



Universidad de Valladolid



**ESCUELA DE INGENIERÍAS
INDUSTRIALES**

UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

International Semester

**Development of Experimental Modal Analysis Tests
Using Dewesoft Software**

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Valladolid, June 2023.

Abstract

Development of a methodology to do Hammer test Modal Analysis using Dewesoft software.

This document reports on the performance and analysis of modal tests on mechanical structures. The modal test is a method often used to determine dynamic properties of a structure, namely natural frequencies. These modal tests were carried out by hammer impact, the objective being to subject the system to one or more impacts in order to capture an acceleration in output with an accelerometer.

The tests were carried out using Dewesoft software, which allows us to carry out the tests in an accurate and reliable manner. The analysis of the results will allow us to evaluate the performance of the system.

Keywords

Modal analysis - Impact Hammer – Dewesoft – Cantilever beam - Slab

Table of content

1. Introduction and Objectives.....	5
2. Modal Analysis and Case Studies	6
2.1. Modal Analysis	6
2.1.1. Modal Test.....	6
2.1.2. Frequency Response Function	7
2.1.3. Natural frequencies of vibration	8
2.1.4. The coherence.....	9
2.2. Case Studies	10
2.2.1. Cantilever beam	10
2.2.2. Slab	10
2.2.3. ISO Standards	13
3. Methodology.....	16
3.1. Instrumentation	16
3.1.1. The hammer	16
3.1.2. The accelerometers.....	19
3.1.2. Sirius Box	23
3.1.3. Dewesoft Software.....	24
3.2. How to measure	33
3.2.1. Hammer Impact.....	33
3.2.2. Results provided by the software	34
4. Results, Presentation and discussion	35
4.1. First acquisitions: The Cantilever Beam	35
4.2. Acquisition on the large structure : The Slab	41
4.2.1. Low frequency measurement	42
4.2.2. High frequency measurement.....	48
5. Conclusion and future lines.....	57
Bibliography	59
List of figures	60

1. Introduction and Objectives

In this report, we will discuss the different aspects of the work carried out on the project of modal analysis of a slab by hammer impact tests. This report will explain the project as well as all the technical terms to know. This project is carried out within the framework of the international semester.

Vibration testing is a common method for evaluating the dynamic properties of objects. This method involves exposing the object to vibrations using a vibration device and measuring the resulting vibrations using sensors. The vibration data can then be analyzed to determine the modal characteristics of the object, such as its natural frequency, damping, and vibration modes. Vibration testing is widely used in many fields, including aerospace, automotive and electronics. [1]

The work was done with Dewesoft software, a test and measurement software that allows us to carry out our study. The way to measure is exciting the structure using the hammer (force input) and acceleration sensors to measure the response (acceleration output). This report will explain how the measurements were made and how we used them.

We will in particular study the modal analysis, the main objective of the modal test is to determine the Frequency Response Function (FRF) over a certain frequency range. The method represents a simple and economical way to determine the behavior of a small structure. Small structure modal hammer impact testing is particularly useful for lightweight structures. These structures can experience significant vibration and dynamic loads during use, and understanding their modal properties is important to their safety and performance.

The aim of this project is to develop a methodology for using Dewesoft software to carry out modal analysis. Firstly, we will study an initial setup, a cantilever beam, in order to develop a good methodology. Secondly, we will study a slab. From these experiments, we will obtain key parameters such as the natural frequencies. We are going to carry out this work on the slab in order to find out whether the requirements of the standard are met.

2. Modal Analysis and Case Studies

2.1. Modal Analysis

2.1.1. Modal Test

A modal test is a process used to determine the transfer characteristics of a system. It is used to determine the modal masses, modal damping ratios and mode shapes of the object under study. An eigenmode is a way in which a system oscillates as a result of a load. The addition of several vibration modes can result in combined modes (Figure 1), which may have different dynamic properties than the individual modes. [2]

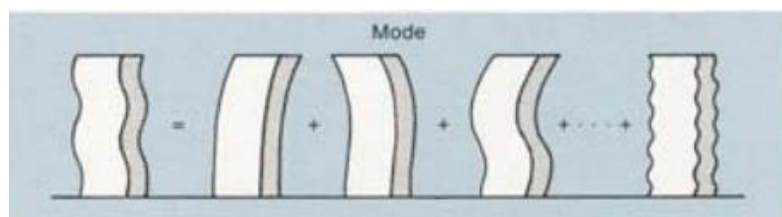


Figure 1 - Vibration modes [2]

The data collected is used to determine the natural frequencies and vibration modes of the structure. The natural frequencies correspond to the resonance frequencies of the structure, i.e. the frequencies at which the structure vibrates most easily. The vibration modes are the vibration patterns associated with each natural frequency.

In our case the way to perform a modal test will be a percussion hammer test (Figure 2). Energy is supplied to the system structural resonances occur and the response is amplified. A transfer function can be obtained from this test to estimate the modal parameters.



Figure 2 - Modal test by impact hammer

2.1.2. Frequency Response Function

The frequency response function (FRF) is an important calculated measure used in engineering to characterise the behaviour of linear dynamic systems. It describes the relationship between the input and output of a system as a function of the frequency of the input. The FRF provides several important information about the vibration response of the system. The Figure 3 shows a diagram of our system and the FRF in frequency and time. [3]

Here is the main information provided by the FRF:

- The natural frequencies and modes of vibration of the system.
- Damping of the system.

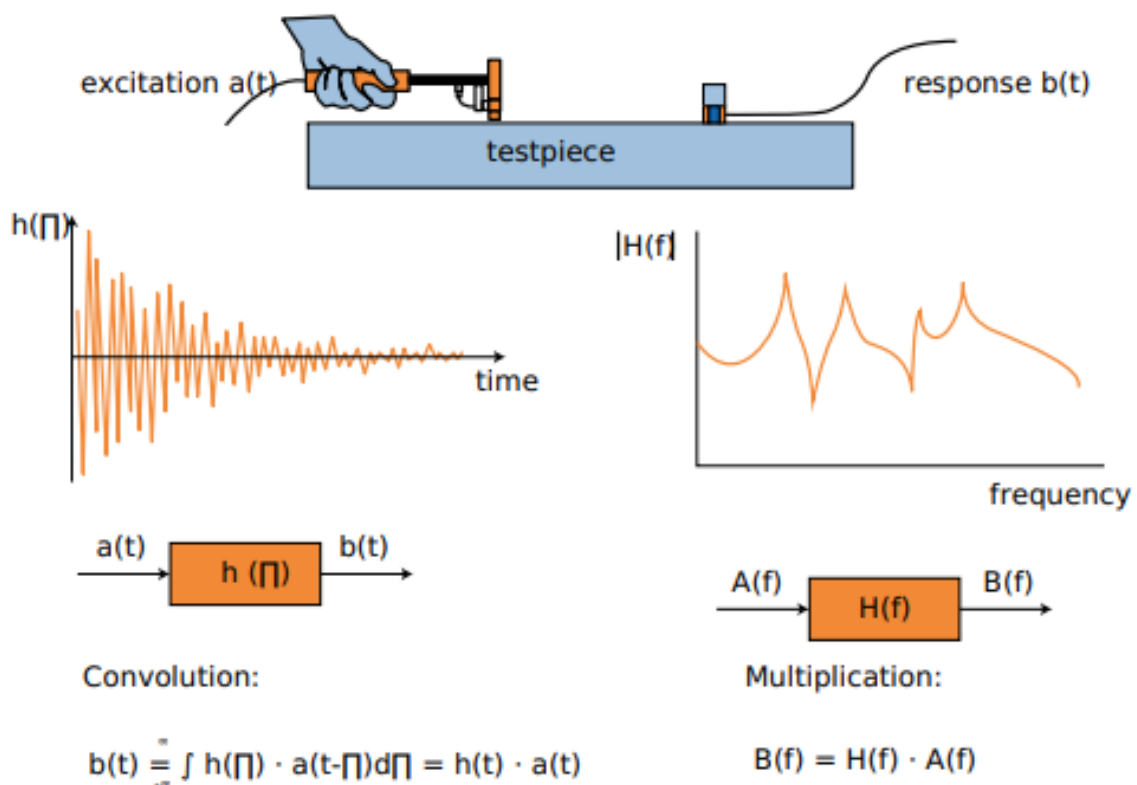


Figure 3 - Modal test system [3]

2.1.3. Natural frequencies of vibration

Natural frequencies or resonance frequency of vibration are the frequencies at which a structure will vibrate most strongly without being excited by an external source. These frequencies depend on the mechanical properties of the structure.

In our case, we will find the natural frequencies by experimental measurement and graphic analysis. In effect, we will use accelerometers to obtain the frequency spectrum. We will then analyse the frequency spectrum to identify the frequency peaks that are associated with the natural frequencies.

The modal frequencies are determined by observing the maximum magnitudes on the FRF (Figure 4). [4]

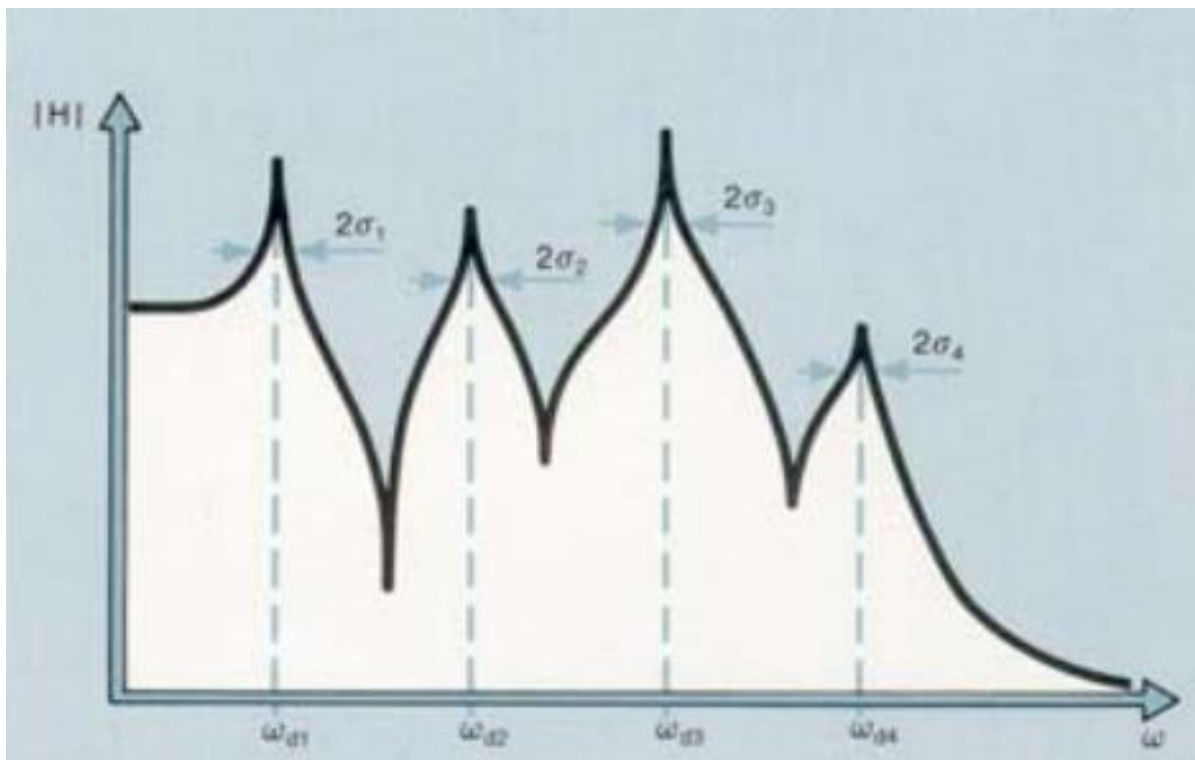


Figure 4 - Example of Frequency Response Function [4]

2.1.4. The coherence

The Coherence Function provides us with a means of assessing the degree of linearity between the input and output signals. [2]

The bounds for the Coherence Function are 1, for no noise in the measurements, and 0 for pure noise in the measurements. The interpretation of the Coherence Function is that for each frequency ω it shows the degree of linear relationship between the measured input and output signals. The Coherence Function is analogous to the squared correlation coefficient used in statistics. [2].

The objective for us will be to have a coherence as close as possible to 1, as this would mean a large linear relationship between the system input and the output, which would mean that the measurement is reliable.

2.2. Case Studies

2.2.1. Cantilever beam

With the aim of developing a methodology that is consistent with the Dewesoft software, we will begin with a small structure: the cantilever beam (Figure 5). This study will serve as a starting point for the modal analysis of the slab.

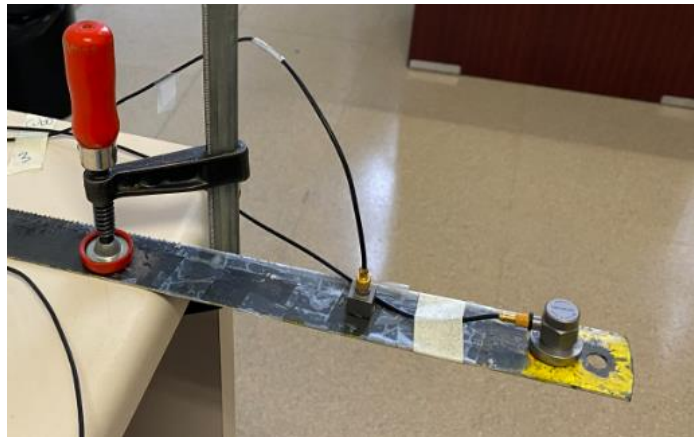


Figure 5 - Cantilever beam setup

2.2.2. Slab

After carrying out a series of tests and settings on the cantilever beam, we will study a larger model (slab), a structure 120 cm long, 80 cm wide and 5 cm thick (Figure 6). This structure is called a small timber floor mock-up (standard concrete). To study this mock-up, we will use the skills acquired during the study of the small model.

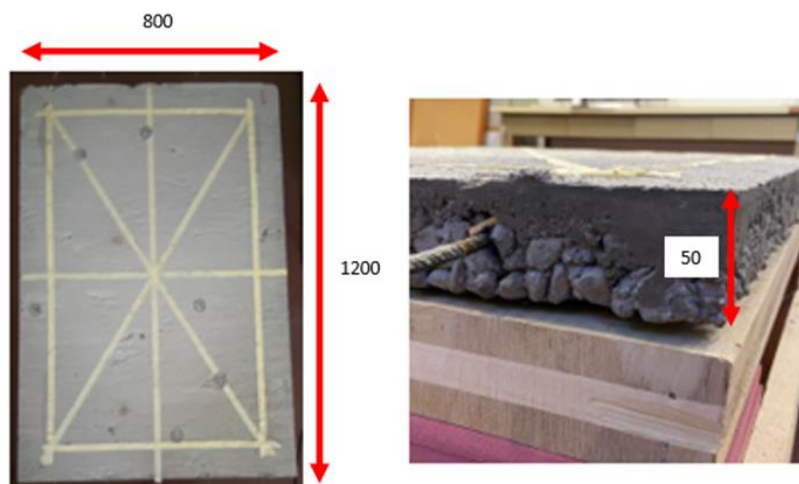


Figure 6 - Slab dimensions

Our structure is placed on a 50 mm thick wooden plate (the wooden plate is the same size as the structure).

We can talk about the measurements taken on the large structure, the slab. We will use the same acquisition system as for the cantilever beam. We will use a coordinate system to locate the points of impact and the locations of the accelerometers. Our structure is placed on a 50 mm thick wooden plate (the wooden plate is the same size as the structure).

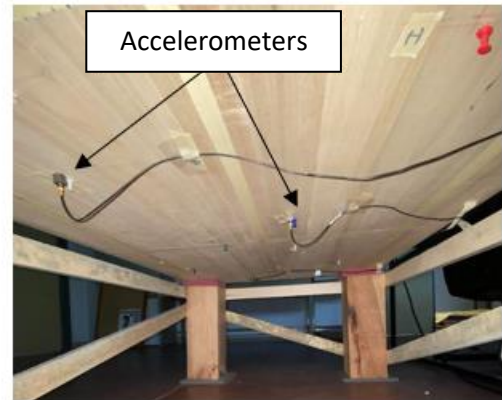


Figure 7 - Slab on wooden structure and placement of accelerometers

As shown in the Figure 7, the accelerometers that pick up the impact response are placed on the underside of the wooden plate.

The accelerometers used are positioned as follows.

- Point A (19, 26) → Cubic Accelerometer
- Point D (30, 108) → Hexagonal Accelerometer

The characteristics of the accelerometers are explained in the section 3.1.2..

The Figure 8 shows the location of each accelerometer.

