Ministério das Obras Públicas, Transportes e Comunicações

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

DEPARTAMENTO DE ESTRUTURAS

Núcleo de Engenharia Sísmica e Dinâmica de Estruturas

Proc. 0305/11/16238

LNEC-SPA, SIGNAL PROCESSING AND ANALYSIS TOOLS FOR CIVIL ENGINEERS

Version 1.0 – Build 12

RELATÓRIO ????/2007 - NESDE

Lisboa, Fevereiro de 2007

Trabalho realizado no âmbito do processo:

Metodologias e Técnicas em Ensaios Sísmicos Laboratoriais

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1 INTRODUCTION

This report describes the software tool named *LNEC-SPA, Signal Processing and Analysis Tools for Civil Engineers v1.0* (build 12), developed exclusively for research at the *Earthquake Engineering and Structural Dynamics Division* (NESDE) – *Laboratório Nacional de Engenharia Civil* (LNEC).

The motivation for developing this software was to improve the efficiency and the analysis capabilities for the experimental research developed at LNEC-NESDE, one of the Europeans' Large Test Facilities, that regularly performs shaking table experiments and other types of tests (e.g. cyclic tests on joints and in-situ system identification tests).

Generically, this software is a group of civil engineering research tools that can be categorized as follows: i) time history generation; ii) data acquisition and output; iii) system control; iv) signal processing; v) engineering tools; vi) strong ground motion analysis; vii) visualization and viii) educational.

The goal of this report is not to be a "User's Guide", which explains how the calculations are made and presents the relevant theoretical issues, but instead, is meant more as a "Getting Started", referencing the software's features and introducing the graphical interfaces. For more detailed information on the algorithms and analytical tools consult [Bendat et al. 1986; Carvalhal et al. 1989; NI 2003].

The next section is dedicated to the general characteristics of the software, focusing the global architecture, some aspects about the licence, file system and system requirements. Section 3 describes in detail the software features and the last section is dedicated to the future developments followed by the list of references. To make the test more readable the graphical interfaces are listed and described in Annex A, and in Annex B is presented an example of a strong ground motion report created by the software.

2 GENERAL CHARACTERISTICS

2.1 Global Architecture

The software is implemented in the *LabVIEW* platform [NI 2004] using the native signal analysis toolkits and many new user developed routines. To compute the more intensive calculations some functions were compiled into dynamic link libraries (dlls) using a

Fortran compiler. The program is compiled into an executable version with a setup package that deploys all the necessary run-time files, allowing the software execution to be independent from *LabVIEW*.

The code is divided into modules to separate different tasks or research topics, and also, to make the code more efficient. All the modules use a common memory and file management interface and are loaded and unloaded dynamically during execution. The modules available are presented in the global scheme of the software architecture presented in Figure 2.1. The Start, Main and Functions Manager are auxiliary modules used to user/licence validation, time histories and functions management, respectively.

