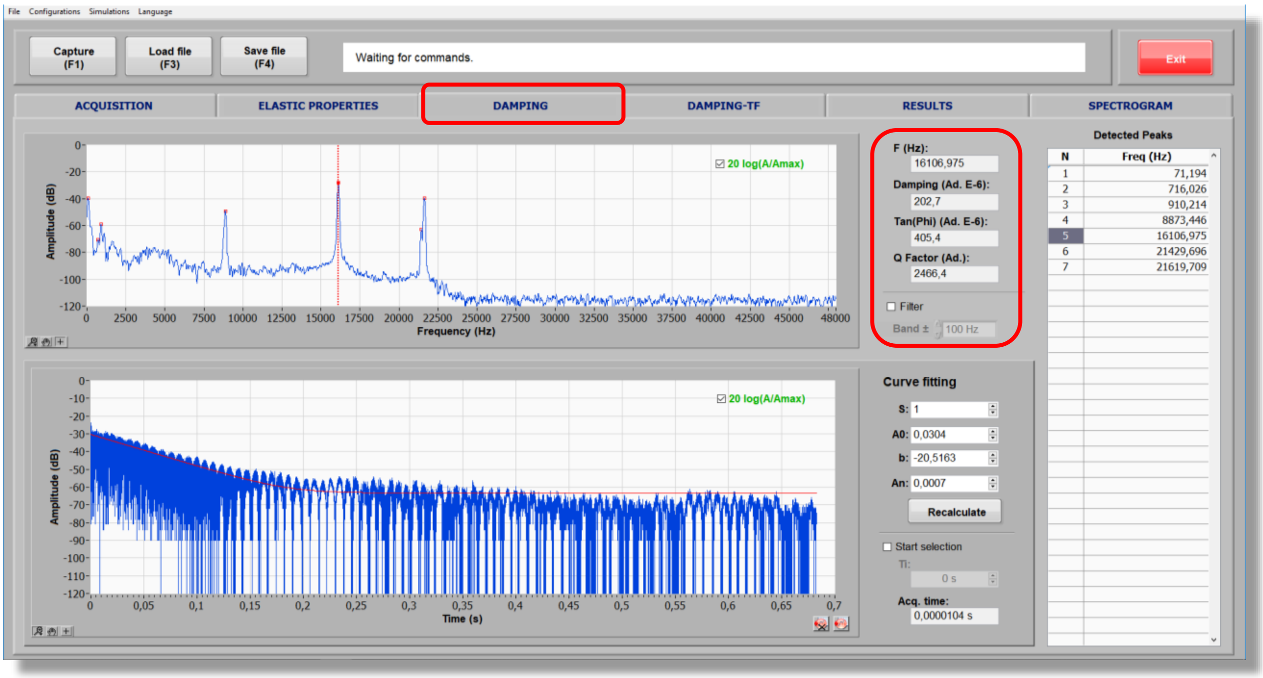


Figure 60 - Sonelastic® Software screen showing the time-domain damping calculation tab.

The software automatically calculates the damping ratio in the time domain when the user clicks on the "Damping" tab.

The screen shows two graphs: the first one, on the top part of the screen, shows the amplitude as a function of frequency; whereas the second one, on the bottom of the screen, shows the amplitude as a function of time (Figure 60). The first graph (Figure 61) is similar to the one that appears on the initial screen at the "Acquisition" tab. The vertical red traced line selects the frequency used for the damping calculation.

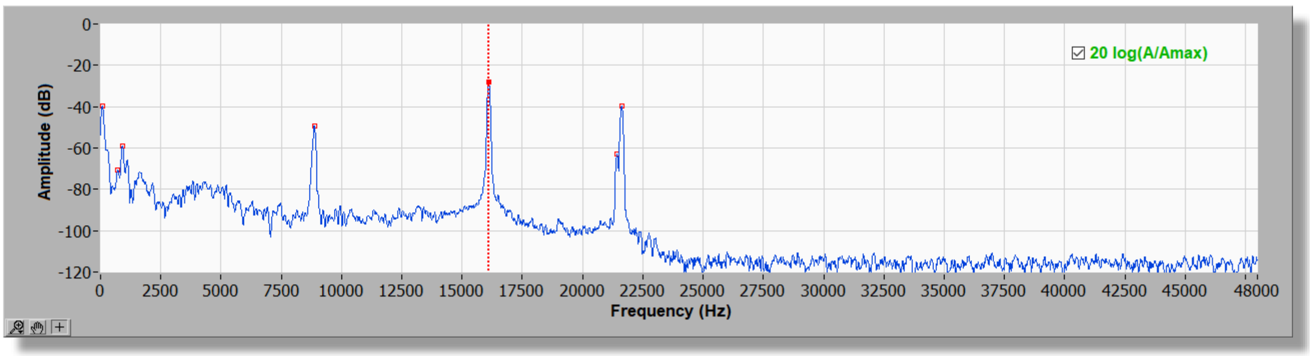


Figure 61 - Example of an amplitude vs. frequency graph used to calculate the time-domain damping ratio.

The user may change the graph to linear scale, being also possible to apply all the tools described in item *8.1.5 Spectrum and pre-processing of the signal.*

The second graph (signal amplitude as a function of time) represents the signal attenuation; the red line is Sonelastic® Software curve fitting for the damping calculation.

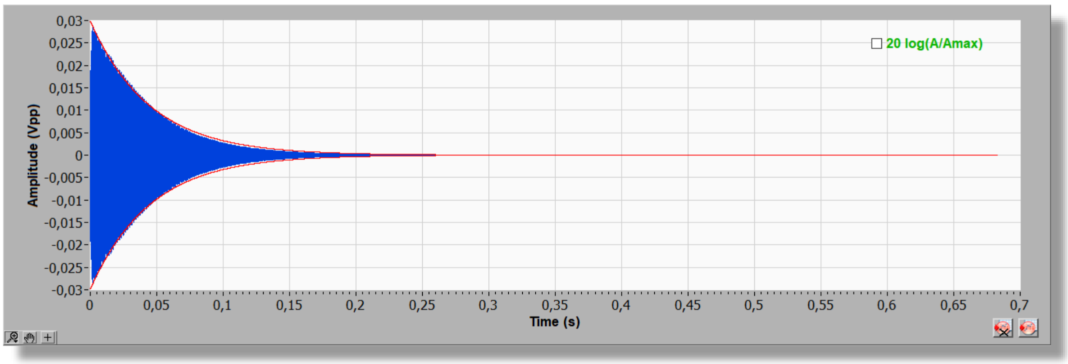


Figure 62 - Example of an amplitude vs. time graph, illustrating the signal exponential attenuation.

These graphs allow the application of the "Zoom" options and the exportation process as described in item *8.1.5 Spectrum and pre-processing of the signal*. To visualize the graph in logarithm scale, select the option "20 log (A/Amax)", highlighted on Fig. 63.

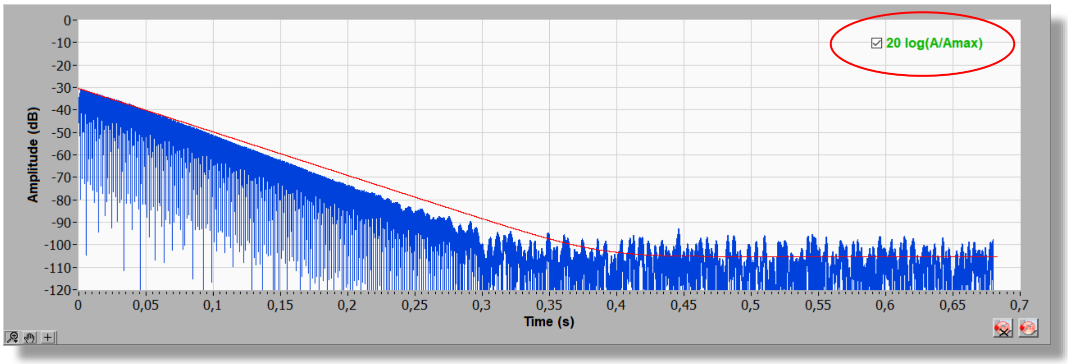


Figure 63 - Example of amplitude vs. time in log scale.

The right side of the screen shows a table with the detected peaks ("Detected peaks") with the frequencies values "Freq (Hz)" (Fig. 64).

Detected Peaks

N	Freq (Hz)
1	8874,049
2	16108,384

Figure 64 - Table of detected peaks ("Detected Peaks").

In Figure 64, there is a characterization in which two peaks were detected ("Detected peaks"), with the frequency's values ("Freq. (Hz)") of 8874.049 and 16108.384 Hz.

The software fits an exponential envelope to the signal, that may be fine adjusted by the tools presented below. Based on this envelope and chosen frequency, the damping is calculated and presented in different units (see *Appendix C – Detailing the damping calculation*).

The chosen frequency for the damping calculation can be changed by dragging the red traced line of the graph in Figure 61, or by clicking on the number ("N") of the chosen frequency presented in Figure 64. The values for the fundamental frequency "F (Hz)" used for the damping calculation, the damping ratio value ("Damping (Ad. E-6)"), the "Tan (Phi) (Ad. E-6)" factor, and quality factor "Q Factor (Ad.)" are displayed in the right of the first graph (Fig. 60 and 65).

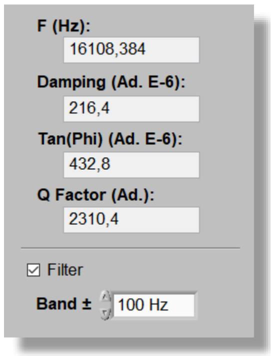


Figure 65 - Section comprising the damping data.

According to Figure 65, the frequency ("F (Hz)") taken for the calculation was 16108.384 Hz, the damping ratio ("Damping (Ad. E-6)") was calculated as being 216.4, "Tan (Phi) (Ad. E-6)" was 432.8, and the quality factor ("Q Factor (Ad.)") was 2310.4.

Aiming to remove the influence of other vibration modes, it is possible to apply a bandpass filter to the signal with the "Filter" option so that only the surroundings of the chosen frequency delimited by the "Band ±" parameter is taken into account.

It is also possible to finely adjust the red exponential fitting through the "A0", "b", and "An" parameters (Figure 66). These values correspond to the adjustment curve parameters, given by equation $x\,(t) = An + A0\,e^{-b\,(t)}$. The "S" parameter allows prioritizing specific regions of the curve: for S=1, the adjustment prioritizes the beginning of the signal; for S=0, the final part is prioritized. This adjustment is useful for the non-linear cases (non-perfectly exponential decay), and for the damping calculation considering different parts of the curve.

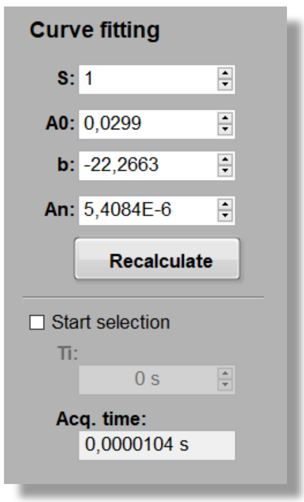


Figure 66 - Adjustment module for adjusting the exponential curve and the beginning of the signal ("Start selection").

Note: The adjustment of these parameters is only recommended for advanced users.

8.4 DAMPING-TF tab

Damping calculation tab combining time (T) and frequency (F) domain (Fig. 67):

Figure 67 - Sonelastic® Software screen for damping calculation in the time-frequency (TF) domain.

This module allows to calculate the damping ratio using a method based on the logarithmic decrease of the peak amplitude at the frequency domain, and not only on the amplitude of the signal at time domain. For further details, please verify the scientific paper: http://www.scielo.br/pdf/ce/v58n346/v58n346a14.pdf.

The software automatically calculates the damping for each frequency when the user clicks on "Damping-TF" tab.

The first graph is similar to the one of the initial screens, under the "Acquisition" tab. The vertical red traced line selects the frequency used for the damping calculation (Fig. 68).

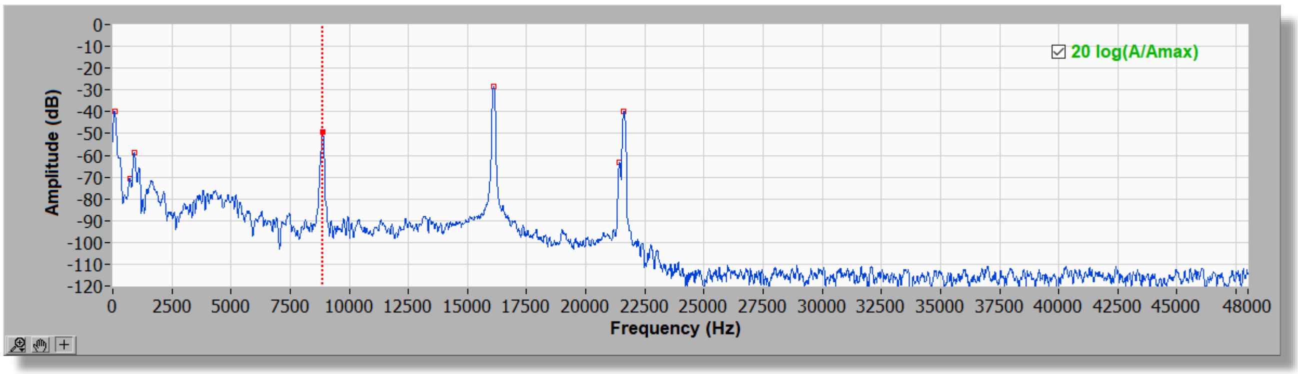


Figure 68 - Amplitude vs. frequency graph for the choice of frequency in the "Damping-TF" tab.

It is possible to use the adjustment tool to better visualize and export the graph, as described in item *8.1.5 Spectrum and pre-processing of the signal.*

The second graph of this module corresponds to the amplitude as a function of time or signal attenuation (Fig. 69).

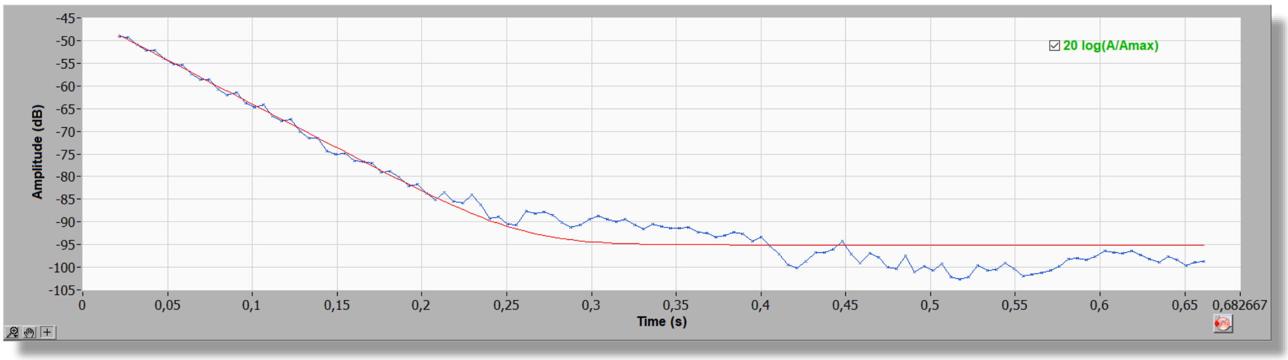


Figure 69 - Amplitude vs. time graph, representing the signal attenuation in a logarithm scale.