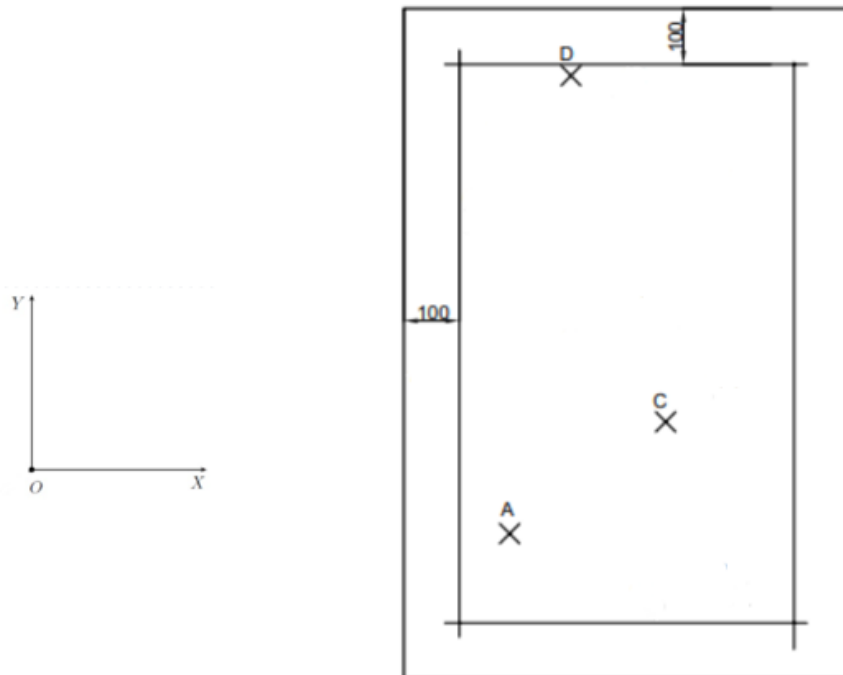


Figure 8 - Accelerometer coordinates on the slab setup

2.2.3. ISO Standards

We can also provide some information about the ISO standard in this area.

ISO 16251-1:2014: Acoustics — Laboratory measurement of the reduction of transmitted impact noise by floor coverings on a small floor mock-up — Part 1: Heavyweight compact floor [5].

ISO 16251-1:2014 specifies a laboratory measurement method to determine the improvement of impact sound insulation by a floor covering when laid on a standard concrete floor mock-up and excited by a standard tapping machine. The method is restricted to soft, flexible floor coverings, which transmit impact sound mainly "locally" into the floor, i.e. through the area close to the points of excitation, so that the size of the flooring specimen does not have an influence on the results. Examples of such floor coverings are carpets, PVC, and linoleum.

The results only provide information about the noise radiated. A subjective classification of the quality of the floor coverings is not intended.

ISO 16251-1 standard describes an alternative method for the experimental obtaining of acoustic parameters reduction of the impact sound pressure level (ΔL) and weighted reduction of the impact sound pressure level (ΔL_w) for soft floor coverings through vibration measurements on a small floor mock-up. The application of the methodology to floating floor systems is of great interest, since, compared to the conventional method, it is less costly and would require smaller specimens.

The method in this part of ISO 16251, where the test set-up consists of two rooms above each other, separated by a standard concrete floor, on which the flooring to be tested is applied.

In this International Standard, the two rooms are removed and the concrete floor is replaced by a small concrete plate of similar thickness (see Annex A). This plate is structurally decoupled from the surroundings by elastic suspensions. A standard tapping machine is used as an impact source and two sound levels "in the lower room" are determined, once with and once without the specimen on the plate.

However, instead of the sound pressure level in the lower room, the structure borne sound level at the lower surface of the concrete plate is determined. It is assumed that for locally reacting floor coverings the structure borne sound level difference equals the impact sound reduction.

In this part of ISO 16251, structure borne sound levels are expressed in terms of acceleration levels.

The test installation is shown in Figure 9. It consists of a concrete slab placed on flexible supports at its four corners. The surface area of each flexible support must

not exceed 10*10cm. The vertical resonance of the concrete slab on the flexible supports must be less than 20 Hz.

The size of the slab must be (120 ± 5) cm* (80 ± 5) cm* (20 ± 1) cm. It must be homogeneous and of uniform thickness. It must be guaranteed that the surface of the slab is smooth with a tolerance of ± 1 mm on a horizontal line from edge to edge and that it is hard enough to withstand the impact of the hammering machine. A screed is permitted to ensure sufficient flatness.

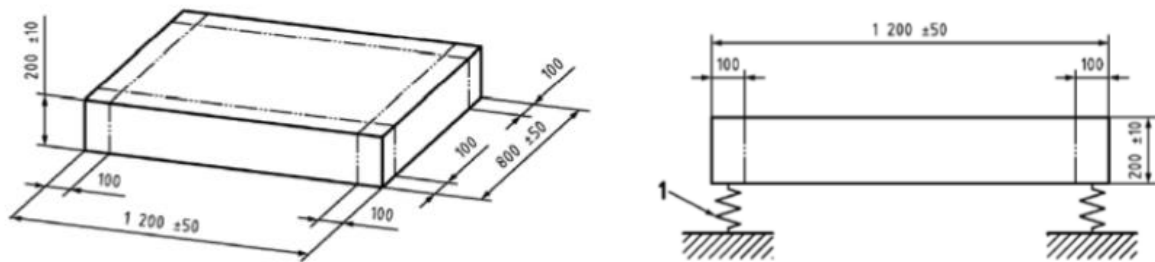


Figure 9 - Slab dimensions and supports [5]

Below (Figure 10) is a rendering of the installation used to study the slab.



Figure 10 - Slab installation

The standard also provides the following information on accelerometers:

The accelerometer(s) must be rigidly fixed to the underside of the concrete slab (screwed or glued). magnetic fields, temperature or temperature variations and the equipment manufacturer's recommendations. At least four accelerometer positions should be used. They should be distributed evenly, but randomly, over the lower surface of the slab, avoiding symmetrical lines and keeping a distance of at least 10 cm from the edges of the slab.

As a reminder, the positioning of the accelerometers used for the vibration study of the slab is shown in Figure 8.

3. Methodology

3.1. Instrumentation

3.1.1. The hammer

The hammer (Figure 11) is used to generate pulses on the structure to be tested, thus measuring the vibrations of the structure.



Figure 11 – Hammer used for modal tests

The hammer has a force sensor integrated in the tip, the tip ends are interchangeable. The components of the tool are shown in Figure 12 [3]. For bigger structures there are big hammers available with more mass to generate a distinct amplitude.

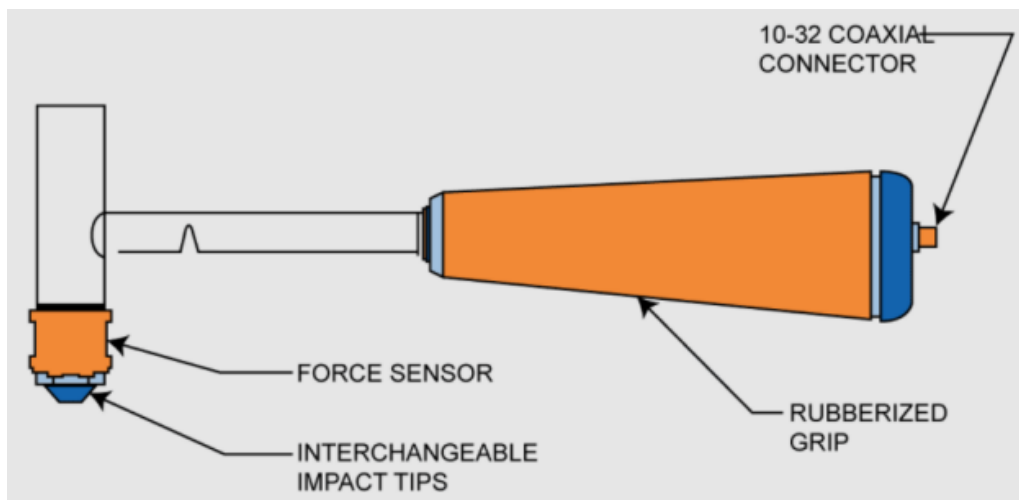


Figure 12 – Hammer components used for modal tests [3]

Our hammer has the following characteristics:

- Sensitivity at output of hammer: 1,01 pC/N
- Frequency range:

Tip	Frequency Range	Pulse Duration	Force Range
Steel	0 to 7kHz	0.20ms	500N to 5000N (112.41 lbf to 1124.10 lbf)
Steel + add. mass	0 to 4.5kHz	0.23ms	
Plastic	0 to 2kHz	0.57ms	300N to 1000N (67.45 lbf to 224.82 lbf)
Plastic + add. mass	0 to 1.3kHz	0.76ms	
Rubber	0 to 500Hz	2.7ms	100N to 700N (22.48 lbf to 157.37 lbf)
Rubber + add. mass	0 to 340Hz	3.1ms	

Figure 13 - Frequency Range / Pulse Duration / Force Range of the hammer depending on the tip [6]

We can see that the frequency range depends on the type of tip (Figure 13). However, in our studies, we will not be working on frequencies that exceed 300 Hz. So the hammer could be used with any tip.

Another special feature of the hammer is that it is IEPE. So let's define what that means. The IEPE and Voltage settings on the Dewesoft software allow the configuration of the inputs to a measurement system, in particular the accelerometers and the hammer used for vibration testing. The Figure 14 shows the Dewesoft window where the IEPE/Voltage option is configured.

What is the difference between the IEPE setting and the Voltage setting?

- The IEPE setting is a common method of vibration measurement that uses an amplifier built into the accelerometer to provide an output voltage proportional to the measured acceleration.
- Unlike the IEPE setting, the Voltage setting requires an external amplifier to convert the output signal of the accelerometer into an output voltage proportional to the measured acceleration.

ID	Used	C	Name	Ampl. name	Range	Measurement
1	Used		martilloPCB	SIRIUS-ACCv2	500 mV	IEPE
2	Used		acelBk cuadrado	SIRIUS-ACCv2	10000 mV	IEPE
3	Unused		AI 3	SIRIUS-ACCv2	10 V	Voltage
4	Unused		AI 4	SIRIUS-ACCv2	10 V	Voltage

Figure 14 - IEPE / Voltage in Dewesoft Window

3.1.2 The accelerometers

The set-up used for the small part hammer impact method vibration study consists of the test piece, the hammer that is used to impact the part, and two accelerometers to collect the output parameters. The accelerometers used in this setup are models BK4513 and BK4508.

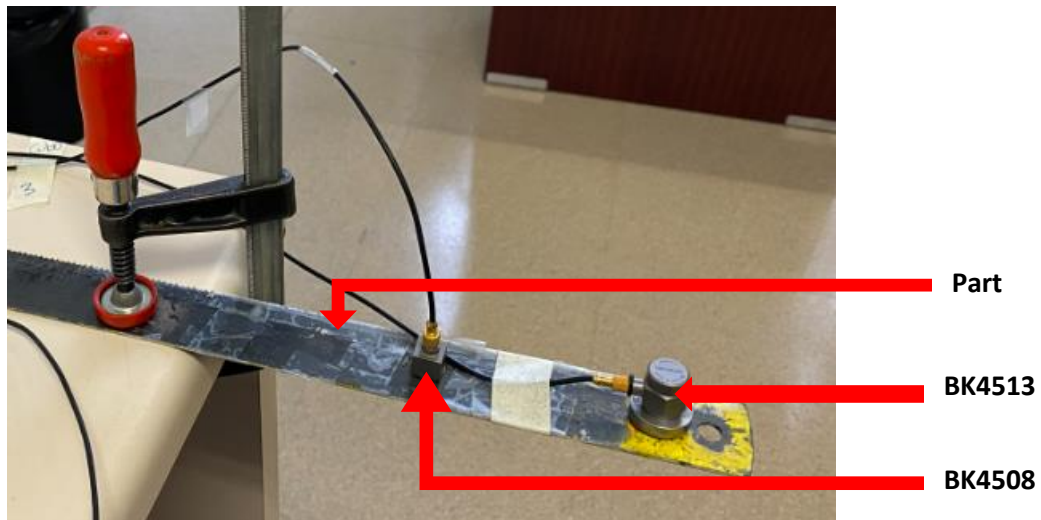


Figure 15 - Cantilever Beam Setup

Here is above the installation which will be used, the studied cantilever beam is fixed on a support (desk). On the Figure 15, we can see:

- 1 Hexagonal Accelerometer BK4513
- 1 Cubic Accelerometer BK4508

When the hammer is used to impact the part, the two accelerometers record the vibrations from two different points on the part. This data is then used to calculate the modal characteristics of the part.

The two accelerometers mentioned have slightly different characteristics. The BK4513 is capable of recording a frequency response of up to 10 kHz and it has a sensitivity of $10 \pm 12/-8\%$ mV/ms⁻². The BK4508 has a frequency response of up to 20kHz with a sensitivity of $10 \pm 5\%$ mV/ms⁻².

We briefly touched on the use of accelerometers earlier. In this section we will describe the characteristics of our accelerometers. We'll see if they meet our expectations for the study.

3.1.2.a) Hexagonal accelerometer: BK4513

We can start with the hexagonal accelerometer type BK4513. Here are the dimensions (Figure 16) of these accelerometers [7]

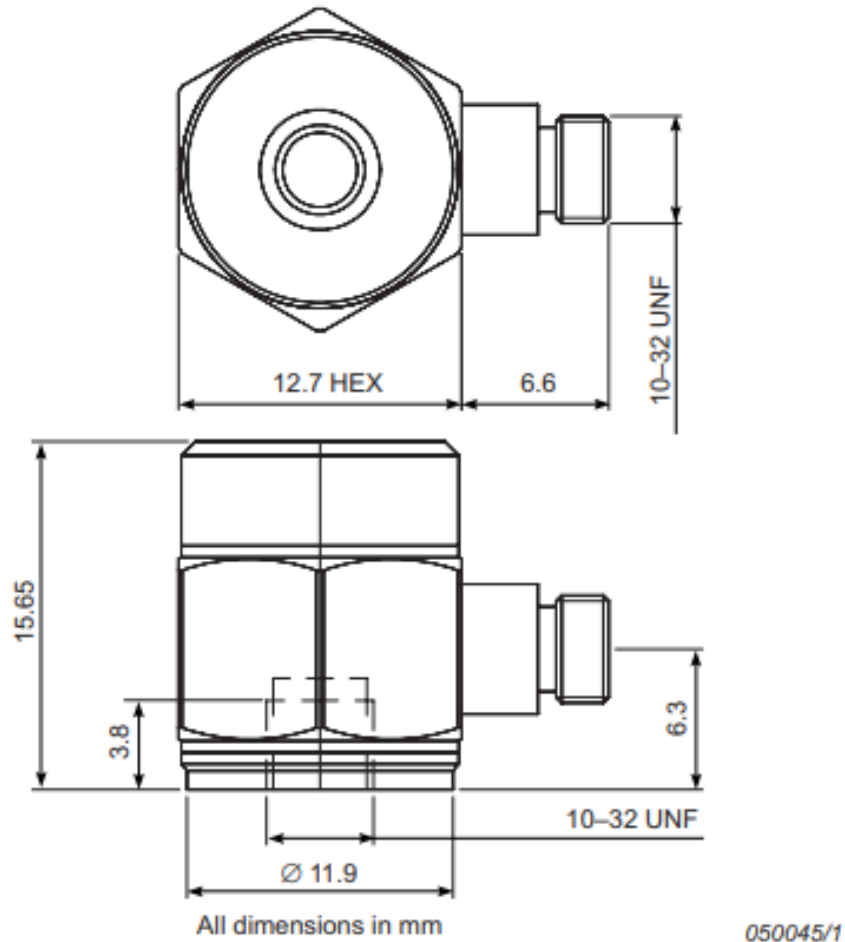


Figure 16 - Technical drawing Hexagonal accelerometer [7]

We can also look at the different specifications (Figure 17) of the accelerometer. It's important for us to check that we can use it as part of our study.

	Units	4513/ 4513-B	4513-001/ 4513-B-001	4513-002/ 4513-B-002
Dynamic Characteristics				
Voltage Sensitivity (@ 160 Hz)	mV/ms ⁻² (mV/g)	1+12/-8% (10±10%)	10+12/-8% (100±10%)	50+12/-8% (500±10%)
Measuring Range (±pk)	ms ⁻² (g)	4900 (500)	490 (50)	98 (10)
Frequency Response		See typical amplitude response		
Mounted Resonance Frequency	kHz	32		
Amplitude Response ±10% (typical) ^a	Hz	1 to 10000		
Residual Noise	mg	0.8	0.2	0.1
Transverse Sensitivity	%	<5		

Figure 17 - Dynamic Characteristics of Hexagonal Accelerometer [7]

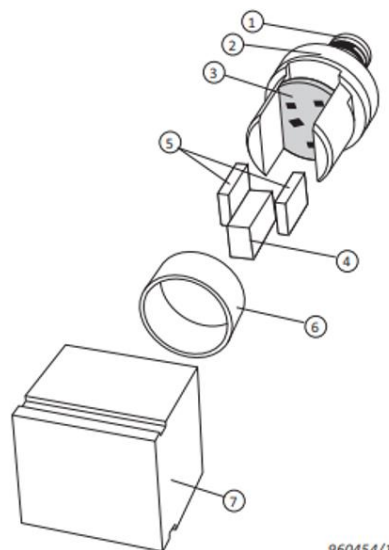
These specifications provide important information such as the sensitivity of 10+12/-8% mV/ms⁻². This also table shows that the accelerometer is suitable for our study, since we will be studying frequencies from 0 to 300 Hz only. It's an IEPE accelerometer.