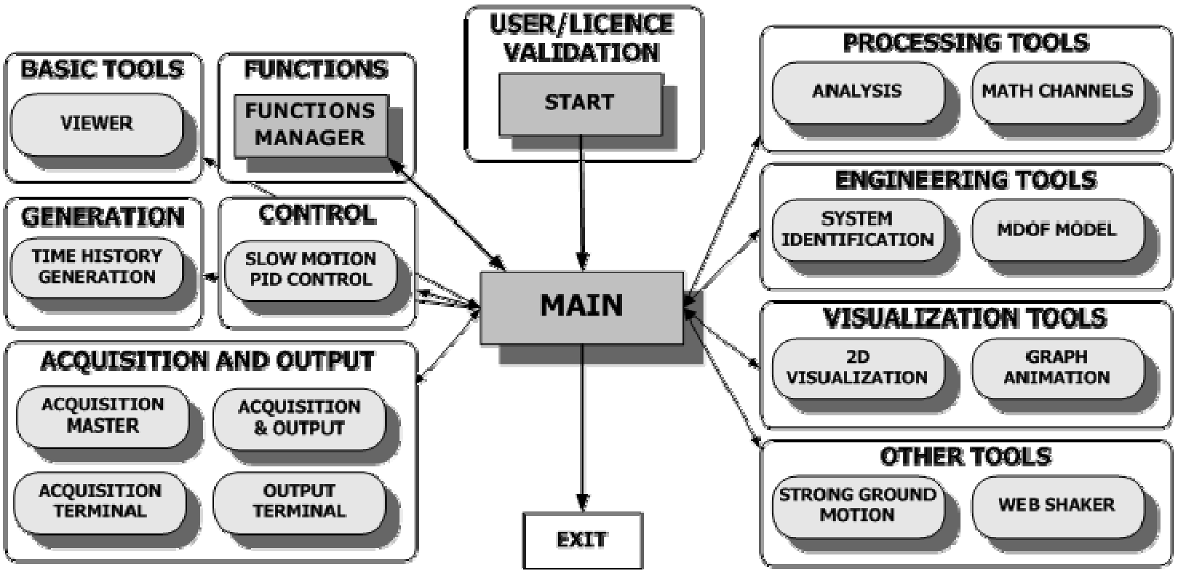


Figure 2.1: Global software architecture.

- File and Buffer memory areas

The software uses 2 different memory areas: *File* and *Buffer*. File is used to perform load and save operations into the supported files types. The buffer area holds the data that is used for calculations. This architecture is implemented for time histories and also for functions. Switching data between these two memory areas can be done in the *Main Module*, for time histories, and in the *Functions Manager Module* for functions.

- Commands queue

Some modules (e.g. *Analysis Module* and *Time History Generation Module*) implement a command queue to process the calculations.

The command queue controls which commands are processed and by what order. Different command sequences can produce results completely different, so this issue is relevant. Buttons to add, remove, and reorder the commands, are available in those modules to easily edit the queue.

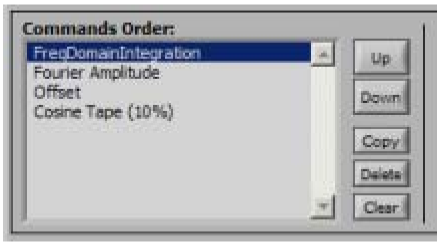


Figure 2.2: Command queue.

- Exporting data

The software was developed with a great concern on practical aspects. Tools for exporting data, numerically or using images of graphs/charts, are available on most modules, making this task extremely easy. Some modules also make automatic reports (e.g. *Math Channels Module*, *Strong Ground Motion Module*).

- Units

Some modules compute calculations that are unit dependent (e.g. the SGM parameters in the *Strong Ground Motion Module*), so time histories have to be defined with coherent units (accelerations time histories in acceleration units, etc). The *Analysis Module* implements an automatic unit conversion procedure (e.g. conversion of the results form the double integration of an acceleration time history expressed in “mg” into “mm”). To use this feature the same cautions about coherent units have to be taken in consideration.

- Automatic settings saving

All the modules save the graphical interface settings into files (*.ini), so the next time the module runs those settings are retrieved.

2.2 Licence

The software requires a licence to operate. This requirement was implemented only for two reasons: i) protect intellectual property; and ii) stimulate the continuous software update. The licence is completely free of charge because the software is not intended for commercial reasons, only research.

The licence mechanism is materialized in a file ("licence.lic") that controls several permissions to the global software or specifically to individual modules. If the software encounters an invalid or expired licence file, it will return an error in the *Start Module*.

To get the software and a valid the licence, you must a read and agree with the *Licence Agreement* (available at http://www-ext.lnec.pt/LNEC/DE/NESDE/software_eng.html) and contact LNEC. If you do not agree with the terms of the licence agreement you can not use the software and must remove it from your computer.

2.3 File System

The software supports several file types for loading/saving time-histories, functions, graphs and other configurations.

2.3.1 Time Histories

1. LNEC's Test File Format (*.ltf)

This is the recommended file type to store time histories because it can take advantage of most software features. This file format supports time histories with different trigger time, time step and number of samples. Read and save operations are supported. The data of each channel can be presented in raw units or in engineering units (EGU) has indicated in the "Data Format" field.