It is possible to choose between a logarithm and a linear scale ("20 log (A/Amax)") to visualize the graph. Figure 69 shows an example of a graph represented in logarithm scale, whereas Fig. 70 shows the same graph in linear scale.

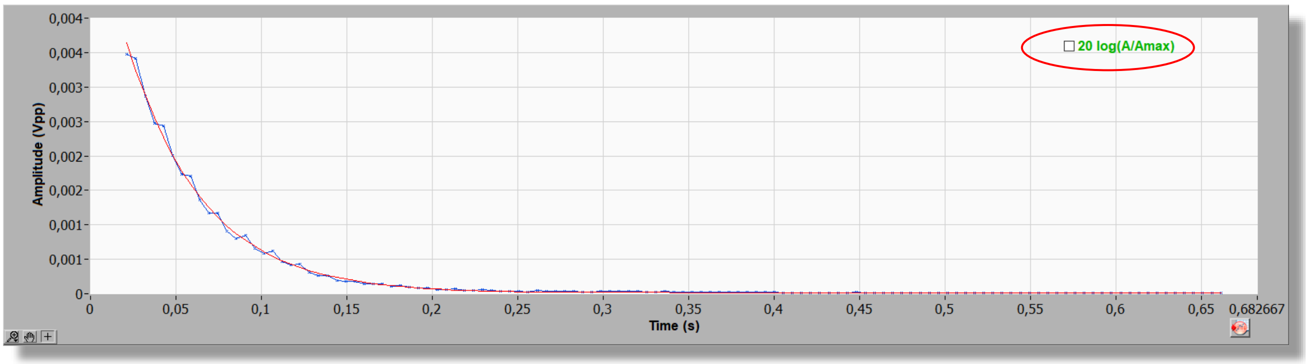


Figure 70 - Amplitude vs. time graph, in a linear scale (non-logarithm).

Next to the frequency spectrum, there is a list (Fig. 71) containing the number of peaks ("N"), frequency in Hz ("Frequency (Hz)"), damping ratio ("Damp. Z (Ad. E-6)"), quality factor ("Q Factor (Ad.)"), the tangent of Phi ("Tan (Phi) (Ad. E-6)"), and the curve adjustment parameter ("S (Ad.)") (Figure 71).

N	Frequency (Hz)	Damp. Z (Ad. E-6)	Q Factor (Ad.)	Tan (Phi) (Ad. E-6)	S (Ad.)
1	2471.488	1074.1	465.5	2148.2	0.2
2	3179.193	558.9	894.6	1117.8	0.2
3	4080.020	425.4	1175.5	850.7	0.2

Figure 71 - Table showing the values of frequency, damping ratio, quality factor, tangent of Phi and adjustment parameter.

The "Curve adjustment" section allows the adjustment of the "S" parameter (curve adjustment parameter), indicates the number of points used and also allows the selection of the beginning and the end of the analyzed signal (Fig. 72).

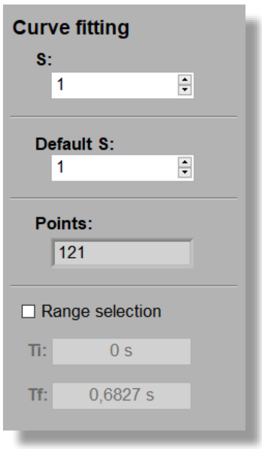


Figure 72 - Section for adjusting the “S” parameter and selecting the signal range to be analyzed.

It is possible to select a region of the graph so that the damping calculation is carried out within these limits. For that, it is necessary to enable the option “Range selection”. Two vertical green lines will appear and the adjustment is done by dragging these lines to the beginning and to the end of the desired region. Figures 73 and 74 exemplifies these adjustments.

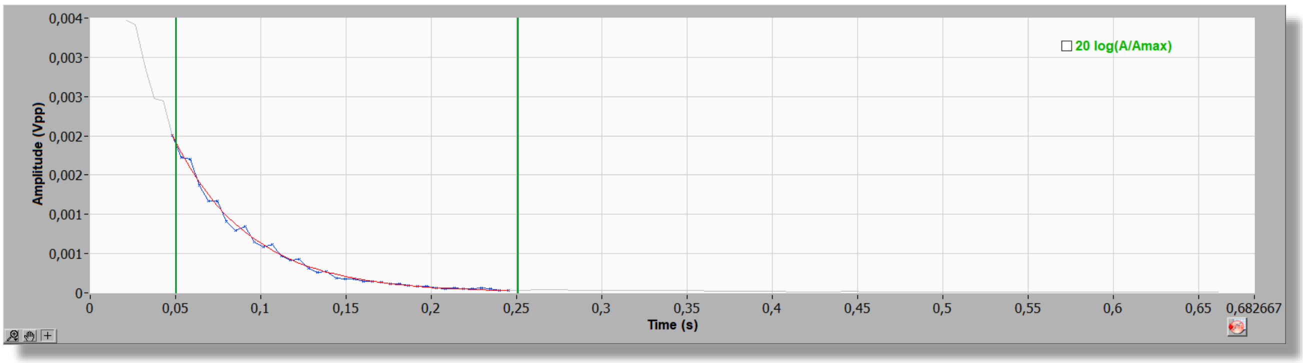


Figure 73 - Amplitude as a function of time graph, with the “Range selection” function enabled.

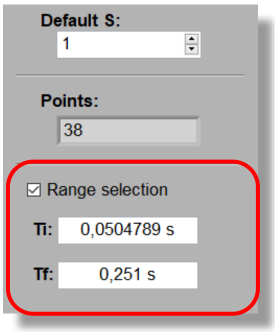


Figure 74 - Area for selecting the range.

Note about the difference between “DAMPING” and “DAMPING-TF”: In DAMPING, the adjustment of the exponential curve is based on the acoustic response, in DAMPING-TF it is based on the amplitude of a specific peak/frequency as a function of time. In DAMPING, the presence of other frequencies may affect the curve adjustment, whereas in DAMPING-TF such influence is much smaller because the adjustment is focused only on one frequency. For further details, verify the scientific paper: http://www.scielo.br/pdf/ce/v58n346/v58n346a14.pdf.

8.5 RESULTS tab

Tab with table for results output:

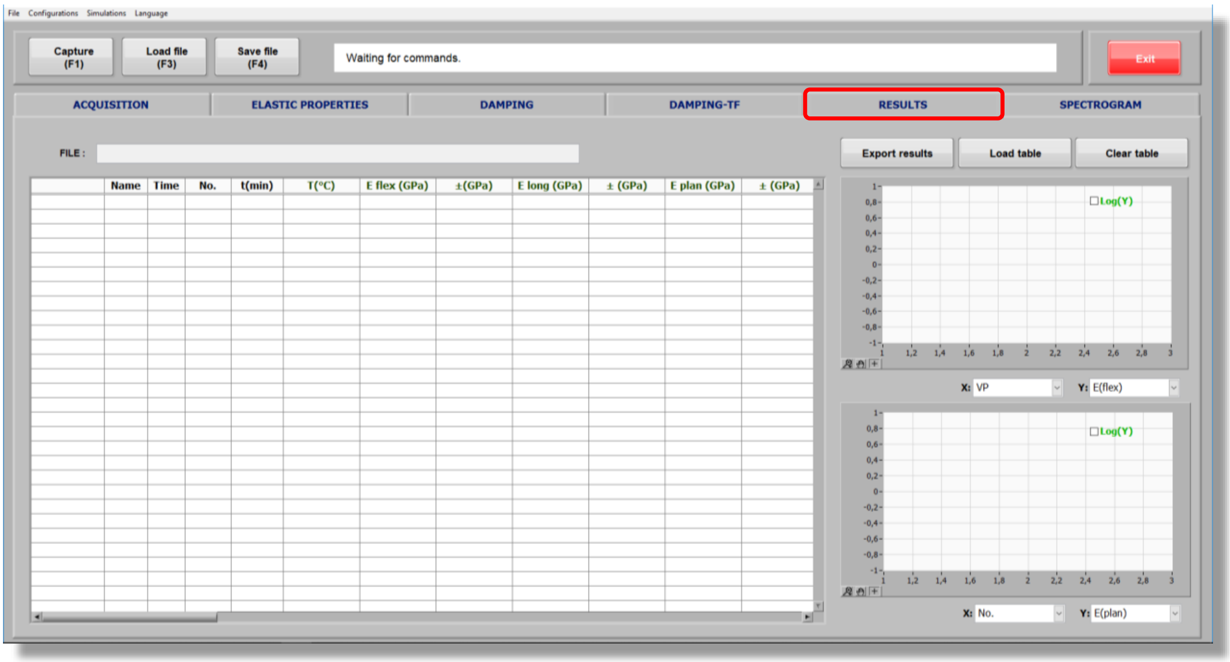


Figure 75 - Sonelastic® Software screen showing the tab for results output.

This tab allows exporting the results into a table that may be posteriorly read and edited by another program. To export the results to this tab, click on “Export results” button.

The software will open a window for the user, indicating the place where the file will be saved. Choose a destination folder, name the file, and click on “Export Table”.

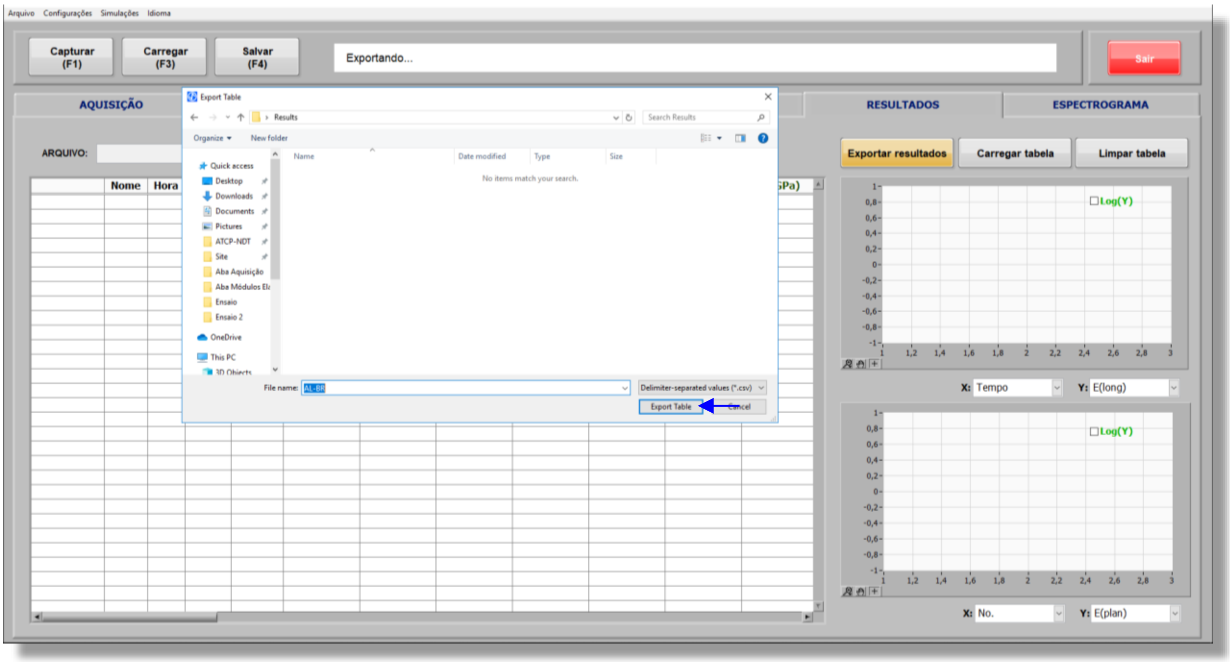


Figure 76 - Window showing where the file will be saved.

Measurement data will appear in the table at the "Results" tab (Fig. 77).

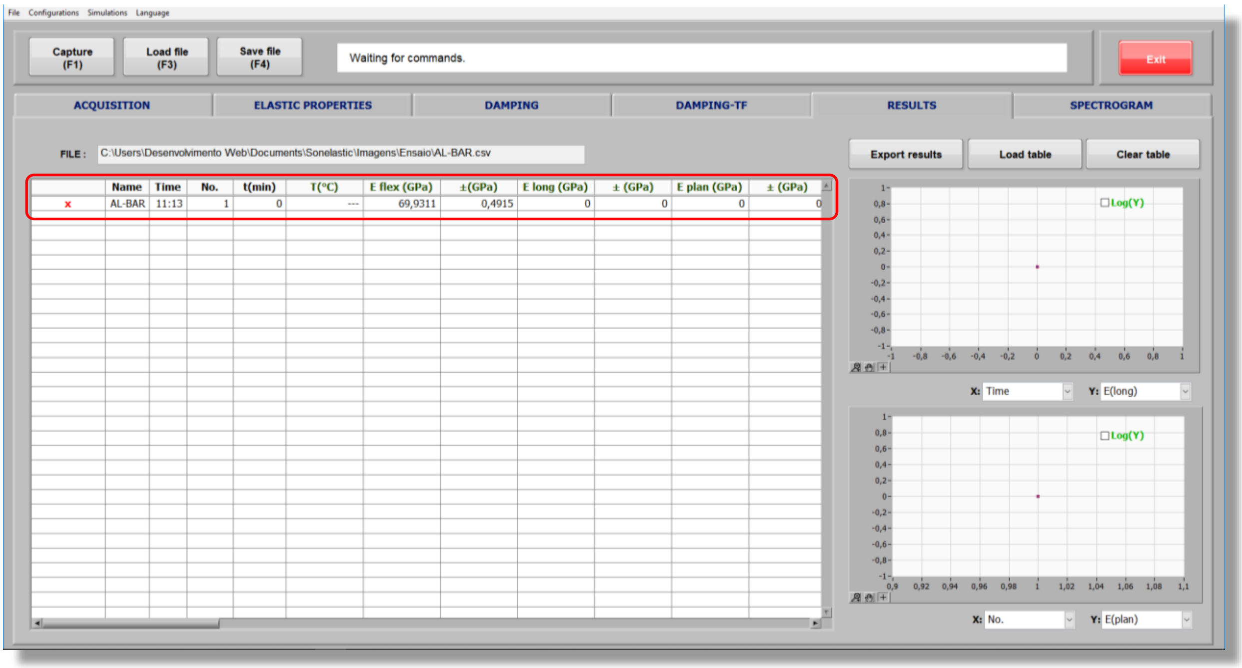


Figure 77 - Sonelastic® Software screen showing the measurements results in the table.