3.1.2.b) Cubic accelerometer BK4508

Let's now look at the characteristics of the second accelerometer, the cubic BK4508.

Below (Figure 18) you will find the technical drawing corresponding to this accelerometer [8]

Exploded view of Type 4508-B showing the ThetaShear design and built-in CCLD preamplifier:
 (1) 10-32 UNF connector
 (2) Top
 (3) Preamplifier
 (4) Seismic mass
 (5) Piezoelectric plates
 (6) Clamping ring
 (7) Titanium housing



960454/1

Figure 18 - Technical Drawing Hexagonal Accelerometer [8]

The table (Figure 19) shows that this accelerometer has a sensitivity of $10 \pm 5\%$ mV/ms⁻² and a frequency range in amplitude between 0.3 to 8000 Hz. It's also an IEPE accelerometer. This accelerometer can therefore be used for our study.

Type Number		4508-B	4508-B-003	4508-B-001	4508-B-002	4508-B-004
General						
Weight	gram	4.8	4.9	4.8	4.8	4.8
	oz	0.17		0.17	0.17	0.17
Voltage Sensitivity (at 159.2 Hz, 4 mA supply current)	mV/ms ⁻²	10 ± 5%		1 ± 5%	100 ± 10%	50 ± 5%
	mV/g	98 ± 5%		9.8 ± 5%	980 ± 10%	490 ± 5%
Frequency Range	Amplitude (±10%)	0.3 to 8000		0.1 to 8000	0.4 to 8000	0.2 to 8000
	Phase (±5°)	Hz	2 to 5000	0.5 to 5000	2 to 5000	1 to 5000
Mounted Resonance Frequency	kHz	25		25	25	25
Max. Transverse Sensitivity (at 30 Hz, 100 ms ⁻²)	%	<5		<5	<5	<5
Transverse Resonance Frequency	kHz	>18		>18	>18	>18
Max Operational Continuous Sinusoidal Acceleration (± peak)	kms ⁻²	0.7		7	0.07	0.15
	g	70	71	700	7	14
TEDS / Data Matrix Code		Yes		Yes	Yes	Yes

Figure 19 - Dynamic Characteristics of Cubic Accelerometer [8]

3.1.2. Sirius Box

In the context of a modal hammer impact test study, the Dewesoft Sirius_m acquisition box (Figure 20) is an important piece of measurement equipment for recording high quality data. It provides real-time data acquisition capability for measuring the dynamic responses of a structure to hammer impacts. The Sirius_m is equipped with both analogue and digital input channels, allowing the acquisition of signals from various types of sensors, such as our accelerometers.



Figure 20 - Dewesoft Sirius Box

The Sirius_m also has a precise synchronisation function, which ensures that data from several sensors can be collected simultaneously for accurate analysis of the structure. In addition, the Sirius_m features an intuitive user interface, allowing engineers to quickly and easily configure measurement parameters, and view measurement results in real time using Dewesoft X software. In short, the Dewesoft Sirius_m acquisition box is a versatile, reliable and high quality measurement tool for modal hammer impact test studies.

3.1.3. Dewesoft Software

In this part, we will present the different windows of the software as well as the different parameters to enter. The software is characterised by two workspaces: Measurement and Analysis. We can therefore carry out all the experimental work in the Measurement section and analyse the results in the Analysis section (Figure 21).

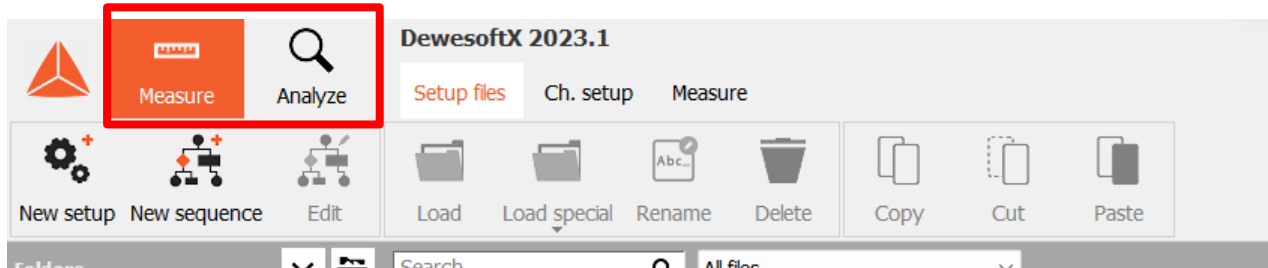


Figure 21 – Measure and Analyse

3.1.4.a) The Measurement

In the Measurement section, we start by configuring the different channels. In channel setup, all the channels in our setup are displayed. They can be configured in Analog in (Figure 22).

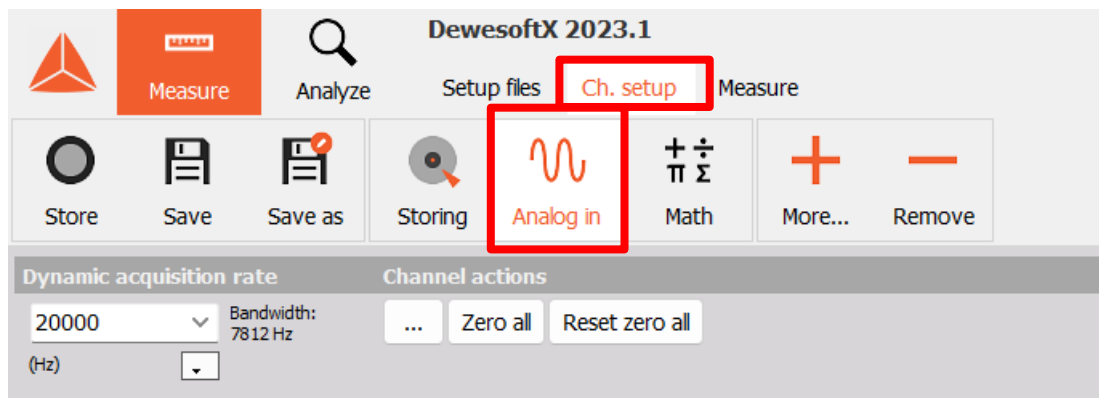


Figure 22 - Analog In section

We're going to look at the display for the following example, the cantilever beam (Figure 23), which is the first structure studied for this project. We have the following system.

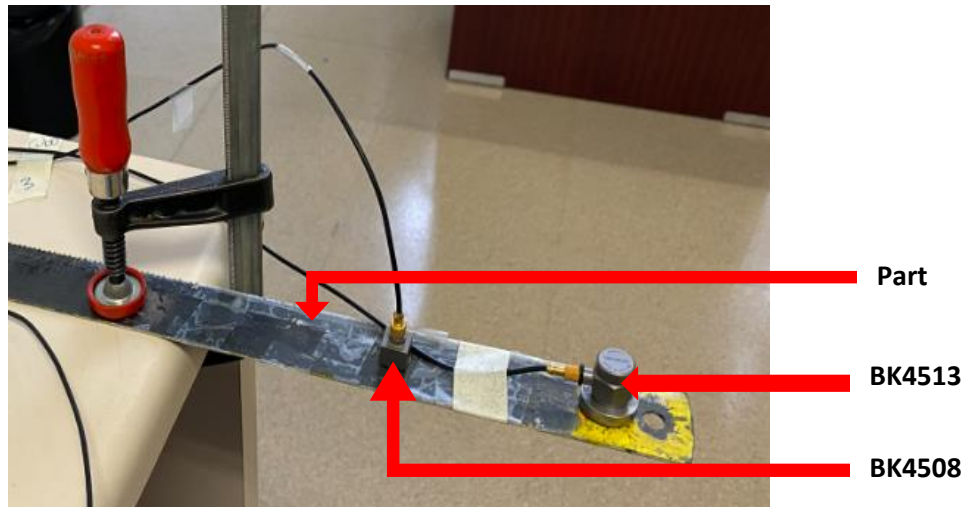


Figure 23 - Cantilever Beam System

Above, you can see the hammer (left) and the assembly containing the part under study and the two accelerometers (right). In Analog In section, we find our components to be parameterised. In this application, we work with the hammer and the cubic accelerometer, and we can choose the components we work with by activating "used" or "unused". A component is ready to be used when its "Ampl. Name" box is displayed in green. The Figure 24 shows the configuration space for the hammer and the cubic accelerometer.

DewesoftX - Setup: marta 8 marzo.dxs

Measure Analyze Setup files Ch. setup Measure

Store Save Save as Storing Analog in FFT analysis MT More... Remove

Device preview SIRIUS PWR1008

Dynamic acquisition rate: 1000 (Hz) Bandwidth: 391 Hz

Channel actions: ... Zero all Reset zero all

ID	Used	C	Name	Ampl. name	Range	Measurement	Min	Values	Max	Physical quantity	Units	Zero	Setup
1	Used		martilloPCB	SIRIUS-ACCv2	500 mV	IEPE	-218,63	0,004	218,63	Force	N		Setup
2	Used		acelBk cuadrado	SIRIUS-ACCv2	10000 mV	IEPE	-998,08	-0,01	998,08	Acceleration	m/s ²		Setup
3	Unused		AI 3	SIRIUS-ACCv2	10 V	Voltage	-1000,00	0,20	1000,00	Acceleration	m/s ²	Zero	Setup
4	Unused		AI 4	SIRIUS-ACCv2	10 V	Voltage	-10,00	0,0024	10,00		V	Zero	Setup

Figure 24 - Channels configuration window

You can define the dynamic acquisition rate (Figure 25), by selecting a value lower than the default value specific to our SIRIUS module. The dynamic acquisition frequency refers to the speed at which data is sampled by the measurement system. The bandwidth in Hz denotes the limit frequency that we will take into account in our measurements. We chose the following parameters because we will be studying frequencies ranging from 0 to 300 Hz.

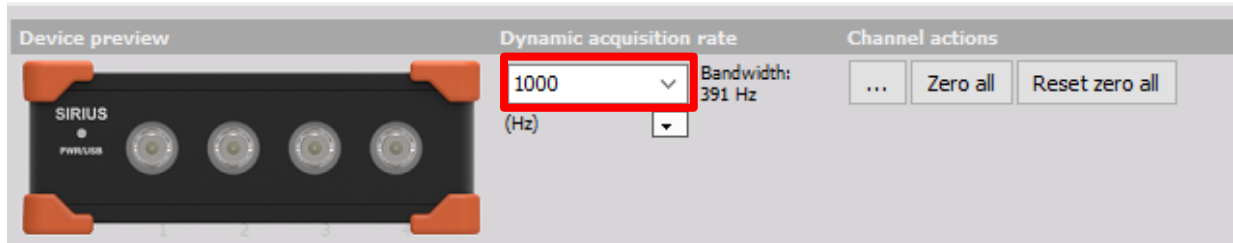


Figure 25 - Dynamic acquisition rate

Let's look at the Modal Test (MT) part (Figure 26). Taking our case study as an example, we use the hammer to give a short impact (input) and one or more acceleration sensors to measure the response (output). The hammer has an integrated force sensor to measure the input force.

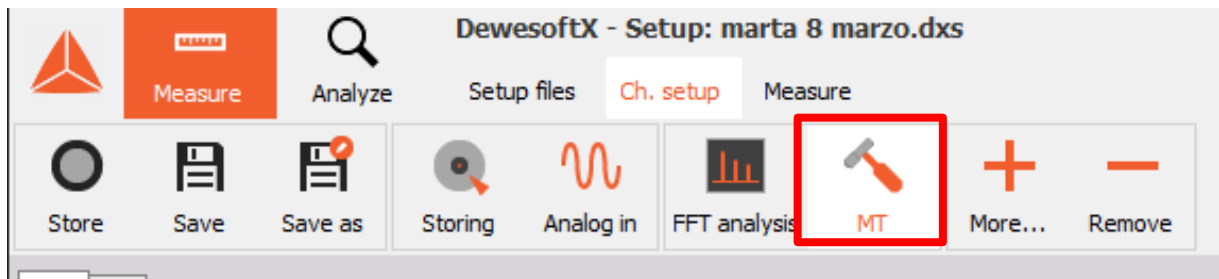


Figure 26 - Modal Test Window

We're going to carry out hammer impact tests. We can therefore set the force at which we want to impact the structure. That's why we're interested in the next window (Figure 27).

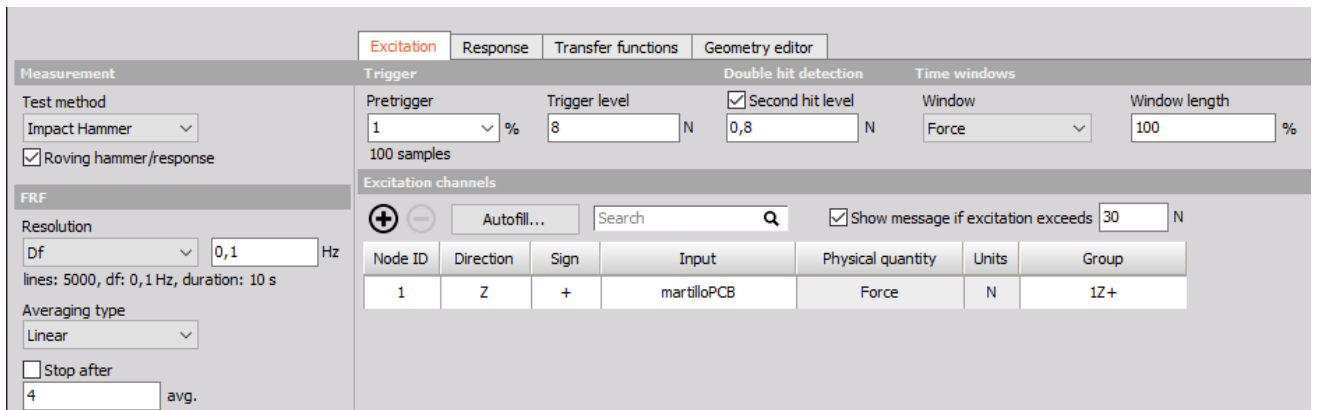


Figure 27 - Modal Test/Excitation Window

It is important to set the parameters in the Trigger window, to give the software the parameters that you can accept or reject.

The "Excitation" window contains the desired parameters for the input force provided by the hammer. The parameters that appear in the "Excitation" window are explained below:

Trigger Level: This is the input force target to be reached. Here the parameter is 8N. This means that whenever the input signal exceeds 8N, calculations can begin (FRF calculation).

Second hit level: The system often sends back one or more signals after the first hit. "Second hit level" can be used to set a minimum level for the second hit.

Pre-trigger: This option lets you set the desired time before waiting for the trigger level.

It can also be used to display a warning message if excitation exceeds a certain level (Figure 28).

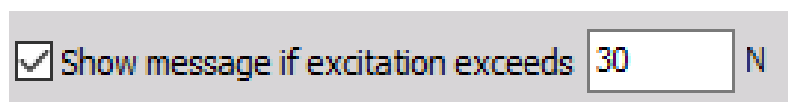


Figure 28 - Warning message configuration

Below (Figure 29) [9] is a graph showing the various parameters defined above.

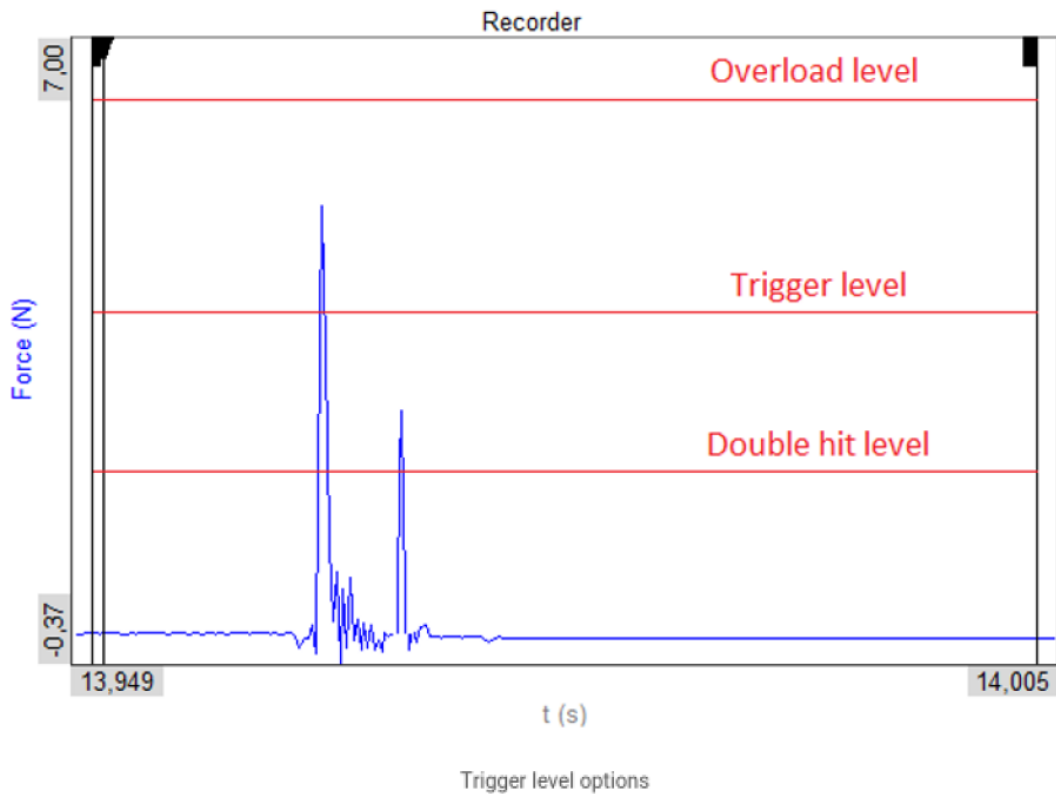


Figure 29 - Trigger Level Parameters [9]

You can then take a measurement using "Store" (Figure 30) in the measurement tab. In our case, the experimental measurement will be taken by making impacts on a small part using a hammer. After starting the acquisition, the test can be started by impacting the structure with the hammer at a precise point. The measurement technique is explained in section 3.2.