Header - 4 string fields (Name, Series, Date, Observations);
For each time history / channel:
    Name;
    Unit (e.g. mg, m, kN, Volts, etc);
    Type (e.g. Acceleration, Displacement, etc);
    Info - any information;
    Trigger time - 128 bits absolute time;
    Time step;
    Time history data - stored with 16 bits of precision (65536 levels);
    Channel ID String - String used to identify the hardware channel of the acquisition;
    Data format - raw units (e.g. Volts) or engineering units (EGU);
    Scale Factor - between raw units and engineering units, [EGU/raw units];
    Offset - between raw units and engineering units, expressed in raw units (e.g. V).

Table 2.1: Data stored in the LTF file format.

2. LNEC's Binary File Format (*.bin)

This file format was intensively used in LNEC's seismic tests and is fully supported. It does not support time histories with different trigger time, time step and number of samples. Read and save operations are supported. The data of each channel is always transformed and presented in engineering units EGU. The data is stored in 16 bits where 32768 represents +10V and -32767 represents -10V, so changing the scale factor and offset to 1 and 0, respectively, the raw units are retrieved (e.g. Volts).

Scan rate [Hz];
Number of samples;
For each time history / channel:
    Name;
    Time history data - stored with 16 bits of precision (65536 levels).

Table 2.2: Data stored in the BIN file format.

3. ASCII column ordered text files (*.txt)

Any ASCII file with the time-histories ordered by column. Read and save operations are supported.

4. GEOSIG's Seismic Recorders files (*.gsr)

GEOSIG's Seismic Recorders, 12, 16 and 18 bits GSR files. Only read operations are supported. The processed data should be saved in the LTF format (small loss of precision in the 18 bit format). The software retrieves the following information from the GSR files:

For each time history / channel:
    Instrument name;
    Trigger date;
    Trigger time;
    Number of samples;
    Sampling frequency [Hz];
    Resolution [mg];
    Time history data.

Table 2.3: Data retrieved from the GSR file format.

2.3.2 Functions

1. LNEC's Function File (*.lff)

The LFF format is a binary file used to store functions and can only be read or saved in the *Functions Manager Module*. Because the number of points in the functions is usually small (less than 100), there is no need to save them using a reduced precision format, so this file type stores the values in double precision (64 bits).

2. ASCII column ordered text files (*.txt)

Any ASCII file with the functions (x values and y values) ordered in columns. Read and save operations are supported.

For each function:
    Name;
    Info;
    XType (e.g. Frequency);
    XUnit (e.g. Hz);
    YType (e.g. Phase);
    YUnit (e.g. rad);
    XValues, stored in double precision (64 bits);
    YValues, stored in double precision (64 bits).

Table 2.4: Data stored in the LFF file format.

2.3.3 Graphs

3. Wavefrom Graph File (*.wfg)

This is a binary file used to store all relevant data and formats from waveform graphs. This file type can only be loaded or saved in the *Export Waveform Sub-Module*.

Waveforms data: trigger time; time step and values; Graph title; Graph x scale label; Graph y scale label; Graph x scale minimum; Graph x scale maximum; Graph y scale minimum; Graph y scale maximum; Graph plots settings: name; color; line style; point style, nº plot shown in legend, etc; Cursor settings: name, color, point style, visible, etc.

Table 2.5: Data stored in the WFG file format.

4. XY Graph File (*.xyg)

This is a binary file used to store all relevant data and formats from XY graphs. This file type can only be loaded or saved in the *Export XY Graphs Sub-Module*.

XY graphs data: x values and y values; Graph title; Graph x scale label; Graph y scale label; Graph x scale minimum; Graph x scale maximum; Graph y scale minimum; Graph y scale maximum; Graph plots settings: name; color; line style; point style, nº plot shown in legend, etc; Cursor settings: name, color, point style, visible, etc.

Table 2.6: Data stored in the XYG file format.

2.3.4 Other File Types

1. Math Channels Data Structure File (*.mc)

This is a binary file used to store the data structure (levels and operations) for computing math channels in the *Math Channels Module*.

For each Level: Type of operation (to individual channel or between channels); Operation data (name, channels, parameters); Channels out names; Channels out units.

Table 2.7: Data stored in the MC file format.

2. MDOF Model File (*.mm)

This is a binary file used to store the data of MDOF models implemented in the *MDOF Model Module*.