Note: The "Export results" option exports the measurement results to Sonelastic® Software spreadsheet and saves it as a .csv file. Although, exporting the result will not save the entire measurement file, for that it is necessary to click on "Save file (F4)", which is located on the top of Sonelastic® Software screen.

All the measurement calculated results will be on the table once the results are exported. Figure 77 shows some of these data: specimen's name ("Name"); measurement time ("Time"); number of measurements ("No."); time in minutes ("t(min)"); if the measurement is carried out as a function of temperature, temperature ("T (ºC)"); flexural elasticity modulus ("E flex (GPa)"); longitudinal elasticity modulus ("E long (GPa)") and planar elasticity modulus ("E plan (GPa)"). The other results available in the table, such as shear modulus ("G (GPa)"); Poisson's ratio ("µ (Ad.)"); frequency used for damping calculation ("F. Damping (Hz)"); Damping ratio in time-domain ("Damping (Ad.)") and estimated secant/chord modulus of elasticity ("Eci (GPa)"), may be seen by moving the spreadsheet view to the right.

After performing the second measurement and clicking again on "Export results", a message box will pop up asking whether you wish to continue saving on the same file or not (Fig. 78).

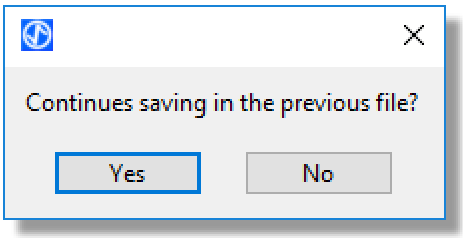


Figure 78 - Window showing the option to continue saving the measurements in the same file.

If the user wishes to continue, must click on "Yes" to store the values on the same table and the data will appear on the line immediately below the previous characterization. Otherwise, click "No" and a new table will be created and saved under a new file name.

If the user wishes to delete the any result, click on the **x** at the respective line.

On the right of the results table, it is possible to see the results in a graphic form. For this, choose the desired parameters at "X" and "Y" fields.

In Figure 79, there is a representation of a Young's modulus graph ("E (flex)") as a function of time ("Time"). In this case, there is only one measurement result.

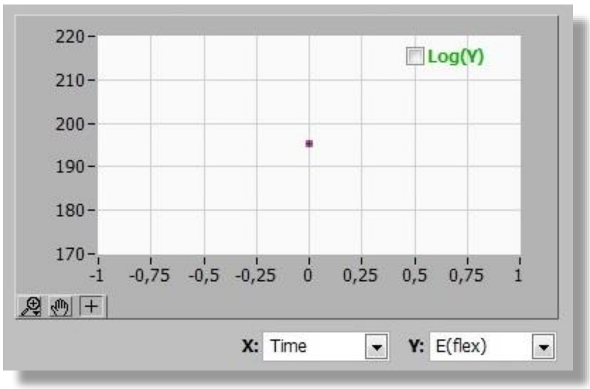


Figure 79 - Young's modulus graph ("E(flex)") vs. time ("Time").

Figure 80 is an example of a damping ratio obtained at the time-frequency domain ("TFD") as a function of the time ("Time"). In this case, there is only one measurement result.

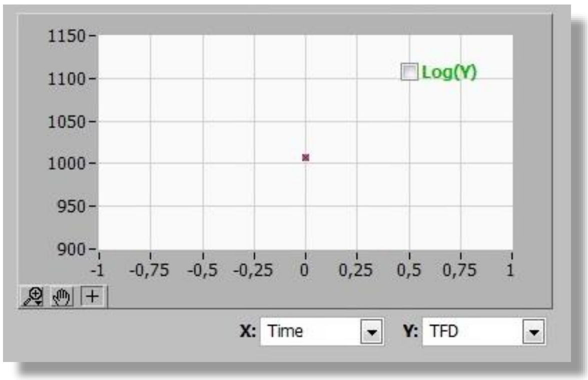


Figure 80 – Damping-TF ("TFD") vs. time ("Time") graph.

The graphs can be represented in a logarithm scale by selecting the "Log(Y)" option. The available parameters for the x-axis are: number of the measurement ("No."), time ("Time"), temperature ("Temperature"), and the voltage applied to the Impulse Device ("VP"). To select an option, choose the desired variable from the list (Fig. 81).

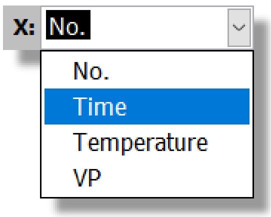


Figure 81 - Available parameters for the x-axis.

The available parameters for the y-axis are: temperature ("Temperature"); damping in the time domain ("TD"); damping in the time-frequency domain ("TFD"); Young's modulus obtained by flexural vibration ("E(flex)"); Young's modulus obtained by longitudinal vibration ("E(long)"); and Young's modulus obtained by planar vibration ("E(plan)"); shear modulus ("G"); estimated secant/chord modulus of elasticity ("Eci (GPa)"); P-waves velocity ("Vp"); and S-waves velocity ("Vs"). To select an option, choose the desired variable from the list (Fig. 82).

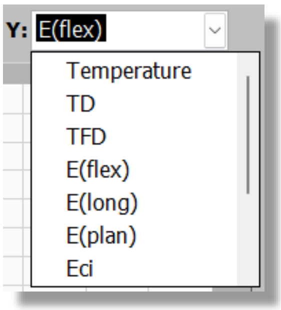


Figure 82 - Available parameters for the y-axis.

To load the results saved in other spreadsheets, click on "Load excel", and choose the desired spreadsheet.

The files generated by the software may be saved by clicking on the "Save file (F4)" button, on the top of the screen.

A screen will pop up showing the possible destinations to save the file. Choose a name for the file, the destiny folder, and click on "OK".

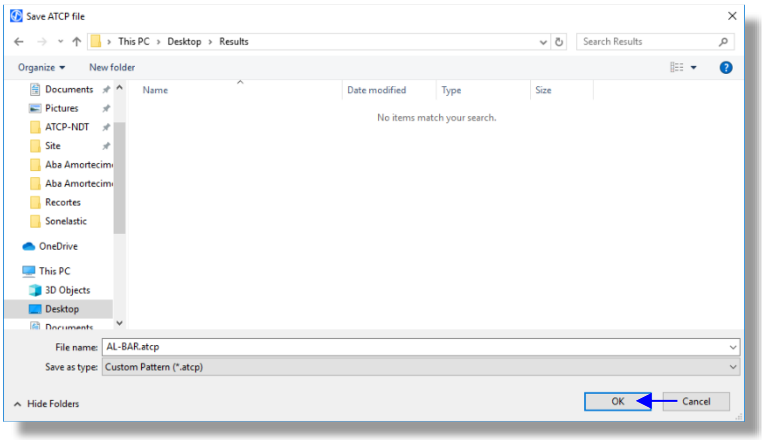


Figure 83 - Window showing where the file will be saved.

Files may be verified and/or modified in the future by clicking on "Load file (F3)", which allows opening a previous saved file.

Just click on "Load file (F3)" and select the respective file.

Note: Saved files will only be opened when Sonelastic® Software is running, through the "Load file (F3)" option. Computers that do not have Sonelastic® Software installed may not open these files, differently from the spreadsheets generated by the "Export results" option, that can be opened by any computer that has .csv compatible software.

8.6 SPECTROGRAM tab

Tab for the 3D visualization of the signal (Fig. 84).

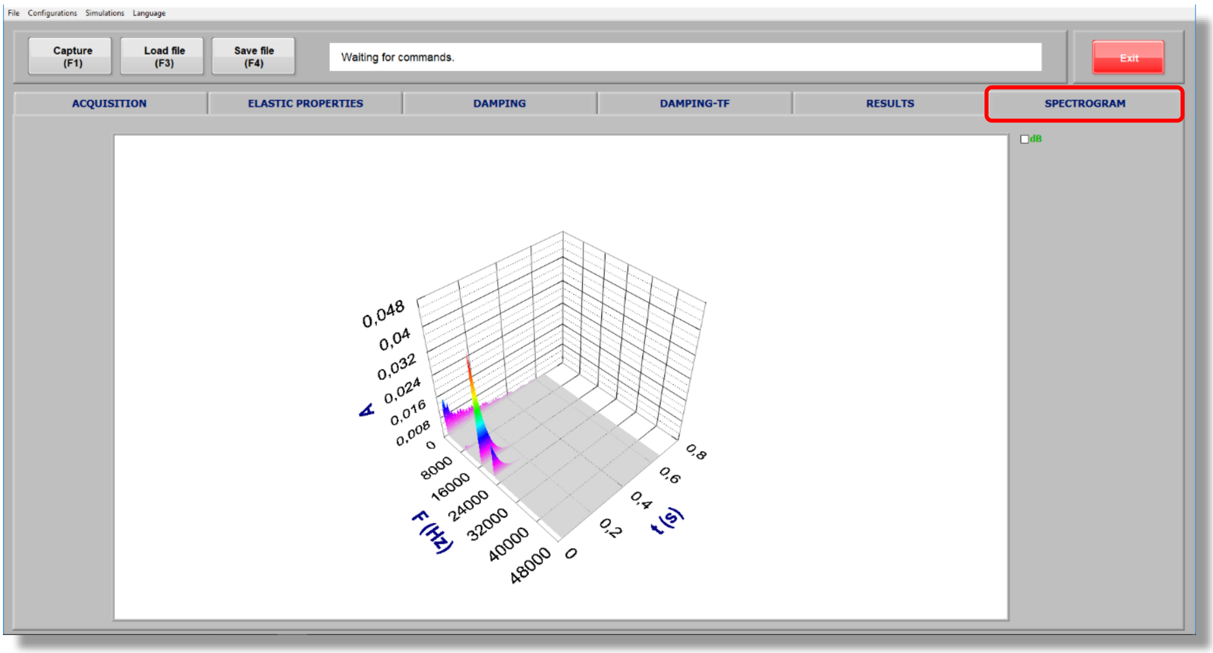


Figure 84 - Sonelastic® Software screen showing the tab for the signal 3D visualization.

In the "Spectrogram" module, a 3D spectrogram (amplitude x time x frequency) of the acquired signal is presented. The user can click on the graph and move the mouse to visualize it from any specific direction. The "dB" option allows the visualization in logarithm scale (Fig. 85).

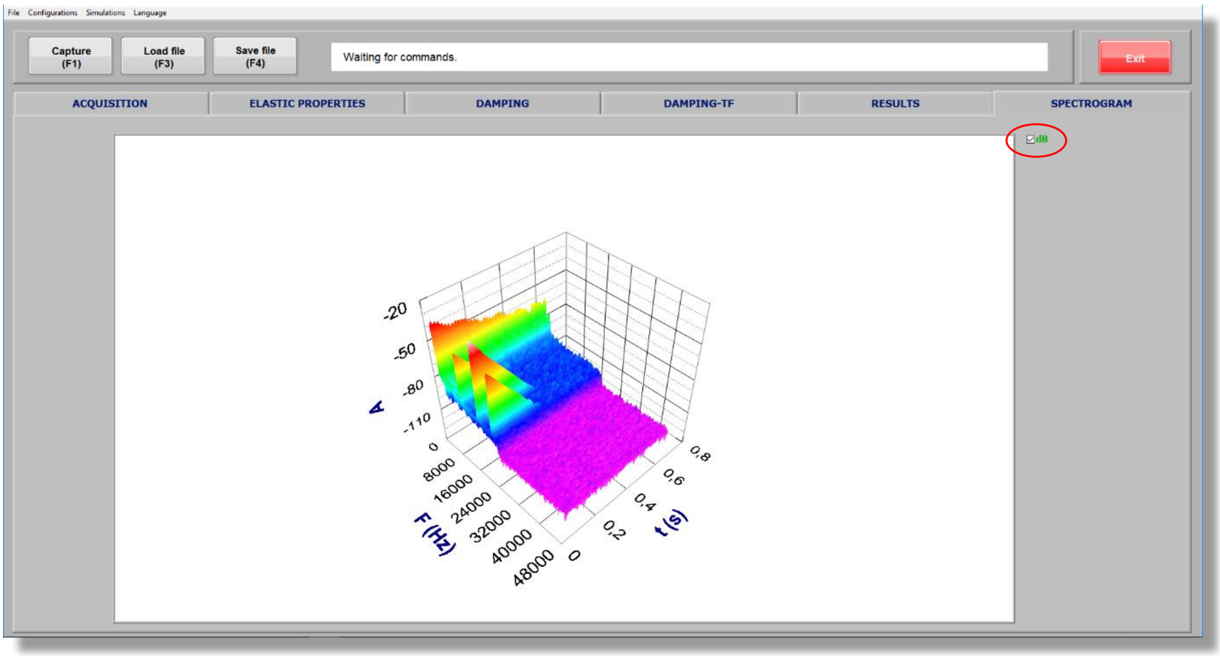


Figure 85 - Visualizing the 3D graph in logarithm scale.

8.7 Automatic acquisition mode

The automatic acquisition mode allows programming Sonelastic® Software to perform automatic measurements during pre-established intervals. To change the acquisition mode from "Manual" to "Automatic", click on "Configurations" under the main Menu, then select "Automatic" within "Acquisition mode" (Fig. 86).

Note: it is necessary the IED Automatic Impulse Device to employ the automatic acquisition mode.

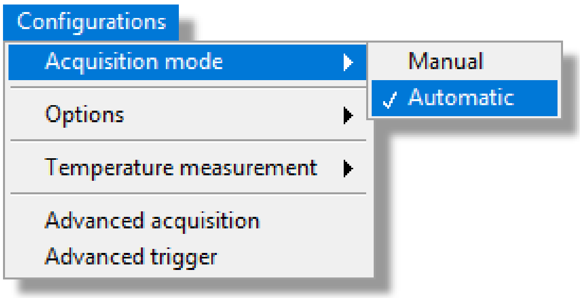


Figure 86 - Menu to choose the automatic acquisition mode.

After selecting the Automatic mode, the options on the top of the screen will change and will be shown as in Fig. 87.