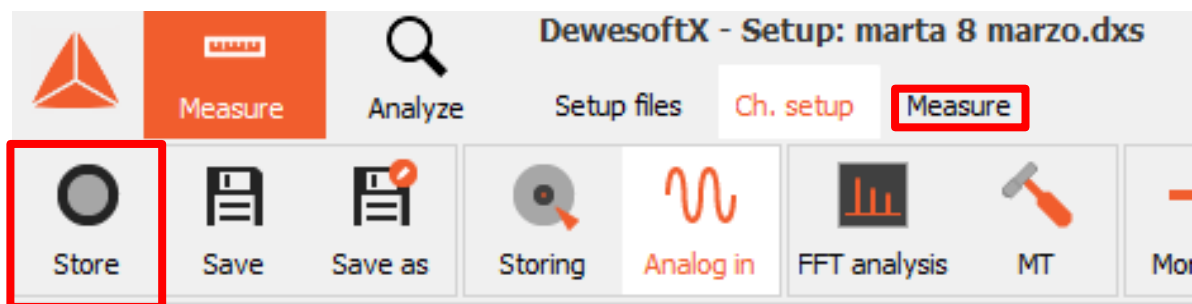


Figure 30 – Start measurements

4.1.4.b) The analysis part:

Once the measurement has been taken, you can go to the Analysis section (Figure 31).

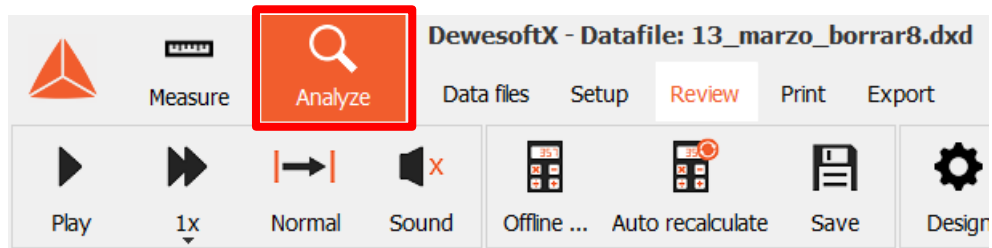


Figure 31 - Analysis Window

For our study, we're going to work with the review tab, which will allow us to view the various graphs and information of interest to us. You can choose which features to display on the dashboard using the widgets available (Figure 32).

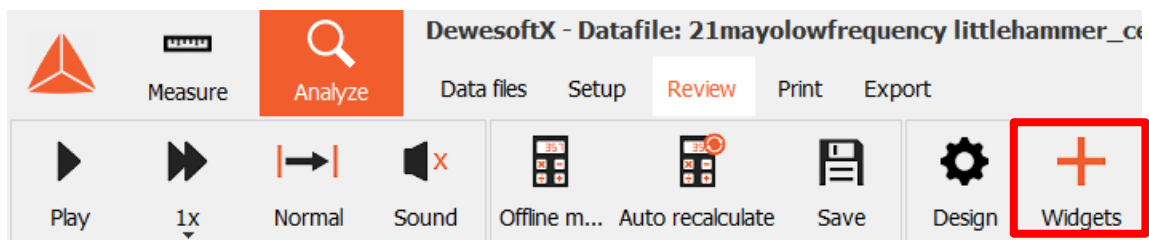


Figure 32 - Widgets

So we have a dashboard at our disposal, and the software offers several graphs or tools to display (Figure 33). Depending on our needs, we can decide which parameters to display.

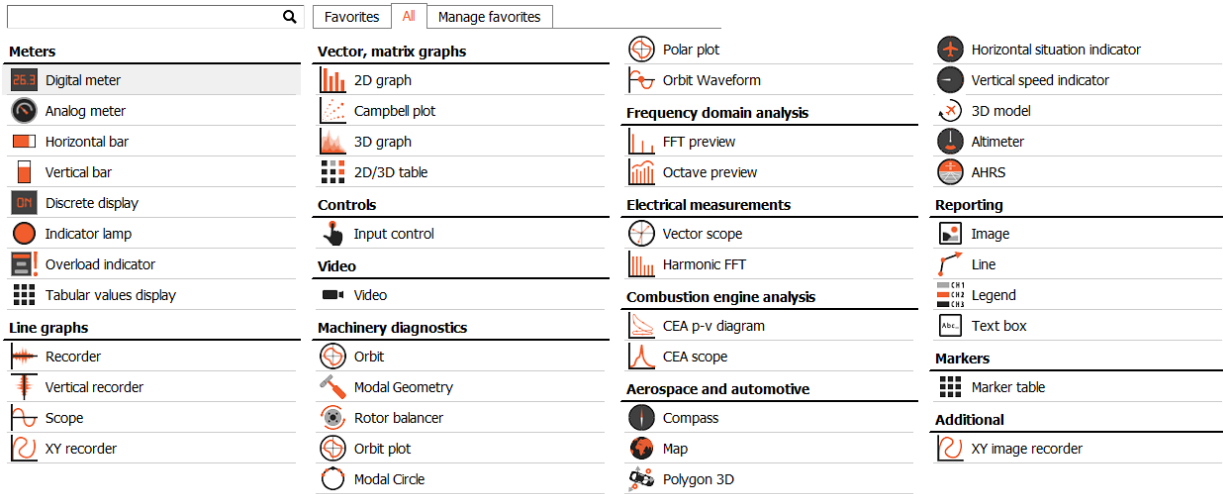


Figure 33 - Graphs or tools to display on the dashboard

Above is an overview of all the widgets that can be displayed. So you can organise your dashboard by displaying only the graphs and indicators that interest you. Here is an example.

The following diagram (Figure 34) shows an example of a dashboard. This is one of the dashboards we used to carry out a measurement.

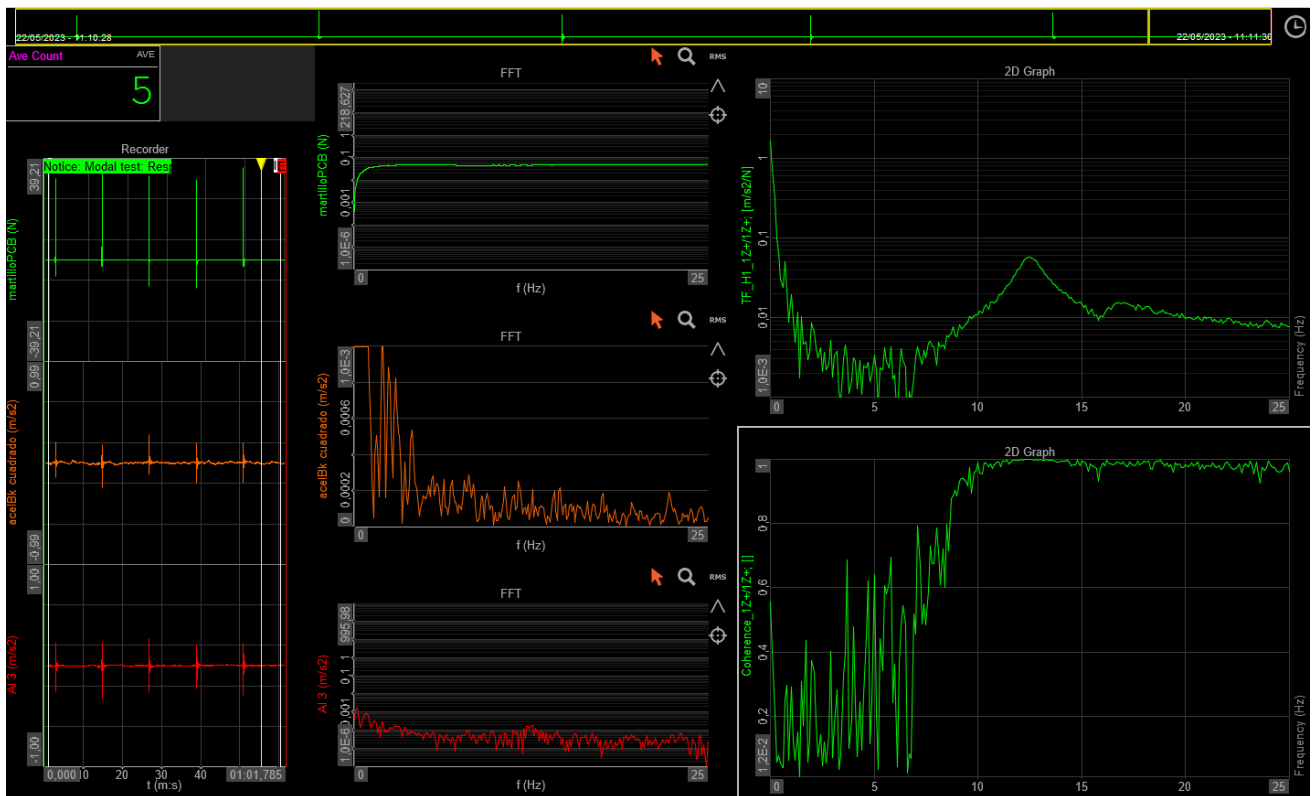


Figure 34 - Example of a dashboard obtained during a measurement

3.1.4.c) Exporting data

We have the option of exporting the data (Figure 35) obtained with the software to Excel, which allows us to analyse a measurement more precisely.

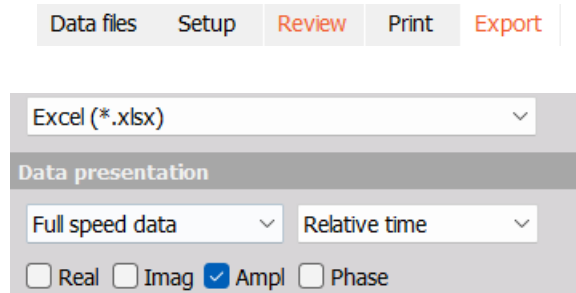


Figure 35 - Exporting Datas Option

We must therefore choose the form in which we want our results (real, imaginary, amplitude, phase).

Export order	Exp...	Ch. no	Name	Sampling	Rate	Data stru...	Data type	Unit
1	Yes	AI 1	martilloPCB	Synchronous	200 Hz	Scalar	Integer	N
2	Yes	AI 2	acelBk cuadrado	Synchronous	200 Hz	Scalar	Integer	m/s2
3	Yes	AI 3	AI 3	Synchronous	200 Hz	Scalar	Integer	m/s2
4	No	MT (Modal test)	Ave Count	Single value	unknown	Scalar	Integer	
5	No	MT (Modal test)	Progress	Single value	unknown	Vector (1)	Integer	
6	No	MT (Modal test)	Hit status	Single value	unknown	Scalar	Integer	
7	No	MT (Modal test)	OVLChannel	Single value	unknown	Scalar	Integer	

Figure 36 - Parameters which appear in the excel sheet

You decide whether or not you want the parameters to appear in the Excel table (Figure 36). Too much information can lead to bugs and difficulties in generating the Excel sheet.

d) Time vs Frequency

In our study, we will be studying various graphs showing the evolution of certain parameters as a function of time (s) and/or frequency (Hz). We can quickly define the difference between these two areas. Firstly, time-dependent graphs show the evolution of certain quantities such as the force exerted by the hammer or the acceleration recorded by the sensors in the time domain. This makes it possible to visualize the input and output of the system in a practical way. However, the

frequency-dependent graphs show the frequency distribution of the recorded responses. These graphs can be used to identify the natural modes and frequencies of the structure. They also provide information on the relative amplitude at each resonance peak.

3.2. How to measure

3.2.1. Hammer Impact

The Dewesoft software has two large sections, Measurements and Analysis. Obviously, we're going to use the measurement section to make the hammer impacts and record the response via the accelerometers.

When the test preparations are done the modal test is ready to start. For Modal Analysis testing, depending on the test situation it might have been chosen to use one or multiple modal exciters and one or multiple response sensors (Figure 37).

For a Roving Hammer Test, this means that only one response DOF (Degree Of Freedom) is needed, i.e., only one accelerometer position. For such a roving hammer test the accelerometer response DOF will be used as the reference DOF, while the hammer will rove between the DOFs. This is an example of what is called a Single-Input Single-Output (SISO) test configuration. [3].

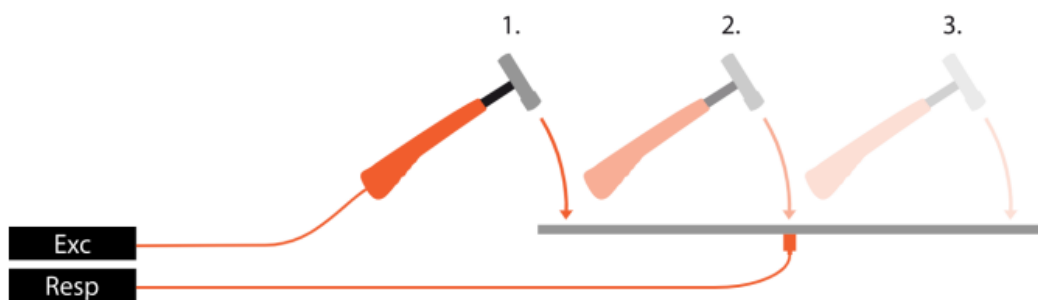


Figure 37 – Impact and Response [3]

It is important to mention a few points to ensure reliable measurements:

- Strike on the same precise point, you can give several impacts for a single measure
- Wait for a lapse of time (between impacts) for the software to take the shot into account, i.e. for the shot counter to increment. The Figure 38 below shows the impact counter, which indicates how many impacts have been made for a measure

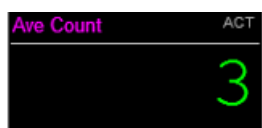


Figure 38 - Impact Counter

3.2.2. Results provided by the software

Once you've taken a measurement, you'll need to analyze the results provided by Dewesoft, so it's at this point that you can move on to the analysis section of the software.

The software offers a number of important options once a measurement has been made. You can choose the characteristics you want to appear on the screen. In our case, we will display the following parameters:

- Hammer input force as a function of time
- Acceleration measured by accelerometer as a function of time
- Force measured as a function of frequency
- Acceleration measured as a function of frequency
- The frequency response function
- The coherence

To make the graphical results easier to read and use, Dewesoft offers the option of exporting the data obtained in Excel. We will use this method to exploit the data.

4. Results, Presentation and discussion

4.1. First acquisitions: The Cantilever Beam

In this section we will present and analyze the results obtained during the measurement session on the cantilever beam. The results will provide information on the dynamic properties of the structure such as natural frequencies. We will carry out this measurement as described in section 3.2. We can determine an impact zone (Figure 39) where we will hit the structure with the hammer.