For each d.o.f: Height and weight and their units; Mass and inertia and their units; Acceleration channels and their units; Displacements channels and their units; Output units.

Table 2.8: Data stored in the MM file format.

3. Visualization Data File (*.vis)

This is a binary file used to store the settings for the visualizations implemented in the *2D Visualization Module*.

For each node: Coord_X; Coord_Y; Movement type; Rigid Body Shape and Points; XType; XChannel; XValue; DispXScale; YType; YChannel; YValue; DispYScale; ZType; ZChannel; ZValue; DispZScale. For each line: Node 1; Node 2; Movement's scale factor.

Table 2.9: Data stored in the VIS file format.

4. Channels Configuration File (*.cc)

This is a binary file used to store channels configurations for acquisitions and outputs.

For each acquisition channel: Active (T/F); Channel ID String - String used to identify the hardware channel of the acquisition; Name; Type (e.g. Acceleration, Displacement, etc); Unit (e.g. mg, m, kN, Volts, etc); Data format - raw units (e.g. Volts) or engineering units (EGU); Scale Factor - between raw units and engineering units, (EGU/raw units); Offset - between raw units and engineering units, expressed in raw units (e.g. V).
For each output channel: Active (T/F); Channel ID String - String used to identify the hardware channel of the acquisition; Name; Type (e.g. Acceleration, Displacement, etc); Unit (e.g. mg, m, kN, Volts, etc); Data format - raw units (e.g. Volts) or engineering units (EGU); Scale Factor - between raw units and engineering units, (EGU/raw units); Offset - between raw units and engineering units, expressed in raw units (e.g. V).

Table 2.10: Data stored in the CC file format.

2.4 System Requirements

To process and analyse multiple channels with large numbers of points (e.g. 100 channels of 50000 samples each) and avoid large computing times, a PC with at least a single core CPU running at 1.5 GHz clock speed and 512 Mb of RAM is recommend. Only the *Microsoft Windows* operating system is supported and software tests were made only in *Windows XP*.

3 MODULES FEATURES

3.1 Auxiliary Modules

3.1.1 Start Module

This module is used to start the software and for licence and user validation. It displays the version, build number and date of the software. This module graphical user interface is described in Figure A.1.

3.1.2 Main Module

The *Main Module* is used as an interface between all modules and for managing the time histories stored in memory. It is also used to transfer time histories between the *File* and *Buffer* memory areas, edit them (name, type, units, etc) and perform file operations (load/save). The graphical user interface is described in Figure A.2.

3.1.3 Functions Manager Module

The *Functions Manager Module* is similar to the *Main Module*, enabling memory and file operations of functions, instead of time histories. It is also possible to create and edit functions and view a graphical representation. This module graphical user interface is described in Figure A.3.

3.2 Basic Tools

3.2.1 Viewer Module

The purpose of this module is to share data with other research partners. It is possible to create a licence only for this module (plus the *Main Module* to load the files), allowing a partner to view and explore the data from one of the supported file types. It is also possible to export the data directly to ASCII files. The graphical user interface is described in Figure A.4.

3.3 Data Generation Tools

3.3.1 Time History Generation Module

The *Time History Generation Module* is used to generate time histories (TH) using several built-in generators and edit functions. This module implements a command queue to process the commands (see §2.1). The graphical user interface is described in Figure A.5 to A.8.

Features:

- Wave generators: sine (see Figure 3.1); triangle; square and sawtooth waves;
- Noise generators: uniform white noise; Gaussian white noise (see Figure 3.2); Poisson noise; Gamma noise; periodic white noise; Bernoulli noise and inverse F noise;