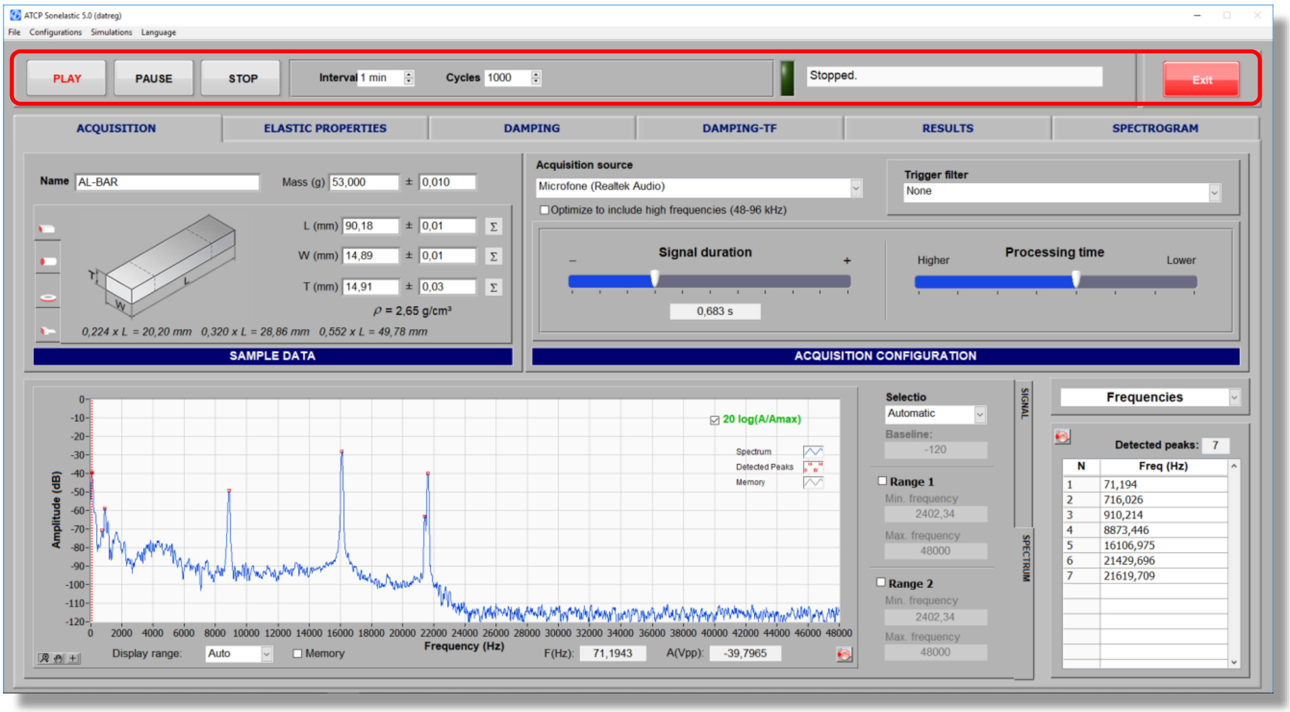


Figure 87 - Sonelastic® Software screen showing the automatic acquisition mode.

In this acquisition mode, the user should configure the measurements interval and the number of cycles to be measured. The adjustments can be made clicking on the arrows next to each option: interval ("Interval") and cycles ("Cycles"), such as shown in Fig. 88.

Figure 88 - Automatic acquisition controls.

After clicking on "PLAY", a new window will pop up for the user to choose a destination folder to save the measurements.

After that, the status of Sonelastic® Software will change to "Automatic measuring, cycle 1". This message will change as measurements cycles progress.

After specifying the location where the software will save the files, the measurement process will initiate automatically.

At any time, measurements may be paused by clicking on "PAUSE". To restart the measurements, click again on "PAUSE" to disable it.

Measurements may be interrupted at any time by clicking on "STOP".

A window will pop up asking whether the user really wishes to interrupt the measurement or not (Fig. 89).

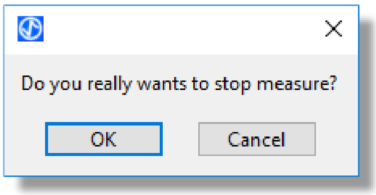


Figure 89 - Dialog box showing the option to cancel a measurement.

If the user wants to interrupt the measurement, click on "OK", otherwise, click on "Cancel".

Each cycle will be saved as a new file, which can be read by Sonelastic® Software. A spreadsheet containing all obtained results will be generated as a .csv file so it can be opened by other applications.

The software will automatically show the screen in which the calculation is being carried out, according to the following order: "Acquisition", "Damping", "Damping-TF", "Elastic Moduli", and "Results". On this last screen, there will be a countdown to the next measurement (Figure 90).

Figure 90 - The countdown to the next measurement carried out in the automatic acquisition mode.

Each point will appear on the graphs presented in "Results" (see item *8.5 Results Module – processing results*) (Fig. 91).

	Name	Time	No.	t(min)	T(ºC)	E flex (GPa)	±(GPa)	E long (GPa)	± (GPa)	E plan (GPa)	± (GP
x	AL-BAR Auto	11:15	1	0	---	69,9707	0,4918	0	0	0	
x	AL-BAR Auto	11:15	2	0,3	---	69,9519	0,4917	0	0	0	
x	AL-BAR Auto	11:16	3	1,3	---	69,9618	0,4917	0	0	0	
x	AL-BAR Auto	11:17	4	2,3	---	69,9638	0,4917	0	0	0	
x	AL-BAR Auto	11:18	5	3,3	---	69,9714	0,4918	0	0	0	
x	AL-BAR Auto	11:19	6	4,3	---	69,9767	0,4918	0	0	0	
x	AL-BAR Auto	11:20	7	5,3	---	69,9799	0,4919	0	0	0	
x	AL-BAR Auto	11:21	8	6,3	---	69,9782	0,4918	0	0	0	
x	AL-BAR Auto	11:22	9	7,3	---	69,9798	0,4919	0	0	0	
x	AL-BAR Auto	11:23	10	8,3	---	69,9798	0,4919	0	0	0	
x	AL-BAR Auto	11:27	11	11,6	---	69,9798	0,4919	0	0	0	

Figure 91 - Tables showing the data of an automatic measurement taken at room temperature.

Note: If the test is carried out as a function of temperature, the column "T (ºC)" will show the values of the temperature in each cycle; otherwise, the column will be blanked (see item 8.1.5 Spectrum and pre-processing of the signal to adjust the parameter related to the furnace).

Next (Fig. 92) it is represented an example of a ceramic specimen measurement as a function of temperature. The top graph presents the damping ratio value ("TD") as a function of time ("Time"). The bottom graph, however, monitors the temperature ("Temperature") as a function of time ("Time").

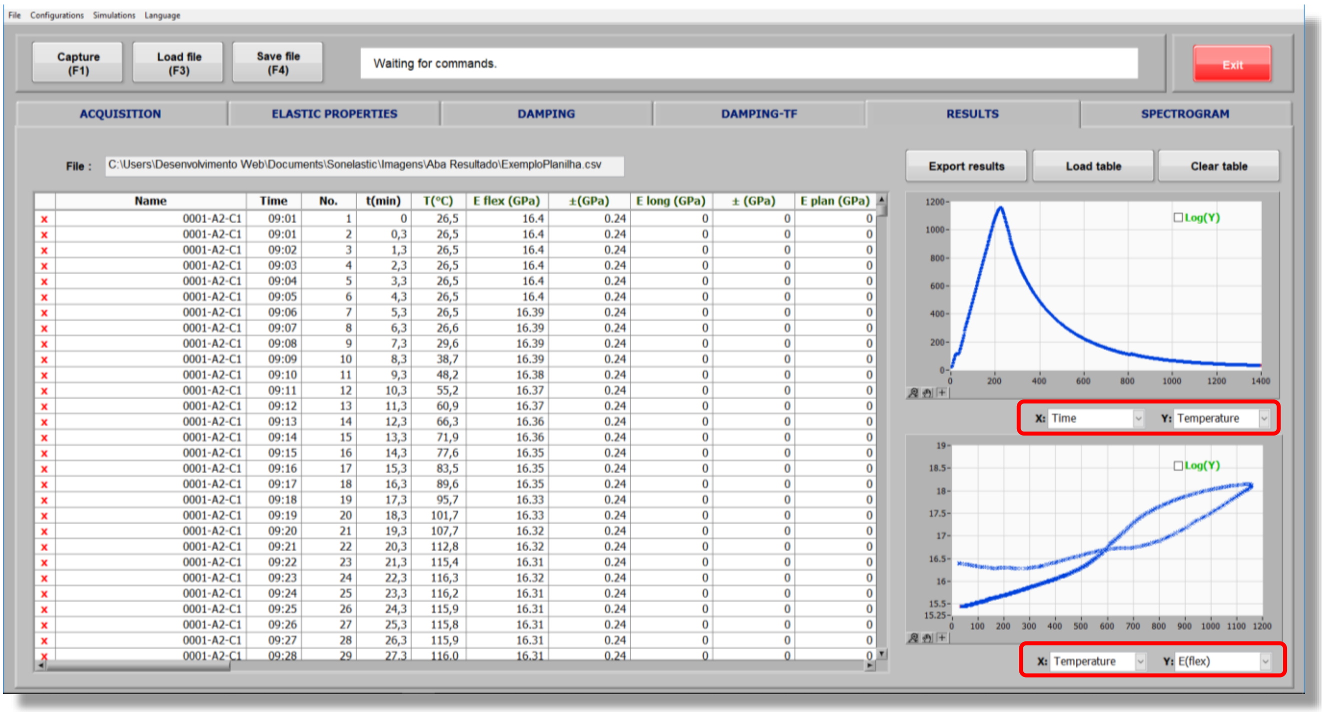


Figure 92 - Sonelastic® Software screen showing automatic measurement data as a function of temperature.

Figure 93 and 94 illustrates a spreadsheet generated by Sonelastic® Software. This data export format (.csv) facilitates the usage and practicality for posterior data processing.

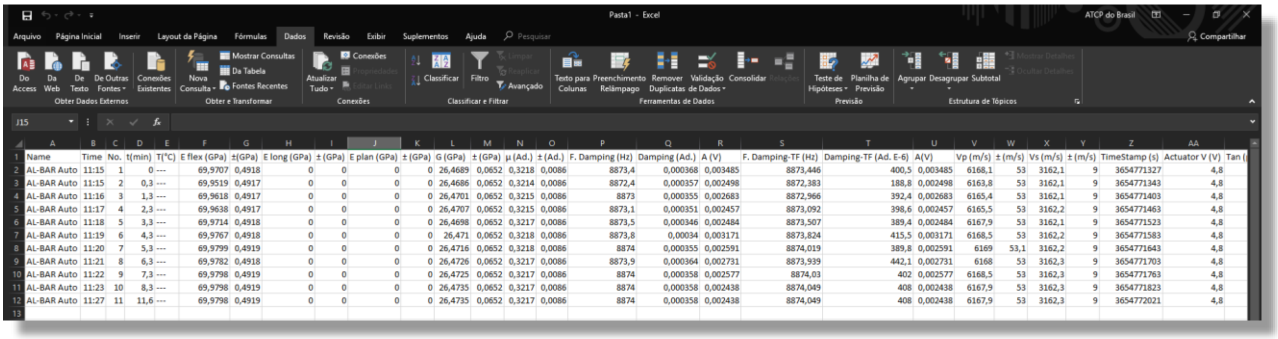


Figure 93 - Example of a spreadsheet generated by Sonelastic® Software and imported by MS Excel.

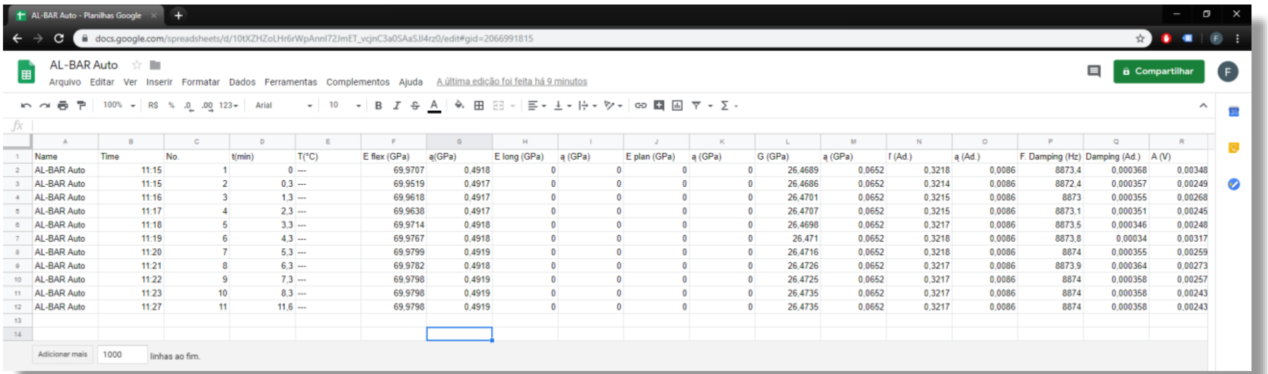


Figure 94 - Example of a spreadsheet generated by Sonelastic® Software, imported by Google's spreadsheets.

8.8 File Menu

The "File" menu (Fig. 95) is a quick form to access the main tools for saving and loading files, as well as loading and exporting data to a spreadsheet. Through this menu it is also possible to access the specimen registration worksheet and generate test reports.

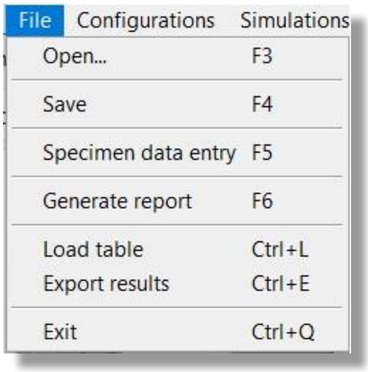


Figure 95 - File Menu.

To load a previous saved file, click on "Open…". To save a measurement in Sonelastic® Software format (.atcp), click on "Save". To load a spreadsheet with previous data characterization, click on "Load Table". Lastly, to export the main results to a spreadsheet, click on "Export results".

From this menu it is also possible to close Sonelastic® Software window by clicking on "Exit".

8.9 Configurations Menu

At the "Configurations" menu (Fig. 96) it is possible to adjust the signal acquisition mode (manual or automatic), adjust the acquisition configurations, enable the software to report the velocity values, adjust the measurement configurations as a function of temperature, and lastly, perform fine adjustments on the processing configurations and data acquisition.

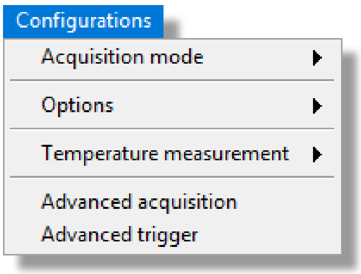


Figure 96 – Configurations Menu.

8.9.1 Acquisition mode

The acquisition mode can run on "Manual", as described in items **8.1** to **8.6**, as well as on "Automatic", as described in item **8.7 Automatic acquisition mode.**

The automatic acquisition mode is recommended for users wishing to perform serial measurements as a function of time and/or temperature (in the case of having a measurement system coupled). To employ the automatic acquisition mode, it is necessary the IED Automatic Impulse Device.

8.9.2 Options

Under the "Configurations" menu (Fig. 97) it is possible to "Allow null values for uncertainties", "Show Vp and Vs Values" (Fig. 97), "Estimating the Eci by Popovics (ABNT NBR 8522-1:2021)" and choose "Cylinder dimensions by ABNT NBR 8522-2:2021".