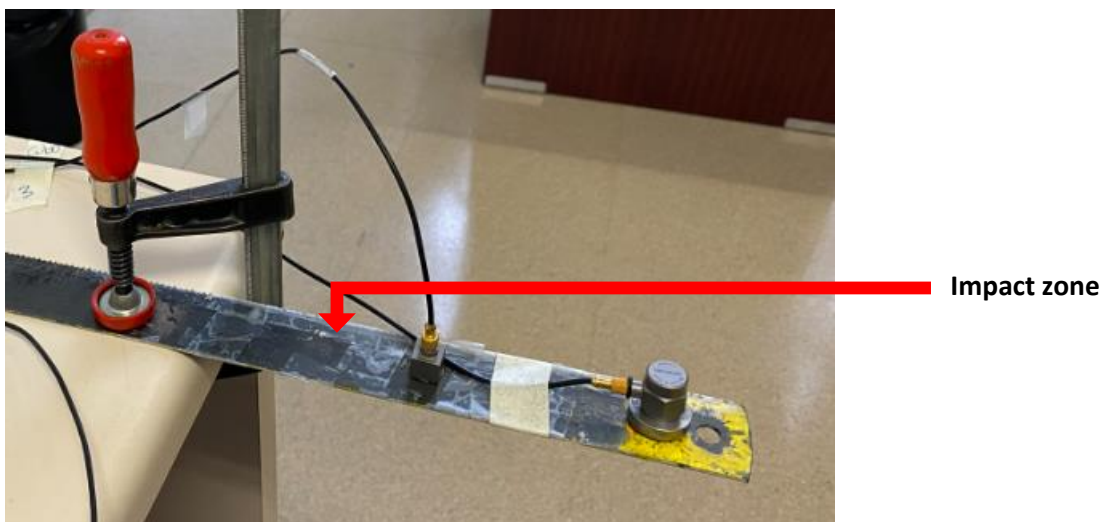


Figure 39 - Impact Zone

In this section we will extract various graphs from the data (the parameters set out in part 3.2.2) We are going to analyze these graphs to draw out the interesting information and the consequences for the structure.

a) Hammer input force as a function of time and frequency

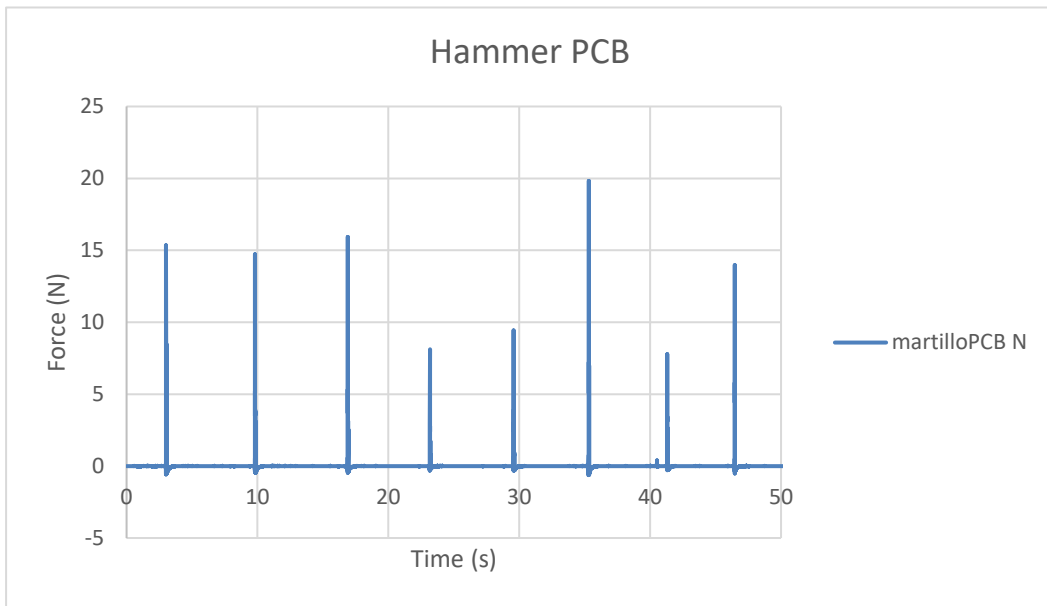


Figure 40 - Hammer input force as a function of time graph (Cantilever Beam)

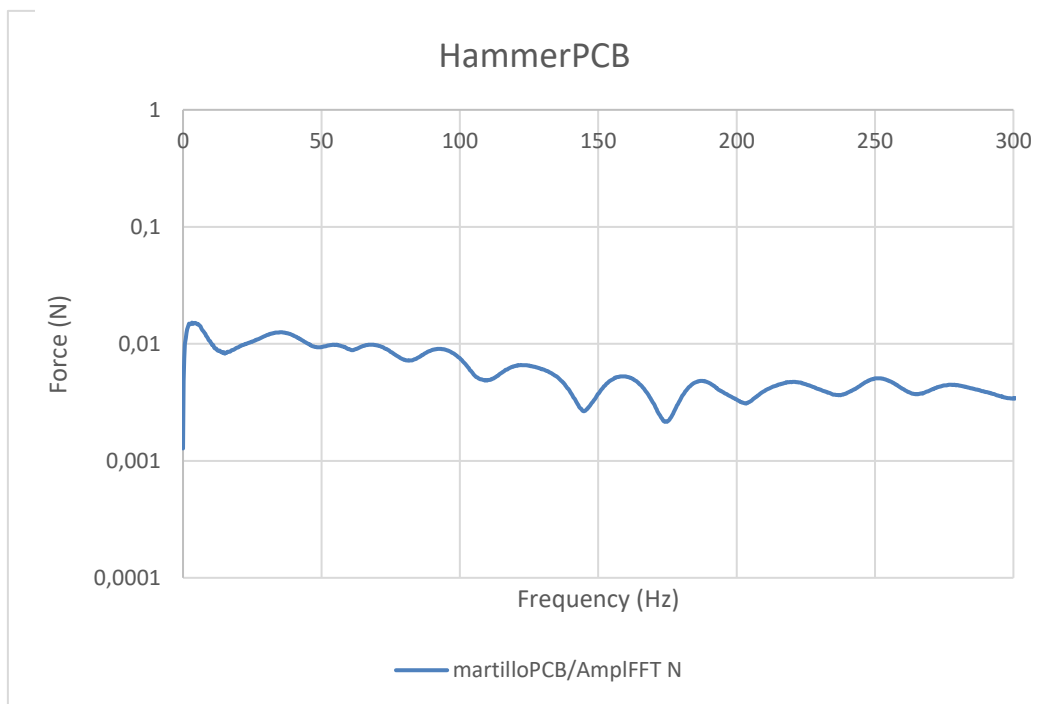


Figure 41 - Hammer input as function of frequency graph (Cantilever beam)

The first graph (Figure 40) displays the force in Newtons of hammer impacts on the structure over time. It can be observed that the force of impacts was measured eight times, at approximately regular time intervals. The impacts were measured between 6 and 20 N, with an average force of around 12 N.

The graph (Figure 41) shows the force exerted by a hammer as a function of the-frequency, ranging from 0 Hz to 300 Hz. We can see that the curve shows a progressive decrease in force as the frequency increases.

b) Acceleration measured by BK4383 as a function of time and frequency

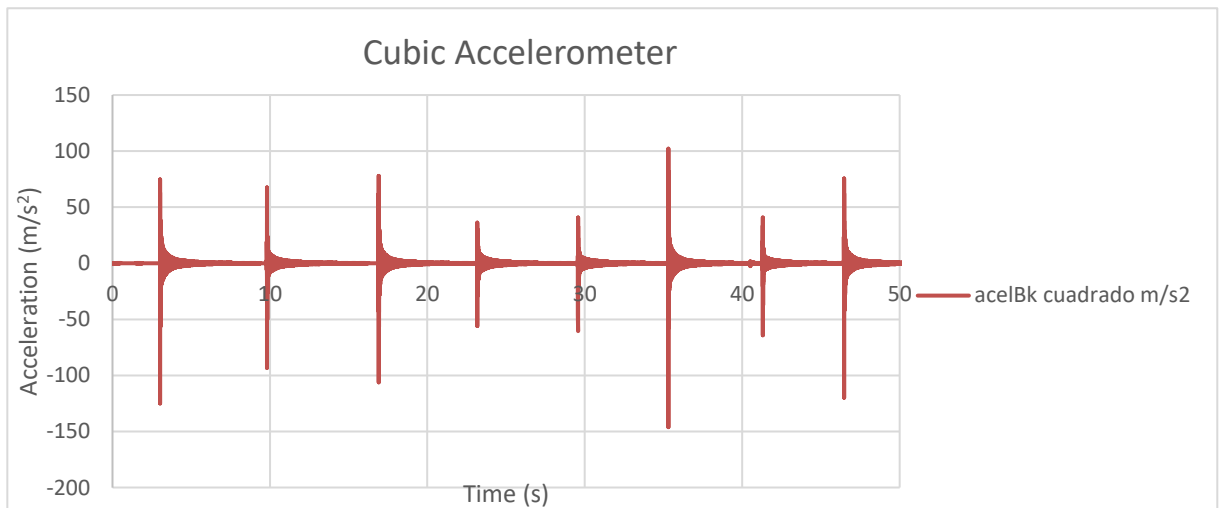


Figure 42 - Acceleration measured by Cubic Accelerometer as a function of time graph (Cantilever Beam)

The graph displays the acceleration output measured by the cubic accelerometer as a function of time. The accelerations were measured between 30 and 100 m/s^2 (Figure 42). It can be observed that the acceleration response follows a similar pattern to the input force, with each impact producing a corresponding peak in the acceleration signal.

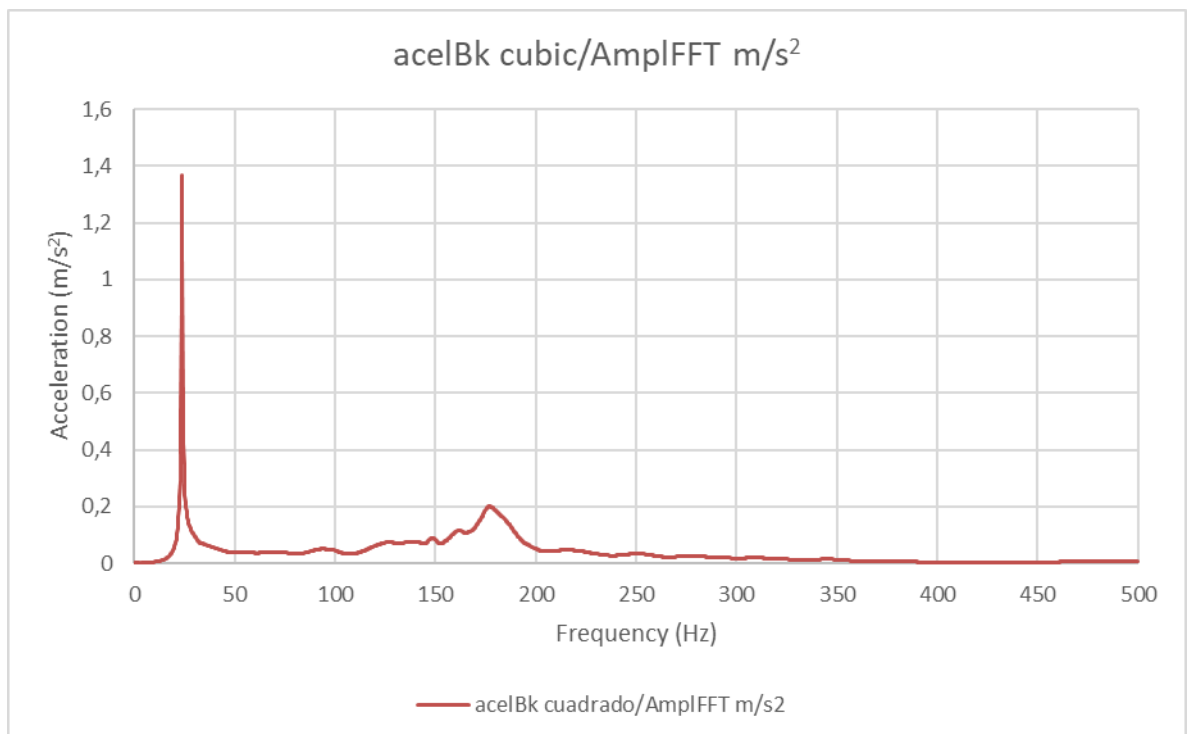


Figure 43 - Acceleration measured as a function of frequency graph (Cantilever beam)

The graph (Figure 43) shows the acceleration measured by a cubic accelerometer as a function of frequency, ranging from 0 Hz to 300 Hz. Three significant peaks are visible on this curve, one at 25 Hz; 147 Hz the other at 175 Hz.

The first peak at 25 Hz indicates that the structure of the system maybe has a natural frequency at which it will begin to vibrate significantly when subjected to an impact force.

c) The frequency response function and the coherence

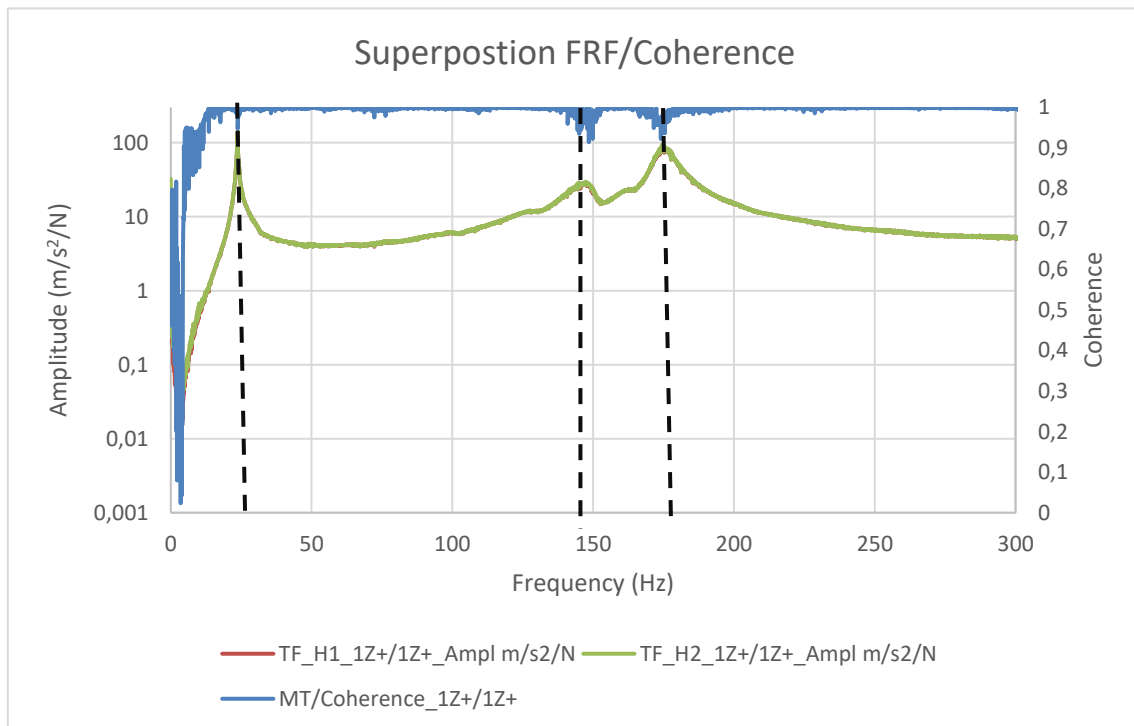


Figure 44 - Superposition FRF/Coherence (Cantilever Beam)

The magnitude of frequency response function (FRF) graph is used to characterize the system. In this graph we can see three distinct peaks located at 25 Hz, 147 Hz and 175 Hz respectively. These frequency peaks in the FRF graph correspond to the resonance frequencies of the system. Resonance occurs when the excitation frequency of the system matches one of its natural frequencies, causing a significant increase in the amplitude of the system response.

Resonance frequencies are very important because they can cause damage to the system and affect its performances.

We can compare the FRF and coherence curves. Indeed, the values can be taken into account according to whether the coherence is close to 1 for a given frequency.

We can see that for each resonance frequency (25; 147 and 175 Hz), the coherence is rather good (above 0.9), so we can take into account the measured resonance frequency.

It is important to make this comparison with the coherence curve at each measurement (Figure 44).

In conclusion of this initial modal test series, we were able to identify the resonance frequencies of the structure under investigation using the Dewesoft Sirius m data acquisition system. The choice of a good measurement setup in the software gave a good measurement of the resonance FRF in the 0 / 300 Hz range.

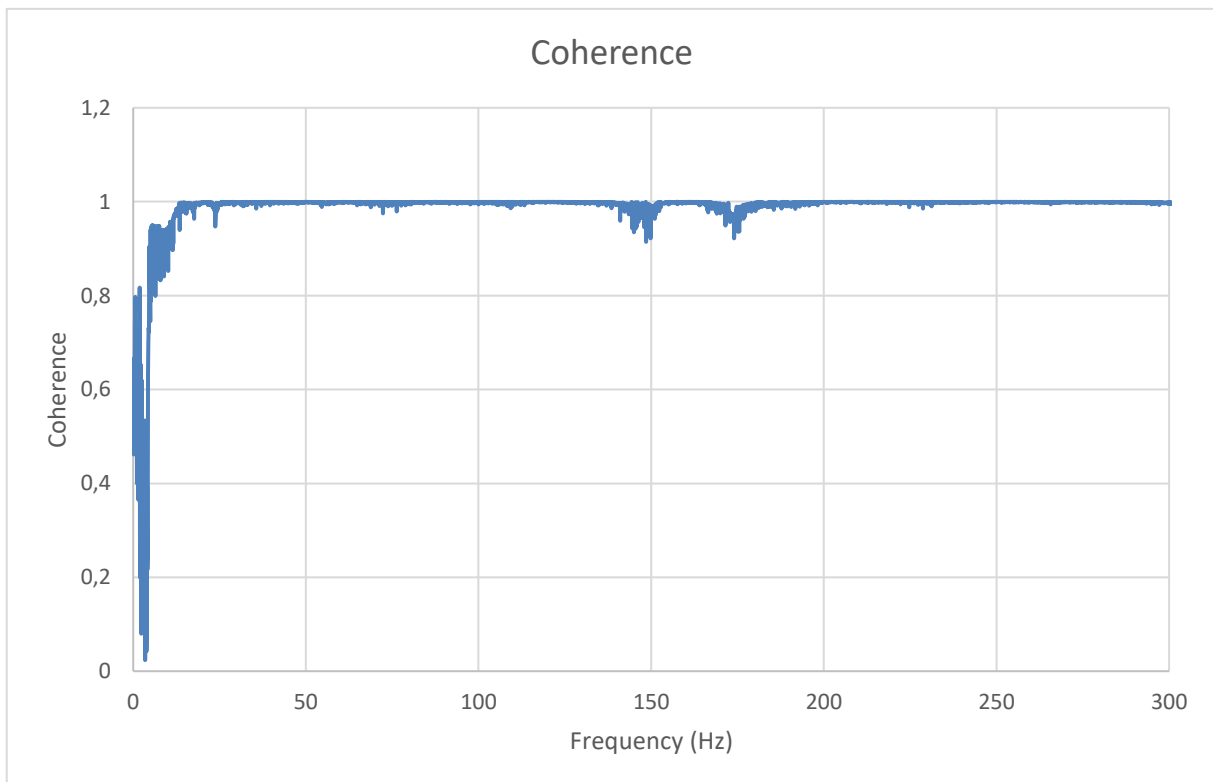


Figure 45 – Coherence graph (Cantilever Beam)

We can also analyse the coherence graph only (Figure 45). The graph shows the coherence of the measurements of the modal test, which is a measure of the correlation between the input signals (impact force) and the output signals (structure response). In other words, coherence indicates how much the structure response is related linearly to the applied impact force.