- Sine sweep generator: constant amplitude, constant 1st derivative amplitude and constant 2nd derivative amplitude (see Figure 3.3);
- Calibration TH generator: used to calibrate displacement transducers (see Figure 3.4);
- Cyclic test TH generator (see Figure 3.5);
- Manually defined TH generator: creates a TH with a auto-sampling procedure from a discrete number of points defined by the user;
- Polynomial function generator: creates a TH using the polynomial coefficients defined by the user;
- Basic time domain functions: offset removal, scale, clip, absolute value and add DC value;
- Trends and fit functions: linear and polynomial fit;
- Time windows: hanning; hamming; blackman-harris; exact blackman; blackman; flat top; 4 term b-harris; 7 term b-harris; low sidelobe; cosine tape (10%);
- Time and frequency domain integration and differentiation;
- Fourier and butterworth filters: low pass; high pass; band pass and band stop;
- Basic frequency domain functions: response spectra, Fourier amplitude and phase spectra, power spectrum and power spectral density (PSD);
- PSD to time history generator: used to generate a stationary TH from a given PSD function (see Figure 3.6);
- Fit time history to PSD function: used to adjust a TH to the frequency content defined in a given PSD function;
- Fit time history to response spectra function: used to adjust a TH to match a given response spectra function (see Figure 3.8);
- Intensity shape functions: used to create non-stationary signals modifying the FFT amplitudes of a given TH (see Figure 3.7);
- Reduce spectral variance function: used to reduce the spectral variance of a TH using an amplitude correction procedure (see Figure 3.9).

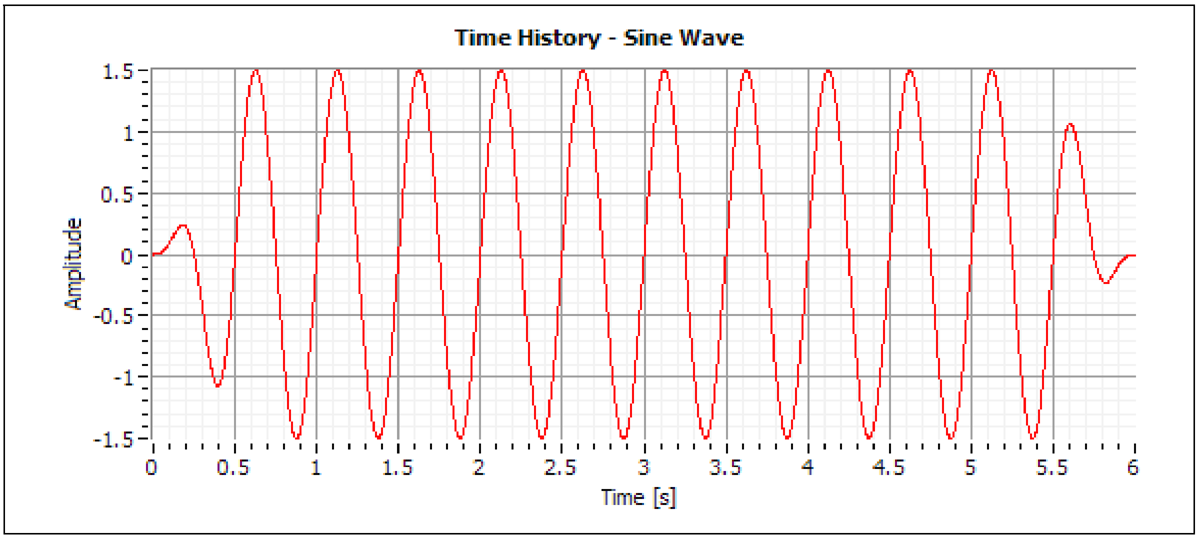


Figure 3.1: Sine wave with cosine tape.