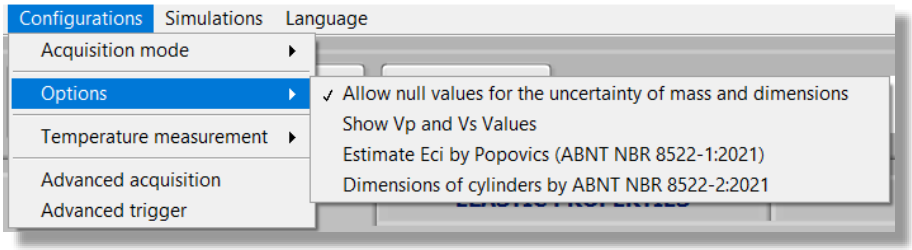


Figure 97 - "Options", under the "Configurations" Menu.

The option "Allow null values for uncertainties" allows uncertainties values of the input parameters to be null, therefore, the user may leave the fields reserved for dimensions and mass uncertainties as being equal to zero.

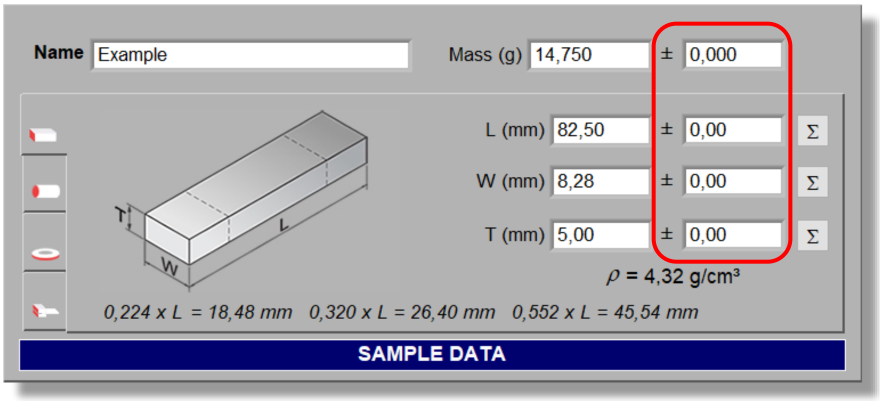


Figure 98 - Fields for uncertainties values.

If the option "Allow null values for uncertainties" is disabled, the user must type some value in the uncertainties field, otherwise the software will not proceed to the next tab for the elastic moduli calculation (Figure 99). Instead, it will show the following message:

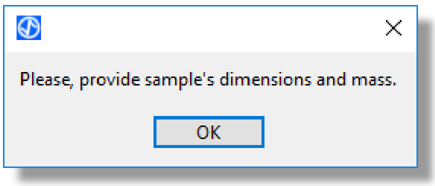


Figure 2 - Software dialog box that will pop up when the option "Allow null values for errors" is disabled and the user tries to skip to the elastic moduli calculation screen.

The option "Show Vp and Vs values" activates the calculation and display of the sound speed for P-waves ("Vp") and the sound speed for S-waves ("Vs") along with the values of the elastic modulus on the tab ELASTIC MODULES (Fig. 100-[a]). The option "Estimate the Eci by Popovics (ABNT NBR 8522-1:2021)" activates the estimation and display of the secant/chord modulus (Eci) (Fig. 100-[b]). This option should be used only for concrete and cementitious materials.

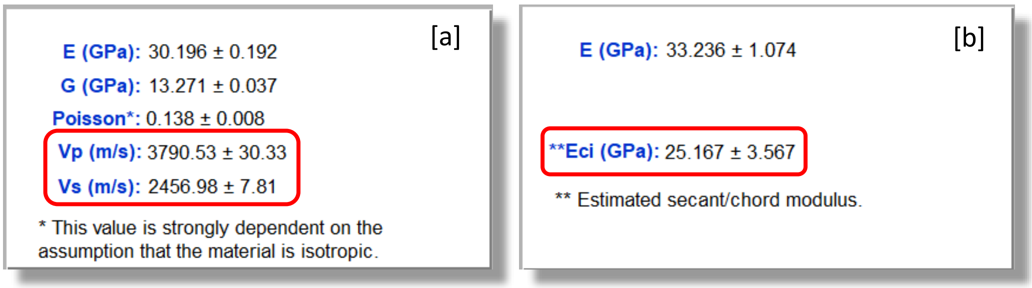


Figure 100 – [a]: Section of the elastic modulus results showing the sound velocity values for P-waves ("Vp") and S-waves ("Vs"); [b]: Section of the elastic modulus results showing the estimated secant/chord modulus of elasticity (Eci).

The option "Estimate Eci by Popovics (ABNT NBR 8522-1:2021)" activates the estimation and presentation of the secant/chord modulus (Eci) in the results tab. This option should be used only for concrete and cementitious materials.

8.9.3 Temperature measurement

In this field is set the temperature measurement data source (Fig. 101). For this, choose the option representing the channel of the furnace communication controller that will perform the test.

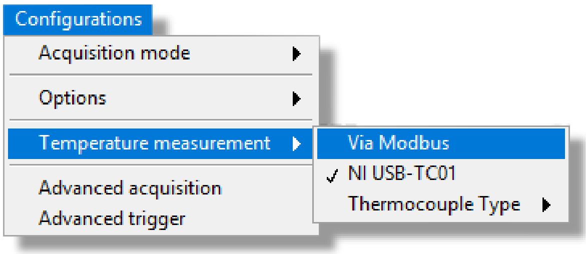


Figure 101 – "Temperature measurement" options, under the "Configurations" menu.

8.9.4 Advanced acquisition

The "Advanced acquisition" mode allows fine adjustments to enable or refine measurements regarding the sound processing (Fig. 102).

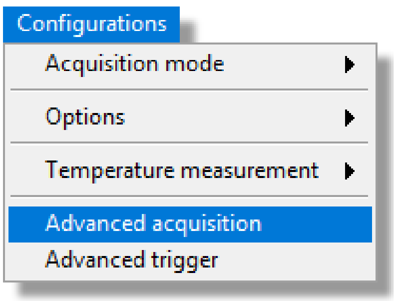


Figure 102 - Menu for selecting the advance acquisition mode.

Once this option is enabled, a new screen will appear in "Acquisition configuration", in "Acquisition" tab. This new screen contains fine advanced adjustments regarding the signal processing. This tool must be used only by the advanced users of Sonelastic® Software.

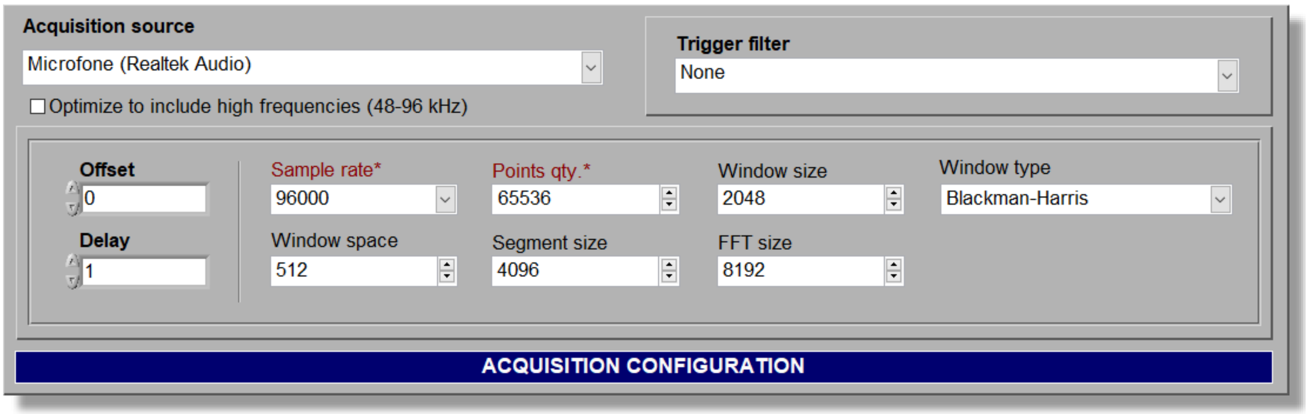


Figure 103 - Section for the advanced adjustments configuration of the signal processing.

8.8.5 Advanced trigger

To select the advanced mode of the Trigger, enable "Advanced trigger", in "Configurations" (Fig. 104). This field allows changing the "Trigger filter" window, under "Acquisition Configuration" (see item *8.1.3 Adjusting the signal acquisition*).

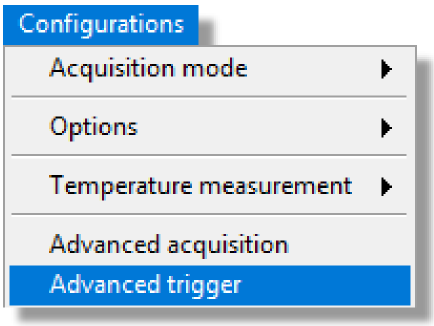


Figure 104 - Menu for selecting the "Advanced trigger".

A new screen will replace the "Trigger filter" field, allowing free adjustment of the frequency range. Select the range of frequencies by pressing the arrows up and down, next to the "High pass" and "Low pass" options (Fig. 105). If the user does not wish to apply any filter, the "Trigger Filter" command must be disabled.

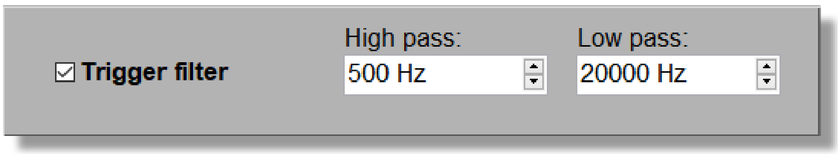


Figure 105 - Section for adjusting the range of frequencies, in "Trigger Filter".

8.10 Simulations Menu

Sonelastic® Software allows the user to estimate the fundamental vibration frequencies of a specific specimen based on its characteristics. To choose this option, select "Simulations" (Fig. 106).

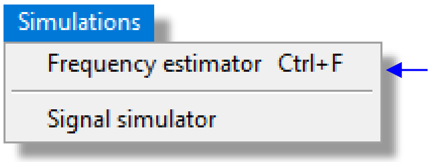


Figure 106 - Software simulations menu.

There are two options under this menu: "Frequency simulator" and "Signal simulator". The first option gives the user the possibility to estimate the flexural, torsional, longitudinal, and planar vibration natural frequencies of a specimen. The second option was created for internal use of ATCP Physical Engineering for running tests and calibration.

To enable the frequencies estimator, click on "Frequency simulator". A new window will open and will contain all the input parameters needed to calculate the frequencies (Fig. 107). Fill in the gaps with the material's approximate Young's modulus (GPa), density (g/cm³) and dimensions.

The "Estimate G and P" command allows the user to define whether or not Sonelastic® Software should estimate the shear modulus (G) and Poisson's ratio (µ) values for the torsional fundamental frequency calculation. If this command is enabled, the software will define the shear modulus for the material as being equal to 0.4E and the Poisson's ratio equal to 0.25. If the tested specimen does not meet these values, it is possible to disable this function and define different values for these properties.

After filling in the gaps with all the necessary information, click on "Calculate (Enter)". The software will inform an approximate value of flexural, torsional and longitudinal frequencies for rectangular bars and cylinders; flexural frequencies for cantilever beams; and only the planar frequencies, for discs and rings.

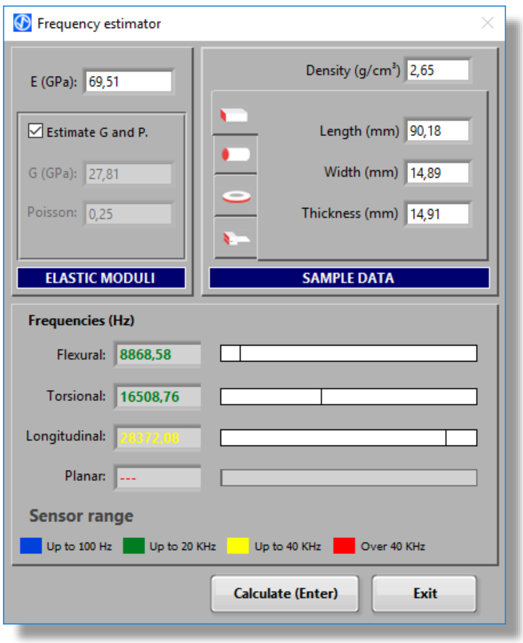


Figure 107 – Frequency estimator.

The caption on the bottom of the screen helps the user to identify the frequency range in which the specimen will vibrate. The frequencies in blue (up to 100 Hz) are critical and may need fine adjustments to be captured (see item *8.9.4 Advanced acquisition mode*). Frequencies above 40 kHz (red) require acoustic pickups and special acquisition devices to be detected. *Note: ATCP's CA-DP and CA-DP-S Acoustic Sensors, as well as the Xonar acquisition board, are capable of capturing frequencies up to 96 kHz.*

This simulator allows the user to estimate if the tested specimen will present frequencies detectable by the software, being able to establish, for instance, a pattern size of specimens. Besides, the "Frequency simulator" helps the user to verify the approximate frequency in which a specific specimen will vibrate for the desired vibration mode.

To close the "Frequency simulator" screen, click on "Exit".

8.11 Language Menu

It is possible to change the main language of Sonelastic® Software by choosing one option from the "Language" menu (Figure 108). The options available are English and Portuguese.

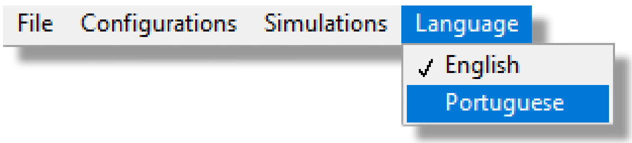


Figure 108 – Language Menu.

8.12 Module for registering specimens

It is possible to carry out prior data entry of the specimens' dimensions and mass using the "Specimen data entry" module. To access it, you can click on the Id button on the acquisition tab (Fig. 109), or go to the "File/Specimen data entry" menu or use the shortcut key [F5].