A coherence close to 1 indicates a strong correlation between the input and output signals, which is a positive indicator of accurate and reliable measurement. Conversely, a low or fluctuating coherence indicates a weak or unstable correlation between the input and output signals, which may be due to factors such as noise or interference.

In our case, examining the coherence plot of the modal test, we can observe that the coherence remains good. It is important to consider this coherence threshold when analyzing the results of our modal test.

The magnitude of the frequency response function (FRF) graph is an important tool for determining the dynamic response of a system to an excitation. However, it's also important to consider the degree of correlation or coherence between the inputs and outputs of the system. That's why it's essential to overlay the coherence graph with the FRF graph.

4.2. Acquisition on the large structure : The Slab

The aim of this acquisition is to obtain a measurement with a coherence as close to 1 as possible. We can then define the resonance frequencies for this structure. We will divide the work into two parts. We are going to carry out two measurements:

- First measurement: behaviour of the structure at low frequency
- Second measurement: behaviour of the structure at high frequency

The difference between these two measurements will therefore be the frequency range studied. For the low-frequency part, we will study the behaviour of the structure for frequencies ranging from 0 to 25 Hz. For the high-frequency part, we will study the behaviour of the structure for frequencies ranging from 25 to 300 Hz. The table below shows the characteristics of the two measurements. We are also going to set a more precise resolution for the low frequency because the range of data studied is smaller.

<i>Low-frequency measurement</i>	<i>High-frequency measurement</i>
<ul style="list-style-type: none">• Frequency range studied 0 to 25 Hz• Resolution: ~ 0.05 Hz	<ul style="list-style-type: none">• Frequency range studied 25 to 300 Hz• Resolution: ~ 0.5 Hz

How to calculate the resolution?

$$\Delta f = \frac{\text{Sample Rate}/2}{\text{Number of lines}}$$

The sample rate designates the frequency at which data points are recorded per second

The number of spectral lines is the number of points used to represent the frequency range in this spectral analysis. For example we have 2048 lines. This means that the frequency range of the spectrum is divided into 2048 intervals.

4.2.1. Low frequency measurement

We will present our results for the low-frequency measurement. To carry out the measurements, we're going to take into account what we saw during the tests on the cantilever beam, such as the reduction in background noise, for example.

For this measurement, there will be five hammer impacts at the point with coordinates (40;60). For this experiment, we have taken the example of one excitation point, but to carry out a modal test with greater precision, we need to take several excitation points at different locations on the slab. The next graph shows the distribution of impacts over time and the strength at which they were distributed.

a) Hammer input force as a function of time and frequency

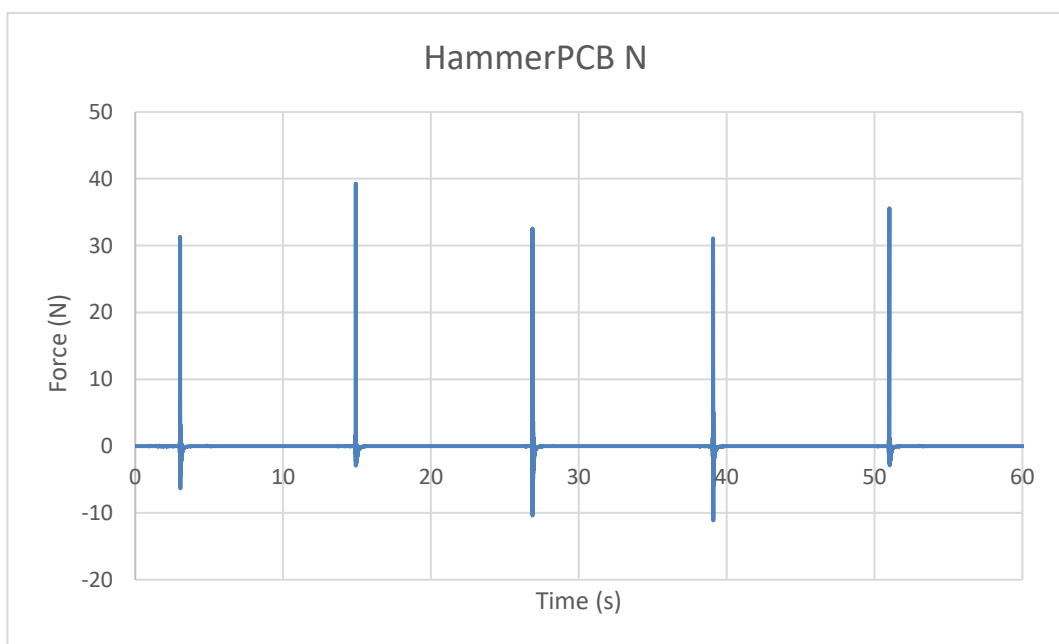


Figure 46 - Hammer input force as a function of time graph (Slab - Low frequency setup)

This graph (Figure 46) shows that each impact force is between 30 and 40 N, for this measurement we have set a minimum impact force of 20 N, which means that if a given impact using the hammer is less than 20 N. The software does not take this impact into account in the measurement.

The software also provides a graph (Figure 47) showing the impact force as a function of frequency. We can see that over this specific frequency range (0/25 Hz) the curve stabilises around a value, approximately 0.044N.

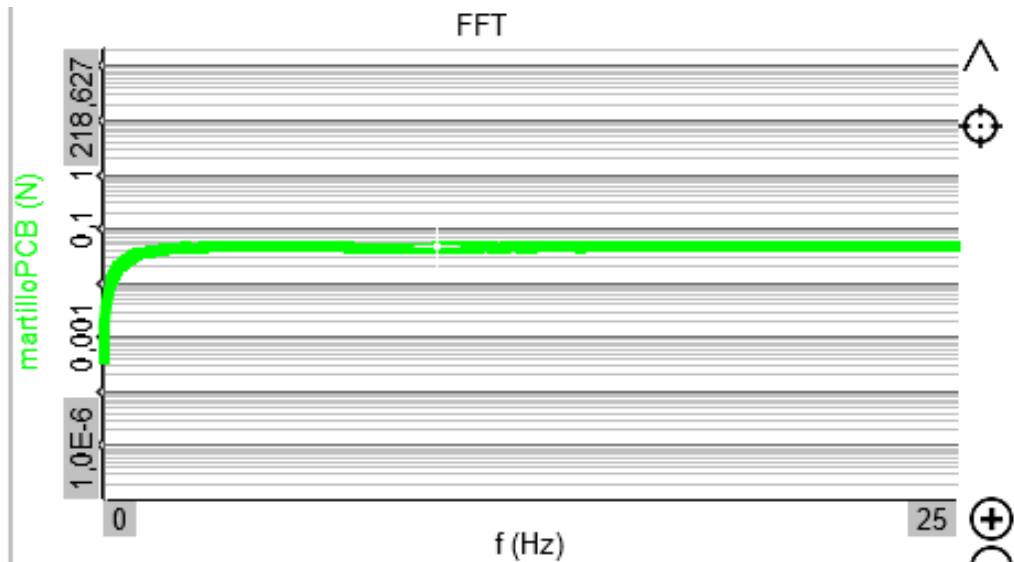


Figure 47 - Hammer input force as function of frequency graph (Slab - Low frequency setup)

b) Acceleration measured by accelerometers as a function of time and frequency

We can also look at the acceleration measured by the cubic accelerometer, which gives us the following graph (Figure 48).

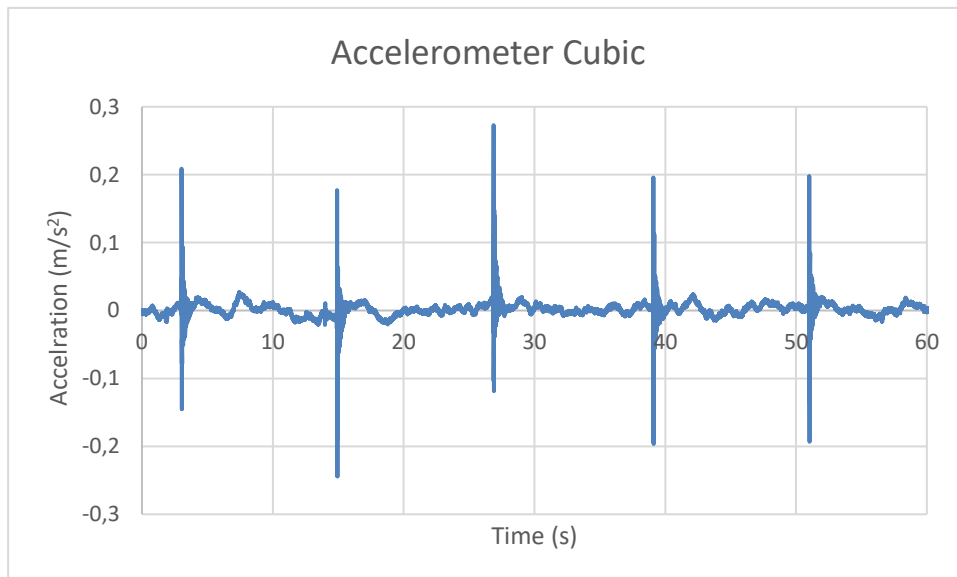


Figure 48 - Acceleration measured by Cubic Accelerometer as a function of time graph (Slab - Low frequency Setup)

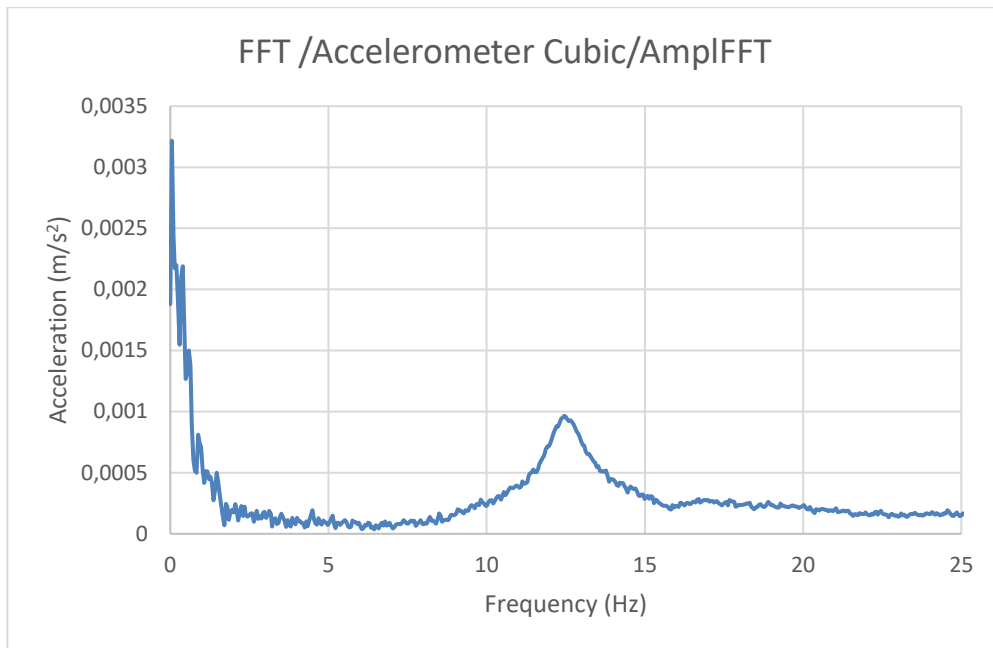


Figure 49 – Acceleration measured with Cubic accelerometer as a function of frequency graph (Slab – Low frequency Setup)

The accelerometer recorded accelerations of between 0.15 and 0.3 m/s² (Figure 48). We can already see on the Figure 49 an initial peak at a frequency of around 12.5 Hz, which maybe corresponds to a natural frequency in our structure. We'll analyze this frequency in more detail when we analyze the FRF.

To check the consistency of our measurement, we're also going to look at the acceleration measured by the hexagonal accelerometer.

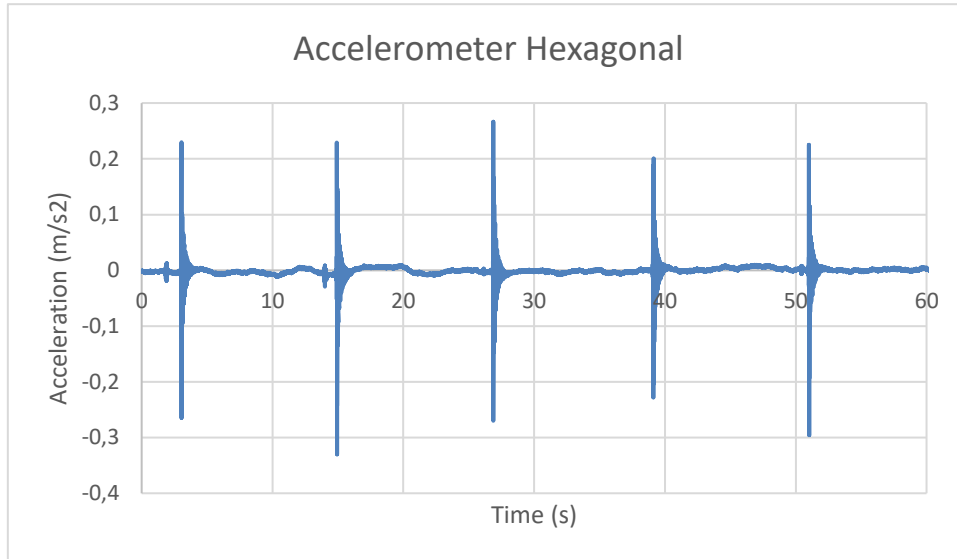


Figure 50 - Acceleration measured with Hexagonal Accelerometer as a function of time graph (Slab - Low frequency Setup)

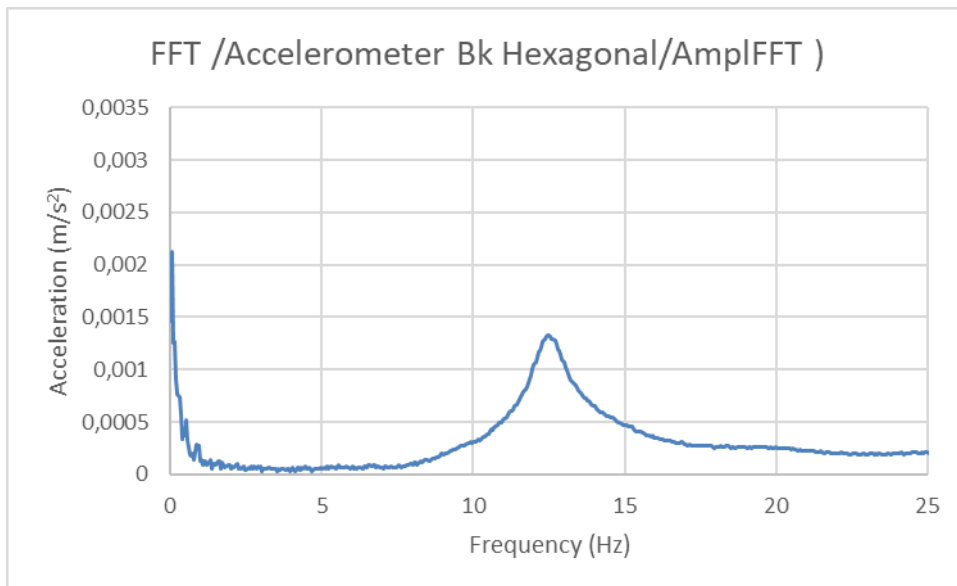


Figure 51 - Acceleration measured with Hexagonal Accelerometer as a function of frequency (Slab - Low frequency Setup)

The accelerometer recorded accelerations of between 0.2 and 0.3 m/s². (Figure 50). This graph showing the acceleration measured by the hexagonal accelerometer as a function of frequency confirms the potential presence of a natural

frequency of vibration at around 12.5 Hz (Figure 51). To study this frequency in more detail, we can use the FRF.

c) The frequency response function and the coherence

We can also export the data from the FRF function, which we will analyse.