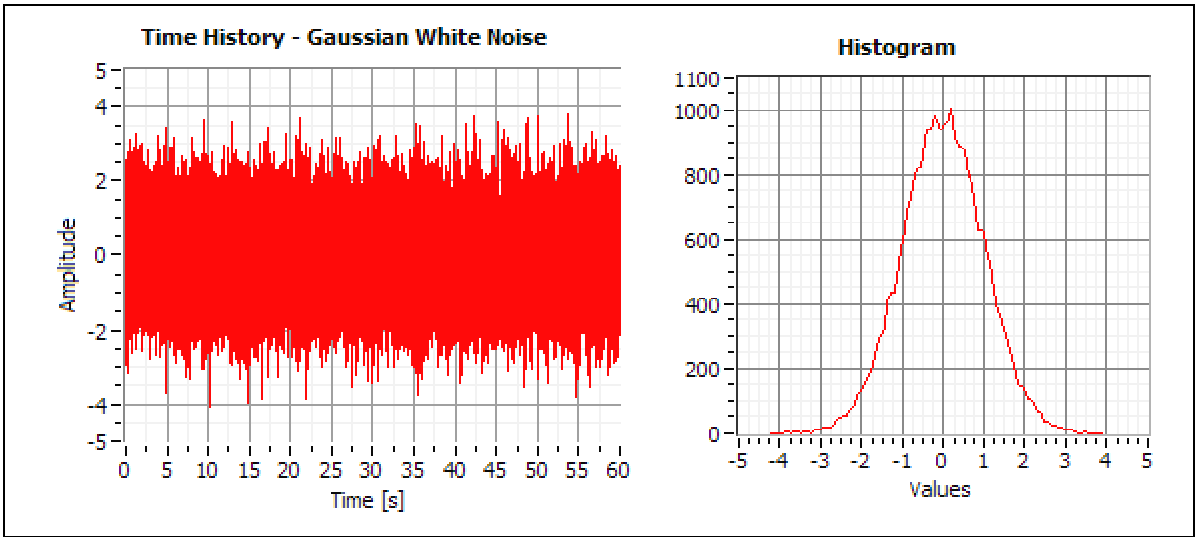


Figure 3.2: Gaussian white noise.

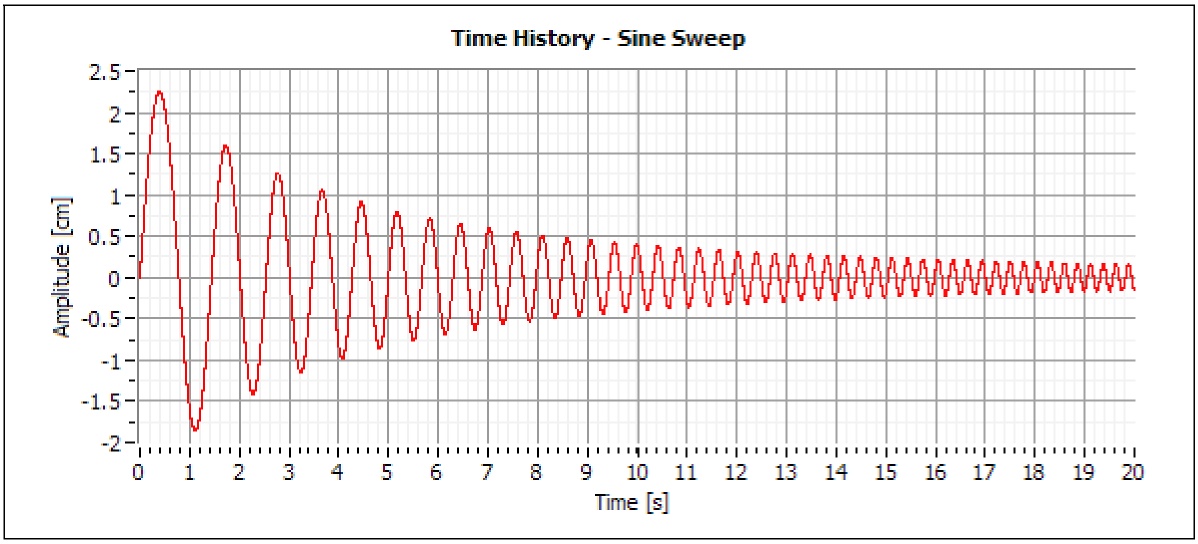


Figure 3.3: Sine sweep TH with constant 2nd derivative.