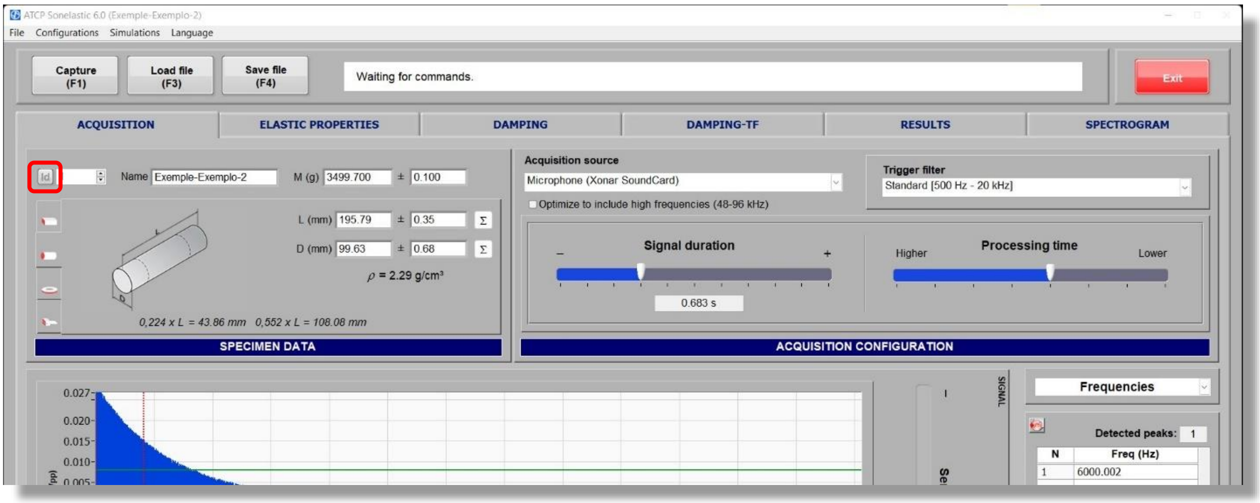
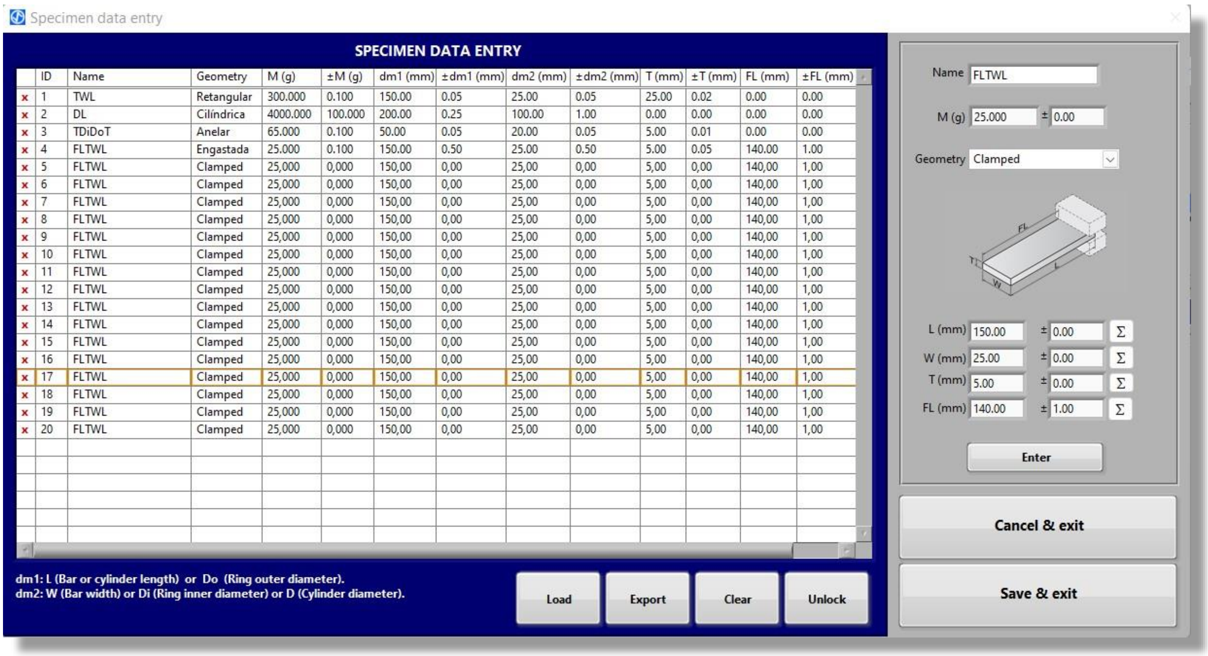


Figure 109 – "Id" button to access the module for prior registration of the dimensions and mass of the specimens.

Figure 110 shows the interface of the “Specimen data entry” module, which comprises a spreadsheet and fields for entering the specimen mass and dimensions.



	ID	Name	Geometry	M (g)	±M (g)	dm1 (mm)	±dm1 (mm)	dm2 (mm)	±dm2 (mm)	T (mm)	±T (mm)	FL (mm)	±FL (mm)
x	1	TWL	Retangular	300.000	0.100	150.00	0.05	25.00	0.05	25.00	0.02	0.00	0.00
x	2	DL	Cilíndrica	4000.000	100.000	200.00	0.25	100.00	1.00	0.00	0.00	0.00	0.00
x	3	TDiDoT	Anelar	65.000	0.100	50.00	0.05	20.00	0.05	5.00	0.01	0.00	0.00
x	4	FLTWL	Engastada	25.000	0.100	150.00	0.50	25.00	0.50	5.00	0.05	140.00	1.00
x	5	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	6	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	7	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	8	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	9	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	10	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	11	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	12	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	13	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	14	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	15	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	16	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	17	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	18	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	19	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00
x	20	FLTWL	Clamped	25,000	0,000	150,00	0,00	25,00	0,00	5,00	0,00	140,00	1,00

Figure 110 – Interface of the “Specimen data entry” module.

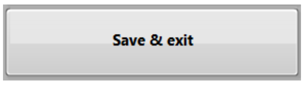
- When clicking on the  button to open the registration module, the data from the “SPECIMEN DATA ENTRY” field of the Acquisition Tab are brought to the interface.

- To register a specimen, enter the data and click on: 

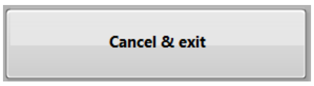
When clicking on the [Register] button, a new row will be created at the end of the worksheet. When clicking on the [Register] button combined with the [Shift] key, the data will be overwritten in the highlighted row in the spreadsheet. The spread sheet capacity is 9999 rows.

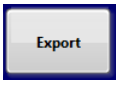
- To delete a row of data from the worksheet, click the [x] in the first column.

- To register a specimen directly from the field “DATA OF THE SAMPLE” of the Acquisition Tab, click on the button  while holding the [Shift] key.

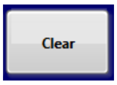
- To save changes and exit, click: 

. When saving and exiting, the data from the highlighted worksheet row will be entered in the “SAMPLE DATA” field of the Acquisition Tab.

- To discard changes and exit, click: 

- To export the spreadsheet data to a csv file, click: 

- To import data from a csv file into the spreadsheet, click: 

- To delete the contents of the worksheet, click on: 

- To edit the contents of the worksheet, click on: 

- To use the data from the specimen register, change the control index shown in Fig. 111 by clicking the arrows or typing. The registration data will be entered in the ""SPECIMEN DATA" fields.

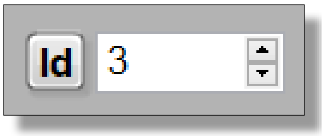


Figure 111 – Control for the selection of specimen registration data.

The [Id] button will be grayed out when the "SAMPLE DATA" imported from the register is edited.

8.13 Generating a test report

The Sonelastic Software can generate a test report, this function can be accessed through the "File/Generate report" menu or the shortcut key [F6]. To generate the report, it is necessary to inform the interface information shown in Fig. 112.

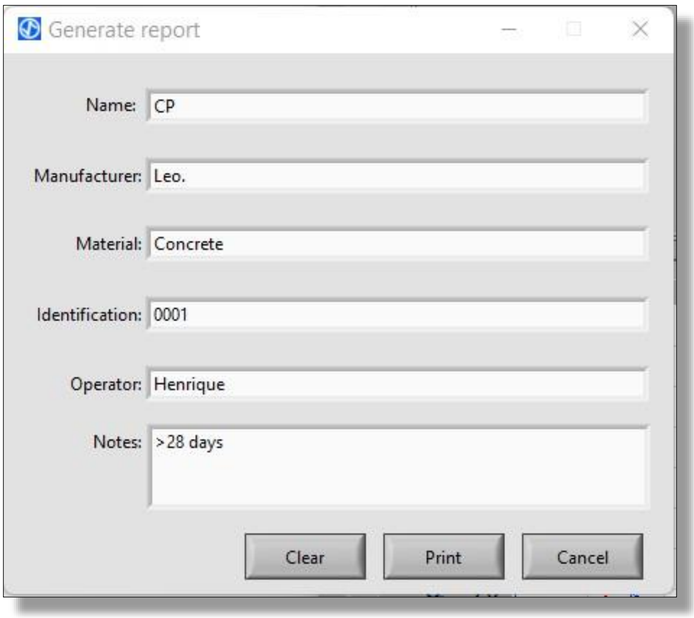
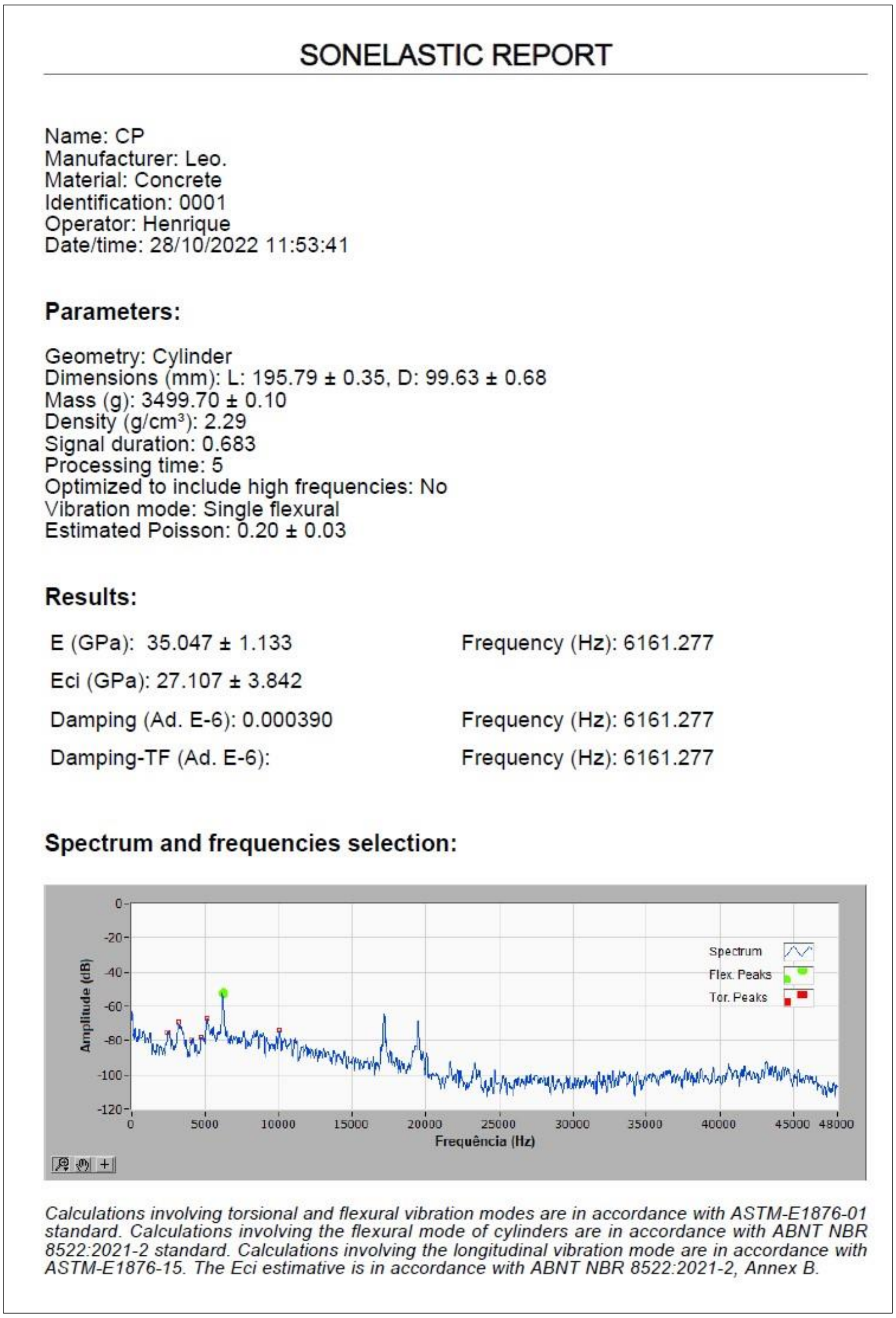


Figure 112 – Data interface for the test report.

Figure 113 presents an example of a test report generated by Sonelastic Software.



SONELASTIC REPORT

Name: CP
Manufacturer: Leo.
Material: Concrete
Identification: 0001
Operator: Henrique
Date/time: 28/10/2022 11:53:41

Parameters:

Geometry: Cylinder
Dimensions (mm): L: 195.79 ± 0.35, D: 99.63 ± 0.68
Mass (g): 3499.70 ± 0.10
Density (g/cm³): 2.29
Signal duration: 0.683
Processing time: 5
Optimized to include high frequencies: No
Vibration mode: Single flexural
Estimated Poisson: 0.20 ± 0.03

Results:

E (GPa): 35.047 ± 1.133	Frequency (Hz): 6161.277
Eci (GPa): 27.107 ± 3.842	
Damping (Ad. E-6): 0.000390	Frequency (Hz): 6161.277
Damping-TF (Ad. E-6):	Frequency (Hz): 6161.277

Spectrum and frequencies selection:

Calculations involving torsional and flexural vibration modes are in accordance with ASTM-E1876-01 standard. Calculations involving the flexural mode of cylinders are in accordance with ABNT NBR 8522:2021-2 standard. Calculations involving the longitudinal vibration mode are in accordance with ASTM-E1876-15. The Eci estimative is in accordance with ABNT NBR 8522:2021-2, Annex B.

Figure 113 Example of test report generated by Sonelastic Software.

8.14 Closing the software

To exit the Sonelastic® Software, click on "Exit", on the top-right corner of the main interface, or choose "Exit" from the "File" menu.

It is highly recommended to exit the Sonelastic® Software by one of the ways above so that the last setting is saved and recalled on the next opening.

9. Warnings

- ⚠ Reading all the information of this installation and operation manual is indispensable for the correct use of Sonelastic® Software;
- ⚠ The power outlet where the computer will be connected must have a functional ground pin;
- ⚠ The non-compliance with the instructions provided by this manual may reduce or invalidate the warranty.

10. Troubleshooting

Problem	Possible cause	Solution
Software does not initialize.	Incorrect installation of the software.	Verify if all the steps described in item 6 of this manual were correctly done and if the license for using the software is correct.
Software does not recognize the IED Automatic Impulse Device or the acquisition USB module ADAC connected to the system.	The IED or ADAC was connected after the software was initiated.	Remove the IED or the ADAC from the input jack, connect it again and then restart the software. Click on "Test" according to specifications for the Impulse Device (or the other item).
After the signal acquisition, the software takes too long to show the results.	The acquisition time is too high.	Lower the "Acquisition time"
	The software was not ready to start the measurement.	Click on "Stop" to interrupt the measurement and perform the acquisition one more time.
No signal was detected by the software.	The scale ("Sensitivity") is incorrect.	Modify the scale ("Sensitivity") so the specimen acoustic response is able to trigger the acquisition.
No frequency peak is detected or there is no triggering.	The measurements adjustments are incorrect.	Verify the adjustments made to acquire the signal as described in item 8.1.3 of this manual.
During an automatic measurement, a "bip" warning was emitted, and in the results table one of the parameter's readings changed to zero.	The software selected a wrong frequency.	Pause the measurements and adjust correctly the region of interest on the spectrum, as described in item 8.1.5 of this manual.
	The software lost communication with the optional items.	Pause the measurements, then return.
During an automatic measurement as a function of temperature, the software stopped saving the temperature.	The software lost communication with the furnace.	Pause the measurements and readjust the acquisition temperature, as described in item 8.1.5 of this manual, updating and saving the temperature value. If the problem occurs again, pause the measurement process, disconnect and reconnect the furnace.