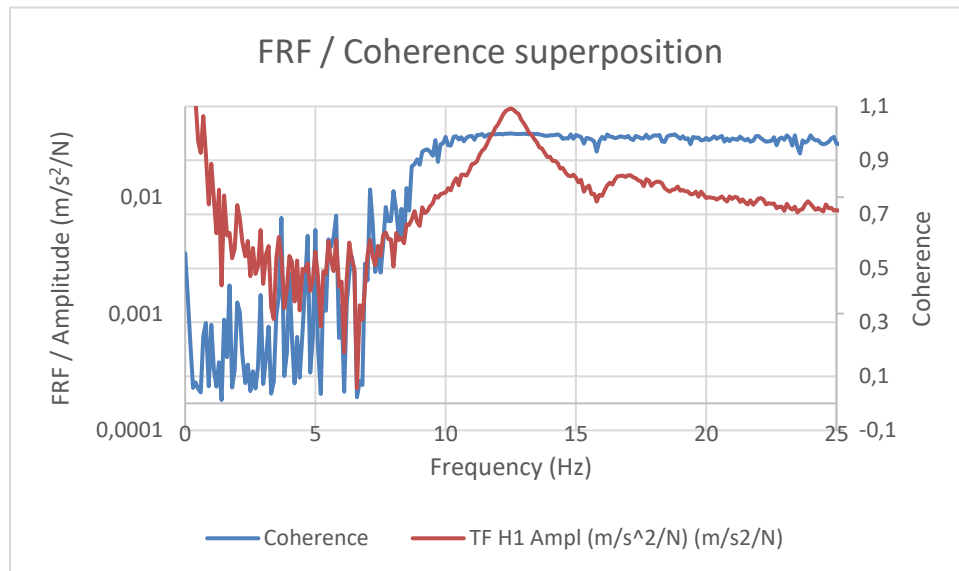


Figure 52 - Superposition FRF/Coherence (Slab - Low frequency Setup)

The values for frequencies from 0 to 10 Hz are not usable because the curve is not smooth, but they do not correspond to any peak. However, a peak can be seen at around 12.5 Hz, which seems to correspond to a resonance frequency. To get a clearer idea, you can look up the value of the frequency corresponding to this peak in the excel exported data table.

Frequency (Hz)	12,5
Coherence	1,00
TF H1 Ampl (m/s ² /N)	0,06
TF H2 Ampl (m/s ² /N)	0,06

Figure 53 - Exported datas at the peak frequency

We can now say that the frequency of 12.5 Hz is a resonance frequency for the structure. The graph (Figure 52) and the table (Figure 53) show that over the frequency range studied (between 10 and 15 Hz), the FRF function reaches a maximum peak at the frequency of 12.5 Hz.

As with the tests on the cantilever beam, we can now compare the FRF with the coherence. On the graph we have the red curve (FRF) and the blue curve

(coherence). This will help us to assess the reliability of our measurement. Remember that a coherence very close to 1 indicates a good match between the system input (excitation) and the output.

To do this, the FRF graph can be superposed on the coherence graph, showing the FRF and coherence values for each frequency.

On the Figure 52, we can see that coherence is not usable from 0 to 10 Hz. All this means is that we can't be certain about this frequency range. However, we must look at coherence at the FRF peak, which corresponds to a resonant frequency of 12.5 Hz. At this frequency, we can see that the coherence is close to 1, so we can take into account this first resonance frequency found.

You can also look in the Excel data table to see which exact coherence corresponds to a frequency of 12.5 Hz. The coherence is therefore about 1,00 (with two significant digits) at the frequency value of the FRF peak, which is a very favourable indicator for taking the results into account

We can summarise the results of our low-frequency measurement of the slab. We were interested in frequencies from 0 to 25 Hz. The results of our measurements show a curve from 0 to 10 Hz with a poor coherence. However, the FRF clearly shows a resonance frequency of 12.5 Hz with a coherence 1. The first resonant frequency at 12.5 Hz indicates the frequency at which the slab is most likely to vibrate significantly in its lowest mode.

In this case, the first resonance frequency of 12.5 Hz means that the slab vibrates mainly at this frequency when excited. This may be due to a variety of factors, such as the stiffness and mass of the slab, as well as the boundary conditions and supports on which it rests.

4.2.2. High frequency measurement

In this section, we're going to look at a measurement that covers a wider range of frequencies, so that we can determine what other frequencies are relevant to the slab. We're going to measure frequencies from 0 to 300 Hz. We're going to do this measurement under the same conditions as the low-frequency measurement. As a reminder, we're going to change the resolution parameter, which was around 0.05 Hz for the low frequency, to 0.5 Hz. The precision of the results will therefore be lower than for the previous measurement, but we'll be able to study more data.

To carry out this test in the same conditions as before, we are going to place ourselves in the same place and apply the same measurement methodology, i.e. 5 hammer impacts at point of coordinates (40;60).

a) Hammer input force as a function of time and frequency

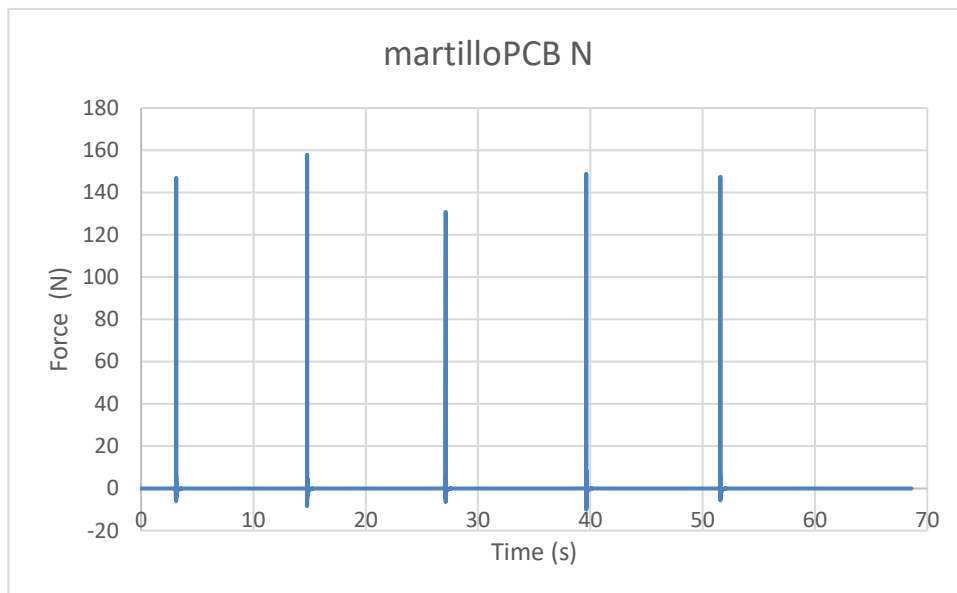


Figure 54 - Hammer input force as a function of time graph (Slab - Low frequency setup)

Note (Figure 54) that the excitation force used for this measurement is greater than for the previous measurement. This time it is between 120 and 160N.

And here is the graph showing hammer impact as a function of frequency

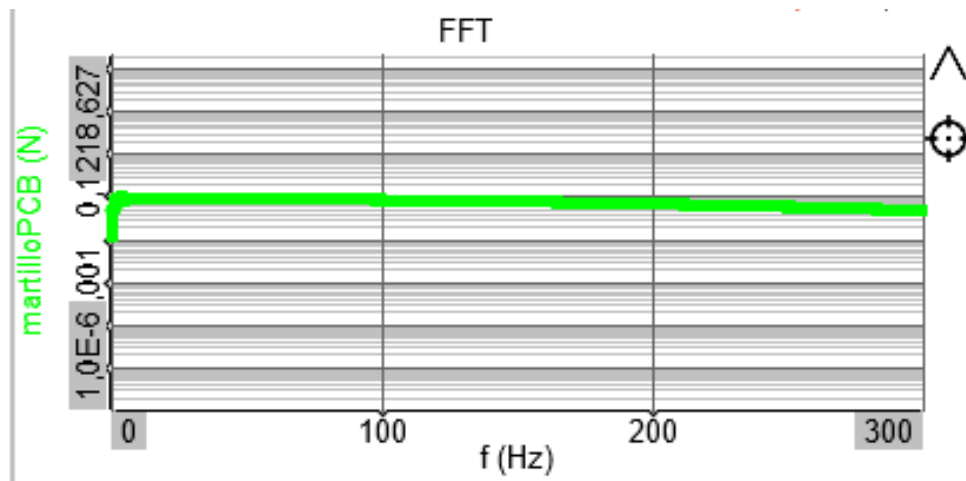


Figure 55 - Hammer input force as function of frequency graph (Slab - High frequency setup)

We can see that the curve is stabilised around the value 0.1N, we can also see that the curve decreases from 150 Hz (Figure 55).

As seen in the previous measurements, we can analyze the acceleration measured by the accelerometers as a function of frequency to get an idea of the potential natural frequencies that can be found in this high-frequency measurement.

b) Acceleration measured as a function of time and frequency

Let's start with the acceleration measured by the cubic accelerometer.

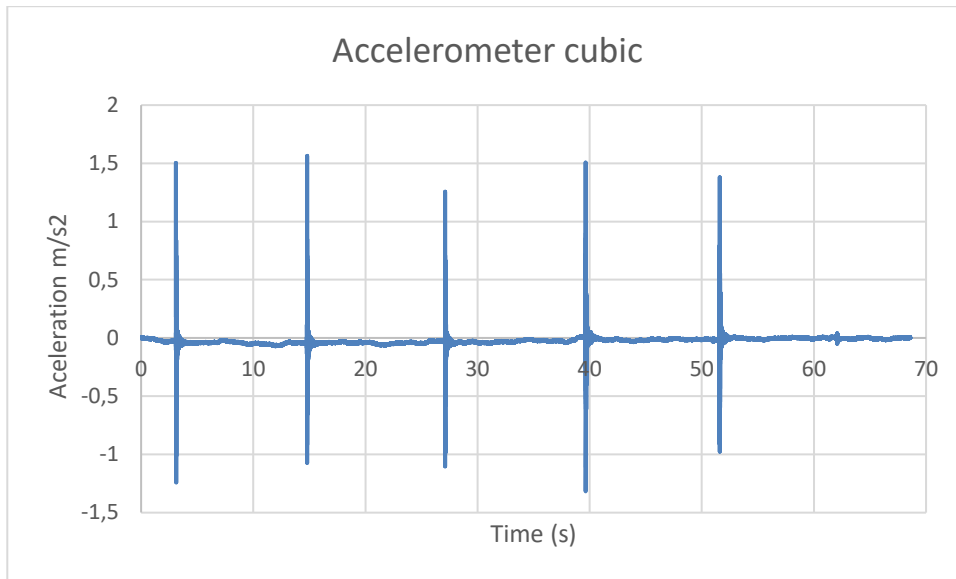


Figure 56 - Acceleration measured with Cubic Accelerometer as a function of time (Slab - High frequency setup)

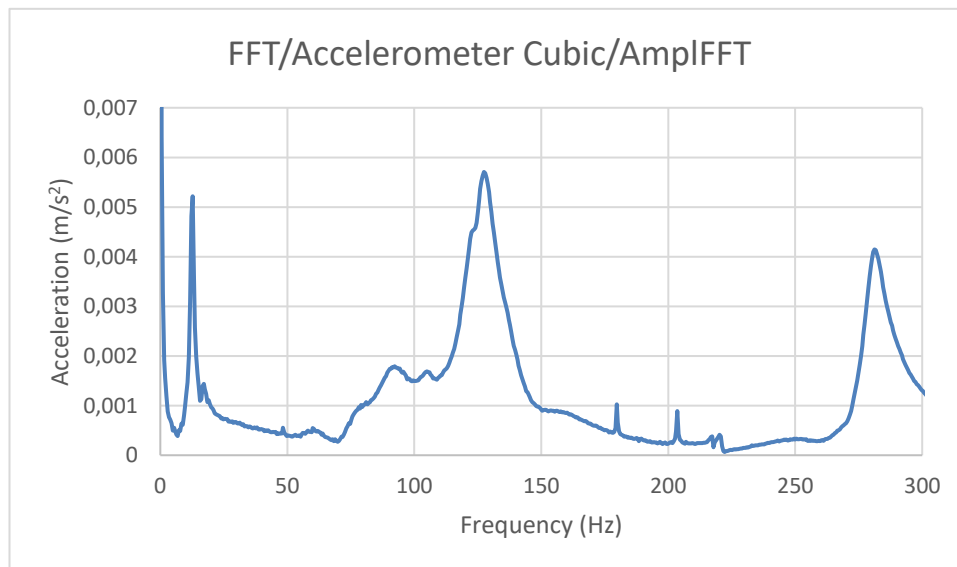


Figure 57 - Acceleration measured with Cubic Accelerometer as a function of time (Slab - High frequency setup)

The graph shows the acceleration measured between 1.25 and 1.6 m/s² (Figure 56). The frequency associated with each peak can be read on the graphic (Figure 57). The following frequencies can be read approximately: 12 Hz; 128 Hz; 280 Hz.

Let's take a look at the results obtained by the hexagonal accelerometer.

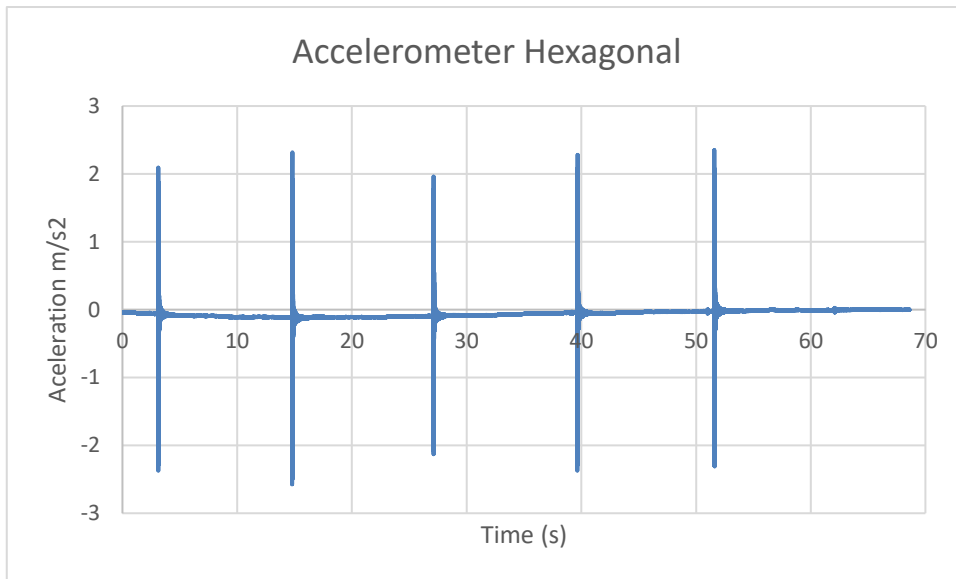


Figure 59 - Acceleration measured with Hexagonal Accelerometer as a function of time (Slab - High frequency setup)

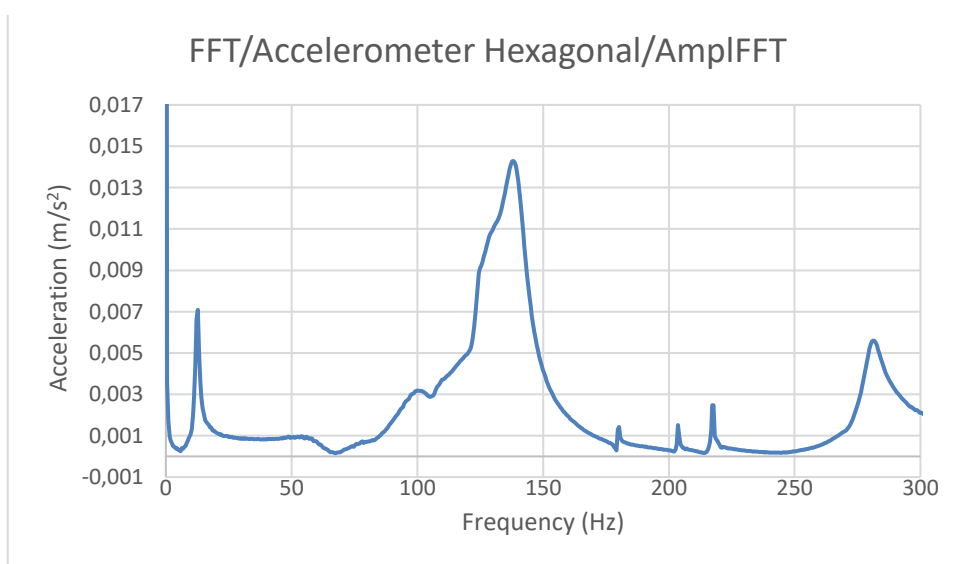


Figure 58 - Acceleration measured with Hexagonal Accelerometer as a function of frequency (Slab - High frequency setup)

The graph shows the acceleration measured between 2 and 2.5 m/s² (Figure 59). The frequency values associated with each peak are similar to the results of the cubic accelerometer. There is, however, a slight difference in the second peak, which here corresponds to a frequency of 140 Hz compared with 128 Hz previously (Figure 58).

c) *The frequency response function*

We will also analyse the FRF (Figure 60) shown in the following graph, based on DEWesoft data exported to excel.