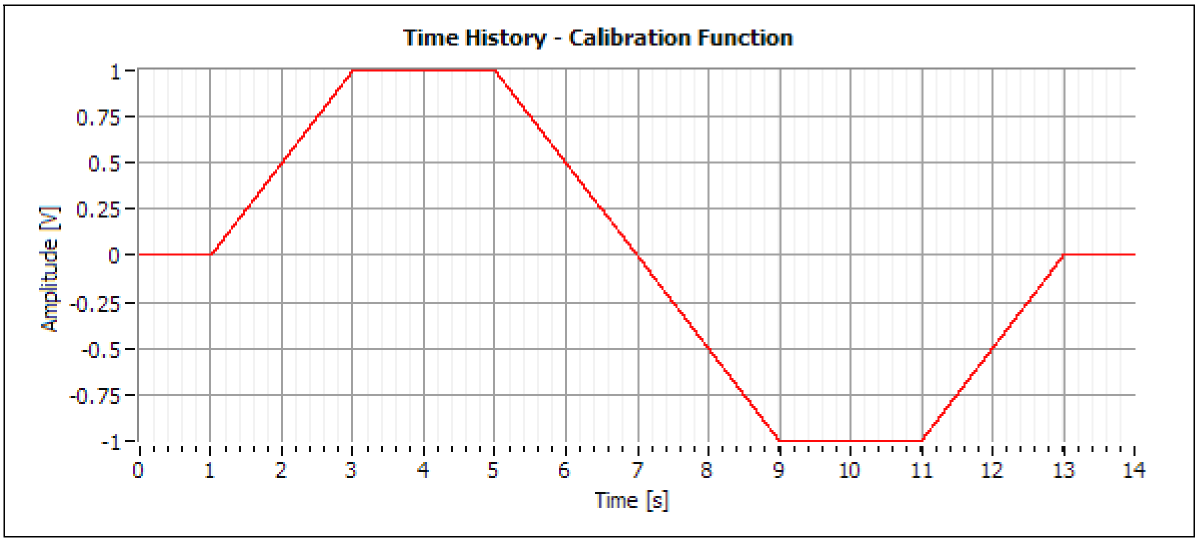


Figure 3.4: Calibration TH.

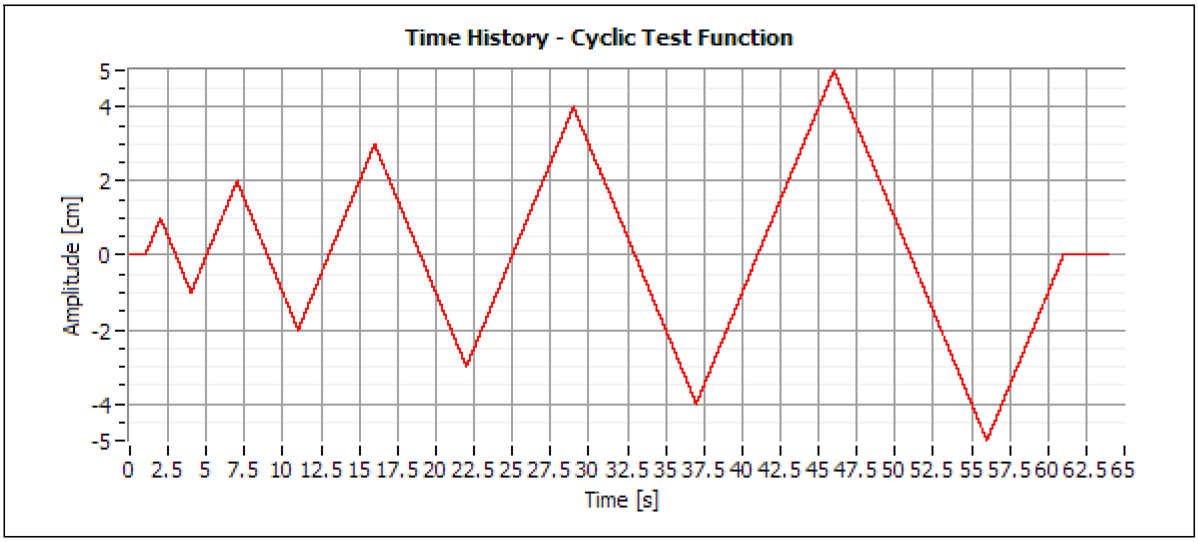


Figure 3.5: Cyclic test TH.