The measurement results are not consistent with the material characterized or are not being calculated.	The specimen is not correctly positioned to perform the measurements.	Position the specimen correctly as described on the installation and operation manual of the specimen used.
	Inadequate support for the specimen type.	Use an adequate specimen support.
	Selected frequencies are incorrect.	Select the correct flexural and torsional frequencies.

11. Technical support

If the software does not run properly, verify first if the problem is not related to any of the issues listed in item *10. Troubleshooting.* If the problem could not be solved, contact ATCP Physical Engineering for assistance (info@sonelastic.com).

12. Warranty

ATCP Physical Engineering offers a 12-month warranty for the software starting from the date of purchase. Factors that may cause the loss of warranty:

1- The non-compliance with the recommended software installation and operation procedures;

2- Incorrect installation or any other damage caused by incorrect use;

3- Violation or modification by non-authorized agent.

After the warranty expiration date, all services and expenses shall be charged as per company's policy.

13. Statement of Responsibility

ATCP Physical Engineering, Sonelastic® Division, takes total technical and legal responsibility over Sonelastic® Software and guarantees that all information provided herein are true.

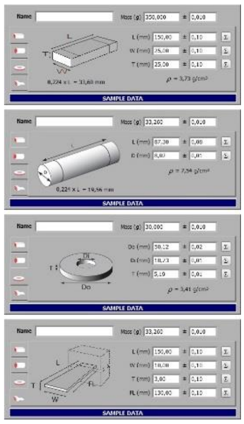
Appendix A –Quick guide for measurements using Sonelastic® Software

Run Sonelastic® Software

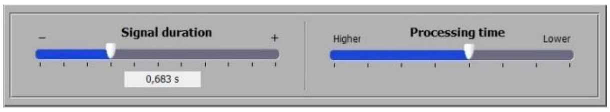
2

ACQUISITION

Choose the specimen's geometry: rectangular bar, cylinder, disk/ring or clamped bar. Insert the name, dimensions and mass with the respective uncertainties.



3



Adjust the "Signal duration" and the "Processing time".

4

Capture (F1)

Perform the signal acquisition by clicking on "Capture (F1)".

5

ELASTIC PROPERTIES

Vibrational mode: Flexural + torsional

- ✓ Flexural + torsional
- Flexural + torsional w/ estimated Poisson
- Single flexural
- Single longitudinal
- Single planar

Under the "Elastic Moduli" tab, choose the type of analysis you wish to perform.

6

N	Freq (Hz)	Amp (Vpp)	F	T	L	P
1	506,710	0,000444				
2	8537,126	0,000717				
3	9710,789	0,000485				
4	9868,362	0,072028	x			
5	18322,986	0,001385				
6	18404,907	0,090421		x		
7	24035,868	0,011216				
8	28273,119	0,000588				

Select the correct frequencies.

7

DAMPING

DAMPING-TF

Go to "Damping" and "Damping-TF" tabs to calculate the damping.

8

RESULTS

Go to "Results" tab to process the results and export the data by pressing on the "Export excel" button.

Export excel

9

Save file (F4)

For further information, visit:

www.sonelastic.com

Appendix B –Equations used to calculate the elastic properties

1. Rectangular-shaped specimen bars

1.1 Young's modulus calculation (Flexural):

$$E = 0.9465\left(mf_f^2/b\right)(L^3/t^3)T_1$$

Where:

E = Young's modulus (Pa)

m = Bar mass (g)

b = Bar width (mm)

L = Bar length (mm)

t = Bar thickness (mm)

f_f = Fundamental frequency for the bar in flexural mode (Hz)

T_1 = Correction factor

- Young's modulus uncertainty calculation (Flexural):

$$\Delta E = \frac{2E}{1.73205}\sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(2\frac{\Delta f_f}{f_f}\right)^2 + \left(\frac{\Delta b}{b}\right)^2 + \left(3\frac{\Delta L}{L}\right)^2 + \left(3\frac{\Delta t}{t}\right)^2 + \left(\frac{1}{40}\frac{\Delta \mu^*}{\mu}\right)^2}$$

1.2 Shear modulus calculation (Torsional):

$$G = \frac{4Lmf_t^2}{bt}R$$

Where:

G = Shear modulus (Pa)

m = Bar mass (g)

b = Bar width (mm)

L = Bar length (mm)

t = Bar thickness (mm)

f_t = Fundamental frequency for the bar in torsional mode (Hz)

R = Correction factor

- Shear modulus uncertainty calculation (Torsional):

$$\Delta G = \frac{2G}{1.73205}\sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(2\frac{\Delta f_t}{f_t}\right)^2 + \left(\frac{\Delta b}{b}\right)^2 + \left(\frac{\Delta t}{t}\right)^2}$$

1.3 Young's modulus calculation (Longitudinal mode):

$$E = 4mf_l^2[L/(b\ t\ K)]$$

Where:

E = Young's modulus (Pa)

m = Bar mass (g)

L = Bar length (mm)

b = Bar width (mm)

t = Bar thickness (mm)

f_f = Fundamental frequency for the bar in longitudinal mode (Hz)

K = Correction factor

- Young's modulus uncertainty calculation (Longitudinal):

$$\Delta E = \frac{2E}{1.73205}\sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(2\frac{\Delta f_t}{f_t}\right)^2 + \left(\frac{\Delta b}{b}\right)^2 + \left(\frac{\Delta t}{t}\right)^2 + \left(\frac{1}{40}\frac{\Delta \mu^*}{\mu}\right)^2}$$

2. Cylinder-shaped specimen bars

2.1 Young's modulus calculation (Flexural):

$$E = 1{,}6067(L^3/D^4)(mf^2)T_1'$$

Where:

E = Young's modulus (Pa)

L = Cylinder length (mm)

D = Cylinder diameter (mm)

m = Cylinder mass (g)

f = Fundamental frequency for the cylinder in flexural mode (Hz)

T'_1 = Correction factor

- Young's modulus uncertainty calculation (Flexural):

$$\Delta E = \frac{2E}{1.73205}\sqrt{\left(3\frac{\Delta L}{L}\right)^2 + \left(4\frac{\Delta D}{D}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(2\frac{\Delta f_f}{f_f}\right)^2 + \left(\frac{1}{40}\frac{\Delta \mu^*}{\mu}\right)^2}$$

2.2 Shear modulus calculation (Torsional):

$$G = 16mf_t^2[L/(\pi D^2)]$$

Where:

G = Shear modulus (Pa)

m = Cylinder mass (g)

D = Cylinder diameter (mm)

L = Cylinder length (mm)

f_t = Fundamental frequency for the cylinder in torsional mode (Hz)

- Shear modulus uncertainty calculation (Torsional):

$$\Delta G = \frac{2G}{1.73205}\sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(2\frac{\Delta f_t}{f_t}\right)^2 + \left(2\frac{\Delta D}{D}\right)^2}$$

2.3 Young's modulus calculation (Longitudinal):

$$E = 16mf_l^2[L/(\pi D^2 K)]$$

Where:

E = Young's modulus (Pa)

m = Cylinder mass (g)

L = Cylinder length (mm)

D = Cylinder diameter (mm)

f_t = Fundamental frequency for the cylinder in torsional mode (Hz)

K = Correction factor

- Young's modulus uncertainty calculation (Longitudinal):

$$\Delta E = \frac{2E}{1.73205}\sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(2\frac{\Delta f_t}{f_t}\right)^2 + \left(2\frac{\Delta D}{D}\right)^2 + \left(\frac{1}{40}\frac{\Delta \mu^*}{\mu}\right)^2}$$

3. Disc-shaped specimens

3.1 Young's modulus calculation:

$$E = \frac{C_e C_d \, m \, f^2}{t(1 - \frac{h^2}{d^2})\mu^2}$$

Where:

E = Elastic modulus;	*β =beta;*
d = Outer diameter (mm);	*ϒ = gamma;*
t = Thickness (mm);	*δ = delta;*
h = Inner diameter (mm);	*ε = epsilon;*
m = Mass (g);	*ω = omega;*
f = Frequency;	*ψ = psi;*
α = alpha;	*μ= mu.*

Table 1: Constant values for the disc

C_1 = 59.8713	C_7 = 67.758	C_c = 0.0049
C_4 = 61.00	C_8 = 9.42	C_d = 1273.24
C_5 = 1.5	C_9 = 42.443	C_e = 12983.95
C_6 = 0.63	C_0 = -26.0	C_c = 0.0049

Table 2: Sequence of equations for the disc

$\alpha = (5\,t/d)^2$	$\varepsilon = \delta - \alpha\,(C_5 + \alpha / C_6)$
$\beta = (h/d)^2$	$\omega = \beta\,(\varepsilon - C_4)$
$\gamma = (C_0\alpha - C_9)\,\beta$	$\psi = \alpha\,(\alpha - 8) + \omega + C_1$
$\delta = (C_7 + C_8\alpha^2 + \gamma)\,\beta$	$\mu = \psi\, t/d - C_c$

- Young's modulus uncertainty calculation:

$$\Delta E = \frac{2E}{1.73205}\sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(2\frac{\Delta f_t}{f_t}\right)^2 + \left(2\frac{\Delta t}{t}\right)^2 + \left(2\frac{\Delta h}{h}\right)^2 + \left(2\frac{\Delta d}{d}\right)^2}$$

4. Poisson's ratio calculation

$$\mu = \frac{E}{2\,G} - 1$$

- Poisson's ratio uncertainty calculation

$$\Delta\mu = \frac{2\mu}{\sqrt{3}}\sqrt{\left(\frac{\Delta E}{E}\right)^2 + \left(\frac{\Delta G}{G}\right)^2}$$

5. P-waves velocity calculation (Vp)

$$V_p = \sqrt{\frac{4G - E}{\rho\left(3 - {}^{E}\!/_{G}\right)}}$$

- P-waves velocity uncertainty calculation (ΔVp)

$$\Delta V_p = \frac{2V_p}{\sqrt{3}}\sqrt{\left(\frac{\Delta E}{E}\right)^2 + \left(\frac{\Delta G}{G}\right)^2}$$

- Vp error calculation for when only E value is available.

$$\Delta V_p = \frac{2V_p}{\sqrt{3}}\frac{\Delta E}{E}$$

6. S-waves velocity calculation (Vs)

$$V_s = \sqrt{\frac{G}{\rho}}$$

- S-waves velocity uncertainty calculation (ΔVs)

$$\Delta V_s = \frac{2V_s}{\sqrt{3}}\frac{\Delta G}{G}$$

7. Calculation of the estimated secant/chord modulus of elasticity (Eci)

$$E_{ci} = \frac{0{,}4275}{\rho}\,E_{cd}^{1,4}$$

Where:

Eci = Secant/chord modulus estimated by the Popovics model for concrete and cementitious materials (Annex B, ABNT NBR 8522-1:2021);

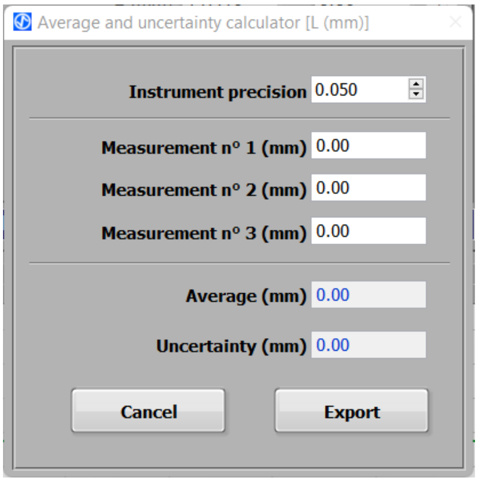
Ecd = Young's modulus (GPa), or dynamic modulus, determined with Sonelastic.

• Uncertainty calculation for the estimated secant/chord modulus (Eci):

$$\Delta E_{ci} = E_{ci}\sqrt{\left(\frac{\Delta E_{cd}}{E_{ci}}\right)^2 + (0{,}138)^2}$$

The constant 0.138 (13.8%) corresponds to the sum of the systematic error (6.7%) and the standard deviation (7.1%) typical of the estimate of the Eci from the Ecd using the Popovics model, as specified in the Annex B of ABNT NBR 8522-1:2021 (topic B2-a, page 22).

8. Uncertainty calculation by auxiliary interface



$$Uncertainty = \sqrt{P^2 + \frac{\sum_3 (Measurement_n - Average)^2}{3}}$$

Where:

P = Instrument precision.

The equation below is used for cases where only two measurements are taken into consideration. This is the case for the length and diameter of cylinders when the option menu "Cylinder dimensions by ABNT NBR 8522-2:2021" is activated.

$$Uncertainty = \sqrt{P^2 + \frac{\sum_2 (Measurement_n - Average)^2}{2}}$$

Appendix C –Damping calculation detailing

- **Damping (E-6)**

- It is related to the damping factor or "damping ratio";
- It is a dimensionless property;
- It corresponds to the decay rate of the oscillation;
- The information between brackets "(E-6)" means $x10^{-6}$.

Considering that the studied oscillation may be described by the product of a cosine function and an exponential decay, the damping or "damping factor" corresponds to the ζ parameter of the equation (A) [2]:

$$x(t) = A_0 \cdot e^{-\zeta\omega_0 t} \cdot \cos(\omega_d t + \varphi) \quad \text{(A)}$$

In which A_0 is the initial amplitude of vibration, φ is the initial phase of vibration and ω_d is called the damped frequency and it is given by:

$$\omega_d = \omega_0\sqrt{1-\zeta^2} \quad \text{(B)}$$

- **Q Factor**

- It is related to the mechanical quality factor;
- It is a dimensionless property;
- It is correlated to the energy consumed per oscillation cycle.