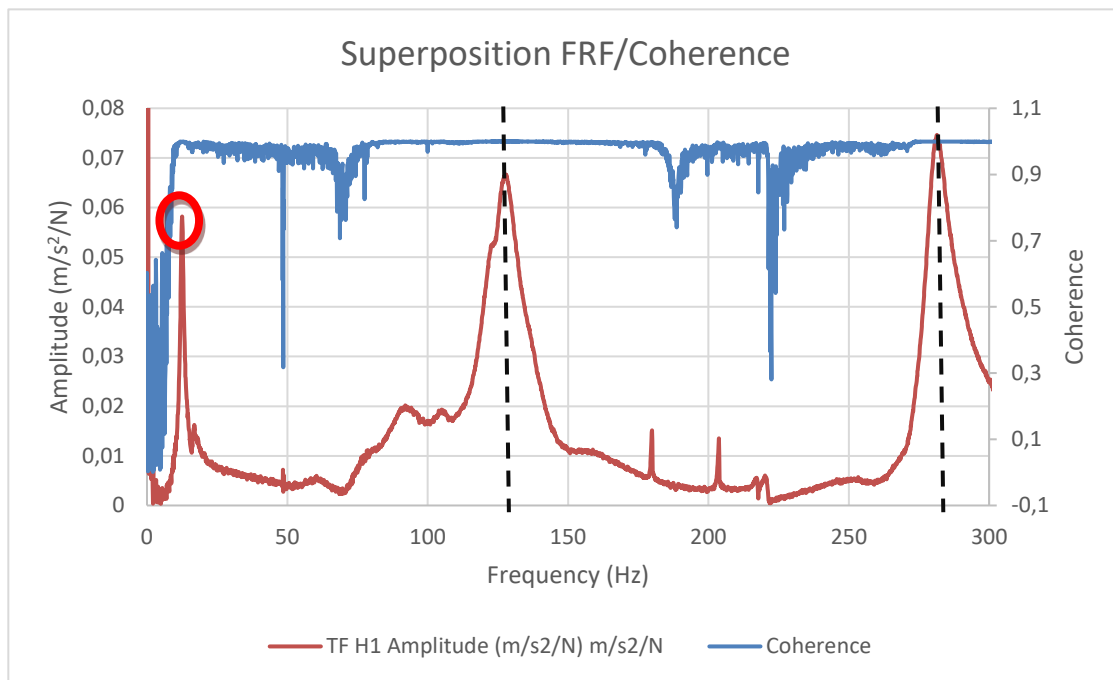


Figure 60 - Superposition FRF/Coherence (Slab - High frequency setup)

1) **First Peak**

First of all, we can concentrate on the first peak (circled in red in the figure above), which should be similar to the resonance frequency found during the low-frequency measurement. We can study this frequency to check that there are no inconsistencies between the two measurements. To do this, we are going to study the frequential value of the first peak using the Excel data table.

Frequency (Hz)	12,50
Coherence	1,00
TF H1 Amplitude (m/s ² /N)	0,06
TF H2 Amplitude (m/s ² /N)	0,06

Figure 61 - Exported datas at the first frequency peak (Slab - High frequency setup)

This measurement confirms the presence of a peak at 12.5 Hz. Both graphically and in the table (Figure 61), we can see that this peak is present. There is also a good coherence of 1 at this frequency. This measurement confirms the results of the low-frequency test.

2) Second Peak

We can now study the second frequency peak, as the wide frequency range studied means we can analyze the next peaks.

The second peak of the FRF corresponds to the structure's second natural mode of vibration. Eigenmodes are the fundamental forms of vibration of the structure, with specific frequencies and associated amplitudes. The second eigenmode is generally the vibration mode following the fundamental mode, and is characterized by a higher frequency.

By reading the graph, we can see that the frequency corresponding to this peak is around 127 Hz (Figure 62).

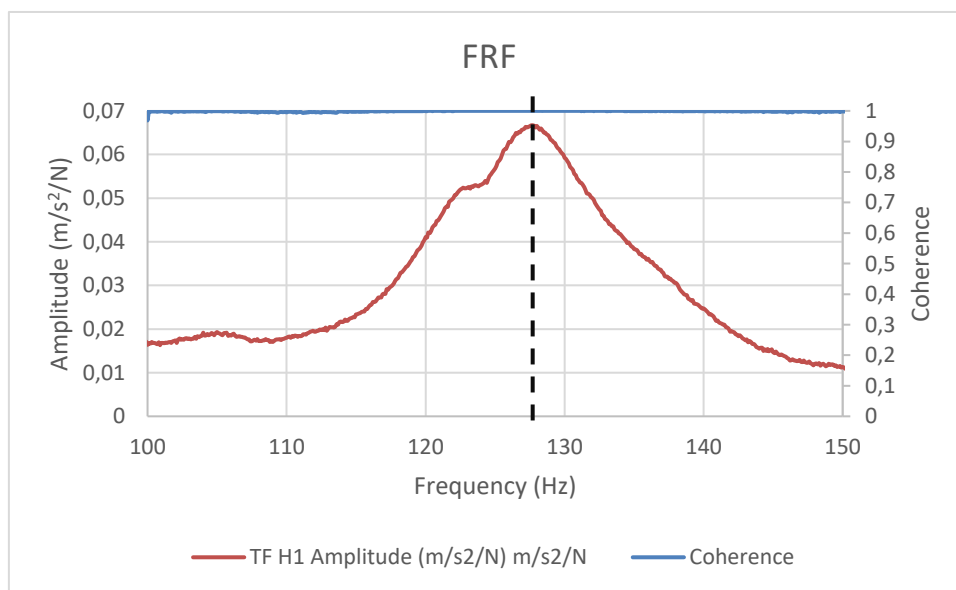


Figure 62 - FRF and Coherence at the second frequency peak

After this graphical reading, we'll look at the table (Figure 63) to see exactly what this peak corresponds to in the Excel table in the same way as above.

Frequency (Hz)	127,60
Coherence	1,00
TF H1 Amplitude (m/s ² /N)	0,07
TF H2 Amplitude (m/s ² /N)	0,07

Figure 63 - Exported datas at the second frequency peak

We can see that the function peaks at a frequency of 127.6 Hz. There is also good coherence of around 1,00 in the measurement, making it reliable. Our second frequency value is therefore 127.6 Hz.

3) Third Peak

The graph also shows a third peak, which we will analyse below. Graphically, we can already approximate the resonance frequency associated with this peak. This frequency is around 282 Hz (Figure 64).

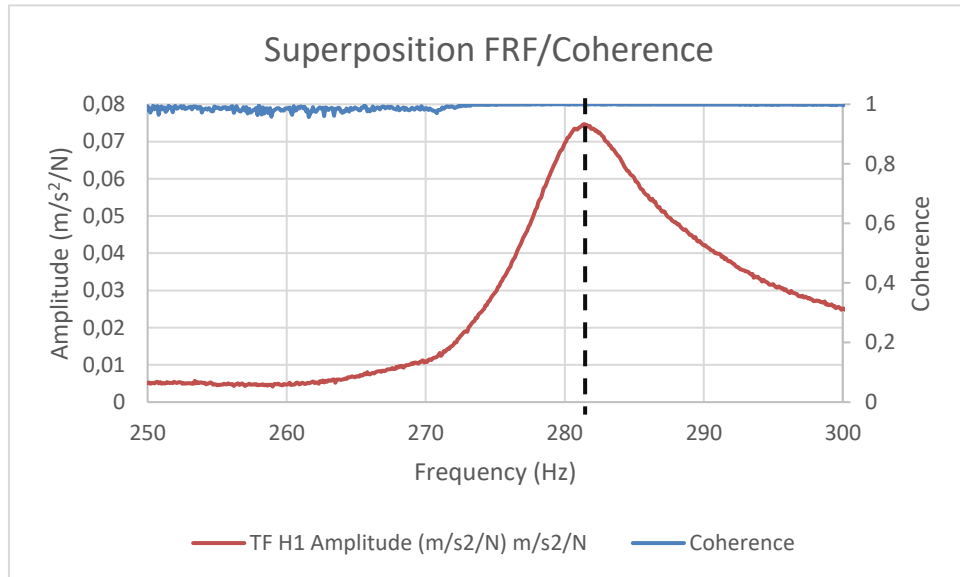


Figure 64 - FRF and Coherence at the third frequency peak

Let's take a closer look at this result again by reading the data table (Figure 65).

Frequency (Hz)	282,5
Coherence	1,00
TF H1 Amplitude (m/s ² /N)	0,07
TF H2 Amplitude (m/s ² /N)	0,07

Figure 65 - Exported datas at the third frequency peak

We can then see that the peak is reached at a frequency of 282.5 Hz. This corresponds to a third mode of vibration, i.e. a third frequency at which the vibration of this structure is amplified.

4) The Coherence

As with the previous measure, here we can look at the superposition of coherence and FRF to see for which values the measure can be taken into account.

The graph (Figure 60) above shows that coherence is not necessarily good for all frequency values. For example, coherence deteriorates between 47 and 82 Hz and between 180 and 250 Hz. However, we are not interested in these two intervals because they do not correspond to FRF peaks. For each FRF peak, we can see that the coherence is very close to 1 (around 0.99 at each peak). The fall in the value of coherence can be due to several factors, in particular background noise. Although the tests were carried out in a quiet room, this room is not completely isolated and can let background noise show through.

We can now summarise our two measurements at low and high frequencies (Figure 66).

	Measurements on slab	
	Low frequency	High frequency
<i>Frequencies studied (Hz)</i>	[0;25]	[0;300]
<i>Impact force (N)</i>	Between 30 and 60	Between 140 and 160
<i>Resolution (Hz)</i>	0,05	0,5
<i>Resonance Frequency Found (Hz)</i>	12,5	12,5 / 127,6 / 282,5

	Measurements on slab			
	Low Frequency	High Frequency		
<i>Resonance Frequency Found (Hz)</i>	12,5	12,5	127,6	282,5
<i>Coherence</i>	1,00	1,00	1,00	1,00

Figure 66 - Key measurement information

The measurements carried out enabled us to determine the resonance frequencies with a good degree of accuracy. Keeping two significant figures, we have a coherence of 1 at each FRF peak.

5. Conclusion and future lines

The results section is divided into two sub-sections: cantilever beam and slab. For each of these sub-sections, we have obtained six interesting indicators for determining the natural vibration frequencies of these two structures. For these two structures we used the same method of taking measurements, trying to take into account certain aspects that could be improved in the second measurement.

The results obtained for the cantilever beam can be used. They have enabled us to define 3 resonance frequencies. This first measurement was important in order to set up the software properly for the second measurement. Several important things were noticed during this measurement. Firstly, it is preferable to leave a fairly long time interval between hammer impacts, as the software takes a certain amount of time to receive the information. Secondly, it is very important to reduce the background noise as much as possible to optimise the consistency of the test.

For the cantilever beam test, the Y axis of the FRF graph is on a logarithmic scale, as this makes for simpler analysis and more visible peaks. This clearly shows the three peaks corresponding to the natural frequencies. It was wiser to use the FRF rather than the graph of acceleration as a function of frequency, as the second peak, which corresponds to the second natural frequency, is not very clearly visible on the graph of acceleration as a function of frequency. It is therefore important to take several graphs into account when studying a natural frequency.

However, it should be noted that during the first test we obtained a graph showing the impact force as a function of frequency, which is not usable. In theory, the curve in this graph stabilises quickly on a value and remains constant (like those obtained during the slab measurement).

For the slab measurements, it was therefore decided to separate the study into two measurements: high and low frequency. This choice provides greater accuracy for the first peak, which corresponds to the first resonance frequency. In addition, it allows us to compare the result of the first resonance frequency found with the 'low frequency' setup with the result of the same peak found with the 'high frequency' setup.

For each test, we were able to study the six graphs, looking in particular at the FRFs in order to identify the resonance frequencies. The most important part of the measurement is always to compare the FRF function with coherence. Coherence is the indicator that shows whether there is a strong correlation between the input and the output of the system, which in turn shows whether the measurement is accurate and reliable.

In our case, each FRF peak corresponding to a resonance frequency has a coherence of around 0.99, which is very close to 1 (the optimum value), so we can take the results obtained into account.

The presence of these resonance peaks can have consequences. When the structure is excited at one of its resonant frequencies, it tends to amplify vibrations at that frequency. This means that if external forces or vibrations are applied to the structure at one of these frequencies, the resulting vibrations will be amplified. This can lead to significant deformation or an accumulated dynamic response of the structure at these specific frequencies. It is important to consider these resonant frequencies when designing the structure and to ensure that they do not coincide with potential sources of excitation.

For future measurements, there are several aspects to take into account. The setup can be improved by adding accelerometers at various other points on the structure, which would give a more reliable response by comparing the responses of the different accelerometers. We used a single excitation point for our measurements. To get a more accurate idea of the modal characteristics of a structure, we would need to study several excitation points on different parts of the structure. In addition, we can gain in accuracy by reducing external interaction with the system as much as possible.

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List of figures

Figure 1 - Vibration modes [2]	6
Figure 2 - Modal test by impact hammer.....	6
Figure 3 - Modal test system [3]	7
Figure 4 - Example of Frequency Response Function [4].....	8
Figure 5 - Cantilever beam setup	10
Figure 6 - Slab dimensions.....	10
Figure 7 - Slab on wooden structure and placement of accelerometers.....	11
Figure 8 - Accelerometer coordinates on the slab setup	12
Figure 9 - Slab dimensions and supports [5]	14
Figure 10 - Slab installation	14
Figure 11 – Hammer used for modal tests.....	16
Figure 12 – Hammer components used for modal tests [3]	16
Figure 13 - Frequency Range / Pulse Duration / Force Range of the hammer depending on the tip [6].....	17
Figure 14 - IEPE / Voltage in Dewesoft Window	18
Figure 15 - Cantilever Beam Setup.....	19
Figure 16 - Technical drawing Hexagonal accelerometer [7].....	20
Figure 17 - Dynamic Characteristics of Hexagonal Accelerometer [7].....	21
Figure 18 - Technical Drawing Hexagonal Accelerometer [8].....	21
Figure 19 - Dynamic Characteristics of Cubic Accelerometer [8].....	22
Figure 20 - Dewesoft Sirius Box.....	23
Figure 21 – Measure and Analyse	24
Figure 22 - Analog In section	24
Figure 23 - Cantilever Beam System	25
Figure 24 - Channels configuration window	25
Figure 25 - Dynamic acquisition rate.....	26
Figure 26 - Modal Test Window	26
Figure 27 - Modal Test/Excitation Window.....	27
Figure 28 - Warning message configuration	27
Figure 29 - Trigger Level Parameters [9]	28
Figure 30 – Start measurements	28
Figure 31 - Analysis Window	29
Figure 32 - Widgets	29
Figure 33 - Graphs or tools to display on the dashboard.....	30
Figure 34 - Example of a dashboard obtained during a measurement.....	30
Figure 35 - Exporting Datas Option	31
Figure 36 - Parameters which appear in the excel sheet.....	31
Figure 37 – Impact and Response [3].....	33
Figure 38 - Impact Counter	33
Figure 39 - Impact Zone	35
Figure 40 - Hammer input force as a function of time graph (Cantilever Beam)	36
Figure 41 - Hammer input as function of frequency graph (Cantilever beam).....	36
Figure 42 - Acceleration measured by Cubic Accelerometer as a function of time graph (Cantilever Beam).....	37

Figure 43 - Acceleration measured as a function of frequency graph (Cantilever beam)	37
Figure 44 - Superposition FRF/Coherence (Cantilever Beam).....	38
Figure 45 – Coherence graph (Cantilever Beam)	39
Figure 46 - Hammer input force as a function of time graph (Slab - Low frequency setup)	42
Figure 47 - Hammer input force as function of frequency graph (Slab - Low frequency setup)	43
Figure 48 -Acceleration measured by Cubic Accelerometer as a function of time graph (Slab - Low frequency Setup)	43
Figure 49 – Acceleration measured with Cubic accelerometer as a function of frequency graph (Slab – Low frequency Setup).....	44
Figure 50 - Acceleration measured with Hexagonal Accelerometer as a function of time graph (Slab - Low frequency Setup)	45
Figure 51 - Acceleration measured with Hexagonal Accelerometer as a function of frequency (Slab - Low frequency Setup)	45
Figure 52 - Superposition FRF/Coherence (Slab - Low frequency Setup)	46
Figure 53 - Exported datas at the peak frequency.....	46
Figure 54 - Hammer input force as a function of time graph (Slab - Low frequency setup)	48
Figure 55 - Hammer input force as function of frequency graph (Slab - High frequency setup)	49
Figure 56 - Acceleration measured with Cubic Accelerometer as a function of time (Slab - High frequency setup)	50
Figure 57 - Acceleration measured with Cubic Accelerometer as a function of time (Slab - High frequency setup)	50
Figure 58 - Acceleration measured with Hexagonal Accelerometer as a function of frequency (Slab - High frequency setup)	51
Figure 59 - Acceleration measured with Hexagonal Accelerometer as a function of time (Slab - High frequency setup)	51
Figure 60 - Superposition FRF/Coherence (Slab - High frequency setup).....	52
Figure 61 - Exported datas at the first frequency peak (Slab - High frequency setup).....	52
Figure 62 - FRF and Coherence at the second frequency peak.....	53
Figure 63 - Exported datas at the second frequency peak	53
Figure 64 - FRF and Coherence at the third frequency peak	54
Figure 65 - Exported datas at the third frequency peak.....	54
Figure 66 - Key measurement information	56