The quality factor, Q, is defined as being 2π times the ratio between the total vibrational energy and the lost energy per cycle because of the existing friction per cycle. The quality factor Q correlates to damping or "damping factor" through the equation (C) [1,2]:

$$Q = \frac{1}{2\zeta} \quad \text{(C)}$$

- **Tan (φ)**

- It is a typical notation of the polymers area of knowledge and it has the following relations to the quality factor and the damping:

$$Tan(\varphi) = \frac{1}{Q} \quad \text{(D)}$$

$$Tan(\varphi) = 2\zeta \quad \text{(E)}$$

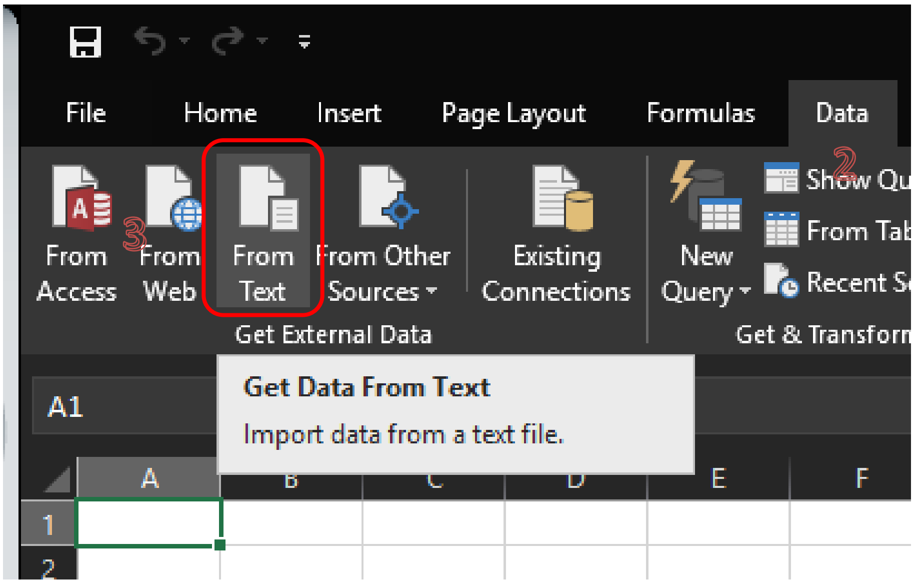
This notation is common in the polymers area of knowledge and it denotes the relation between the complex and real component of the elasticity mode:

$$Tan(\varphi) = \frac{E''}{E'} \quad \text{(F)}$$

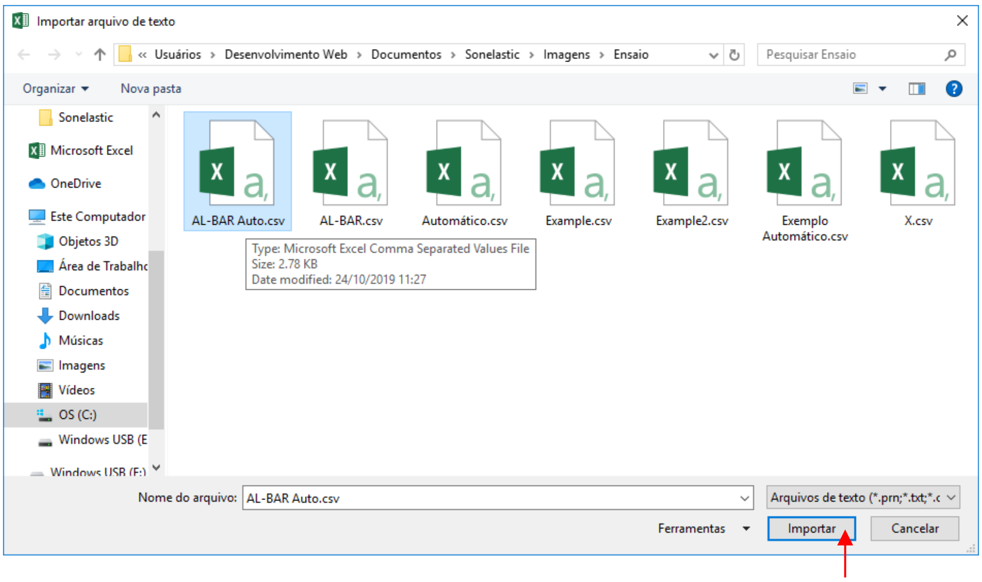
Appendix D – CSV file Import in Microsoft Excel

You can import data from a text file into an existing spreadsheet.

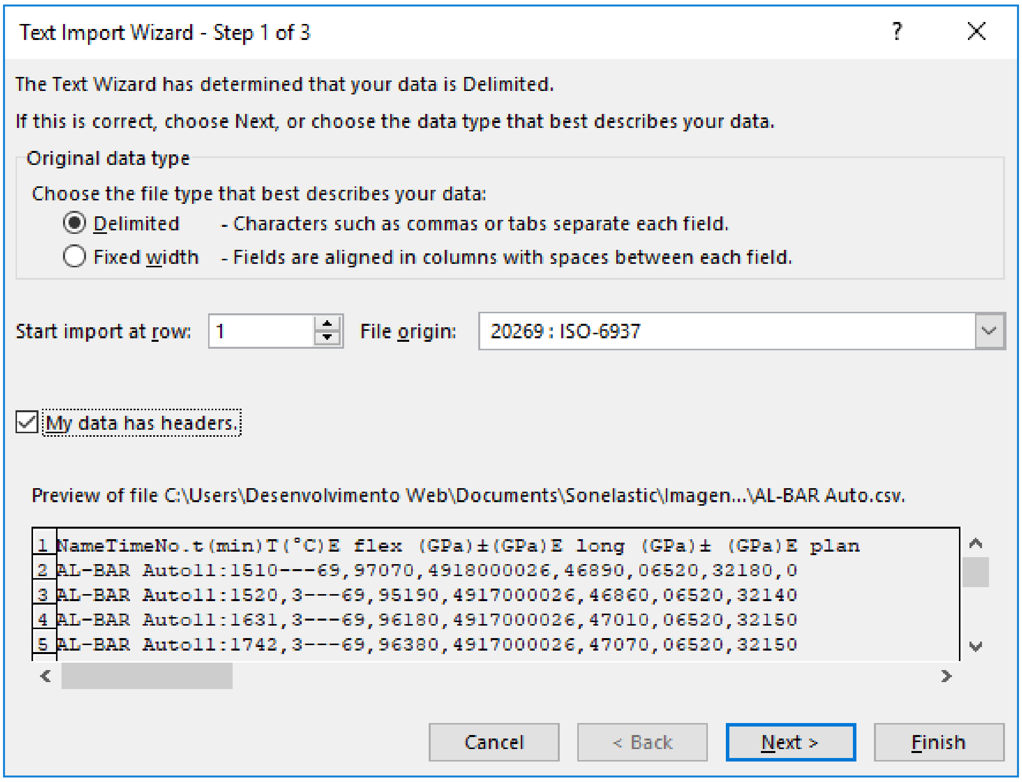
1. Click in the cell where you want to place the text file data.
2. Click on “Data”.
3. In the "Get External Data" group, click "From Text".

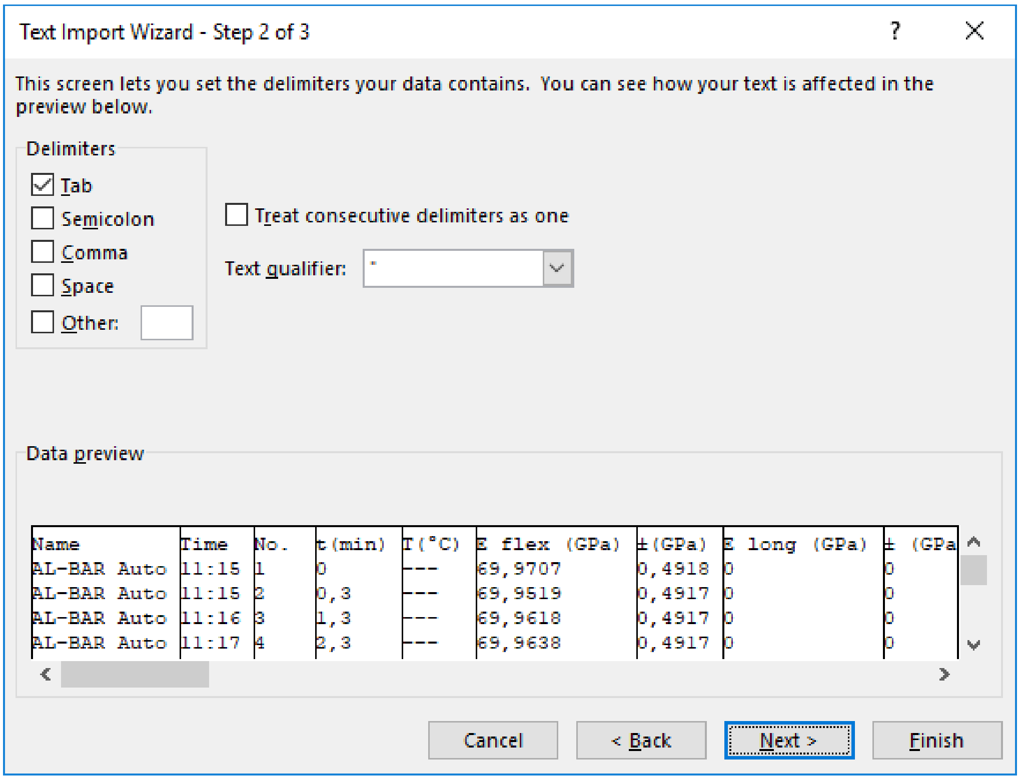


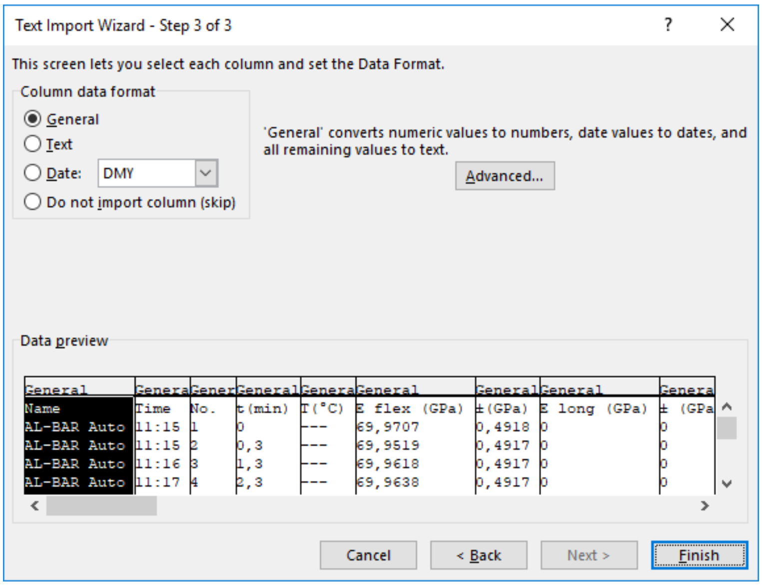
4. In the import data dialog box, locate and double-click the text file you want to import and click import.



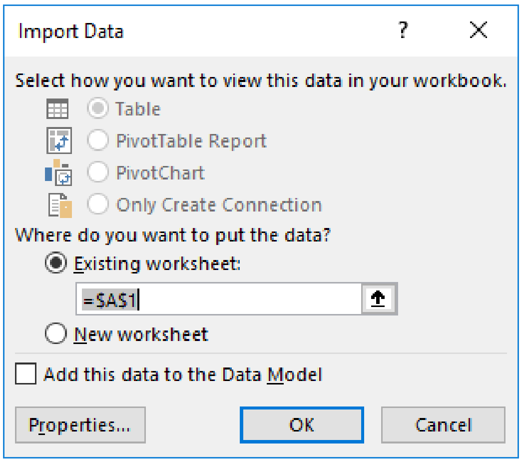
5. In the Import Wizard, configure according to the following images and click next.



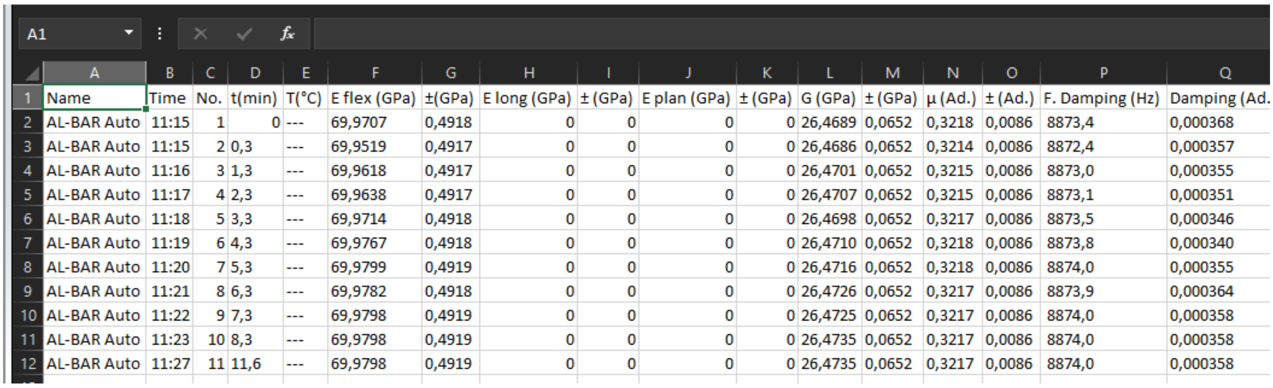




6. Click finish. At the "Import Data" screen, click OK.



7. Done!



Name	Time	No.	t(min)	T(°C)	E flex (GPa)	±(GPa)	E long (GPa)	± (GPa)	E plan (GPa)	± (GPa)	G (GPa)	± (GPa)	µ (Ad.)	± (Ad.)	F. Damping (Hz)	Damping (Ad.
AL-BAR Auto	11:15	1	0	---	69,9707	0,4918	0	0	0	0	26,4689	0,0652	0,3218	0,0086	8873,4	0,000368
AL-BAR Auto	11:15	2	0,3	---	69,9519	0,4917	0	0	0	0	26,4686	0,0652	0,3214	0,0086	8872,4	0,000357
AL-BAR Auto	11:16	3	1,3	---	69,9618	0,4917	0	0	0	0	26,4701	0,0652	0,3215	0,0086	8873,0	0,000355
AL-BAR Auto	11:17	4	2,3	---	69,9638	0,4917	0	0	0	0	26,4707	0,0652	0,3215	0,0086	8873,1	0,000351
AL-BAR Auto	11:18	5	3,3	---	69,9714	0,4918	0	0	0	0	26,4698	0,0652	0,3217	0,0086	8873,5	0,000346
AL-BAR Auto	11:19	6	4,3	---	69,9767	0,4918	0	0	0	0	26,4710	0,0652	0,3218	0,0086	8873,8	0,000340
AL-BAR Auto	11:20	7	5,3	---	69,9799	0,4919	0	0	0	0	26,4716	0,0652	0,3218	0,0086	8874,0	0,000355
AL-BAR Auto	11:21	8	6,3	---	69,9782	0,4918	0	0	0	0	26,4726	0,0652	0,3217	0,0086	8873,9	0,000364
AL-BAR Auto	11:22	9	7,3	---	69,9798	0,4919	0	0	0	0	26,4725	0,0652	0,3217	0,0086	8874,0	0,000358
AL-BAR Auto	11:23	10	8,3	---	69,9798	0,4919	0	0	0	0	26,4735	0,0652	0,3217	0,0086	8874,0	0,000358
AL-BAR Auto	11:27	11	11,6	---	69,9798	0,4919	0	0	0	0	26,4735	0,0652	0,3217	0,0086	8874,0	0,000358

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