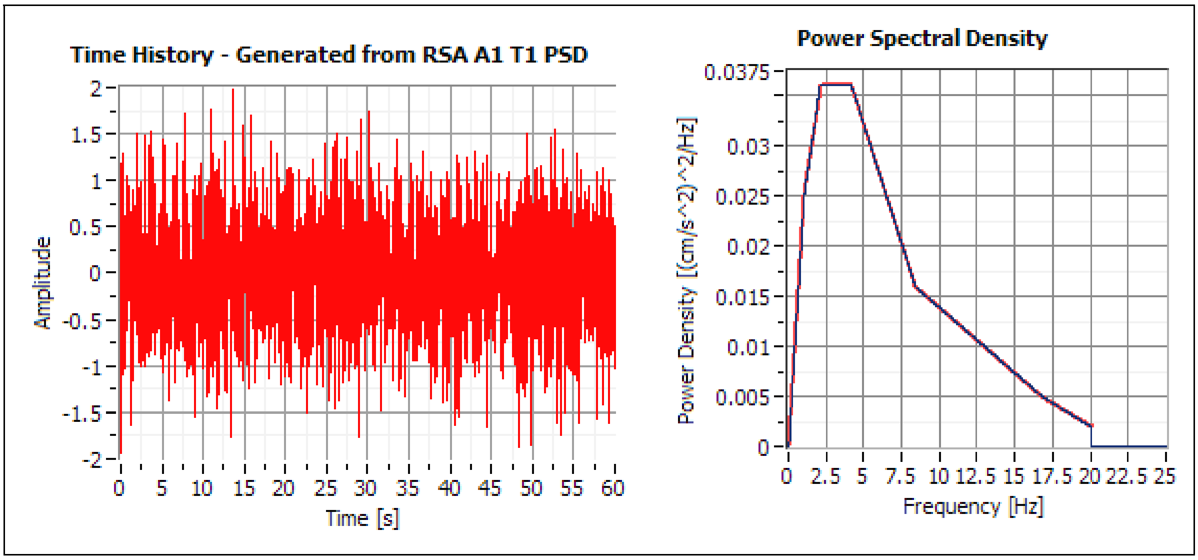


Figure 3.6: Time history generated from RSA [RSA 1983] (A1, T1) power spectral density.

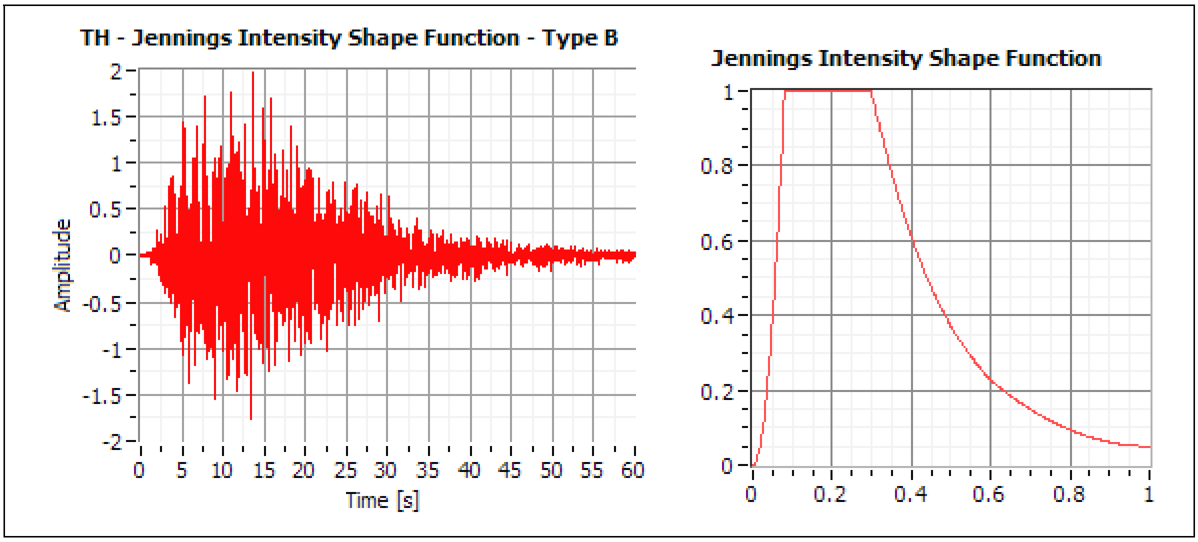


Figure 3.7: Time history from Figure 3.6 after applying Jennings intensity shape function (Type B).

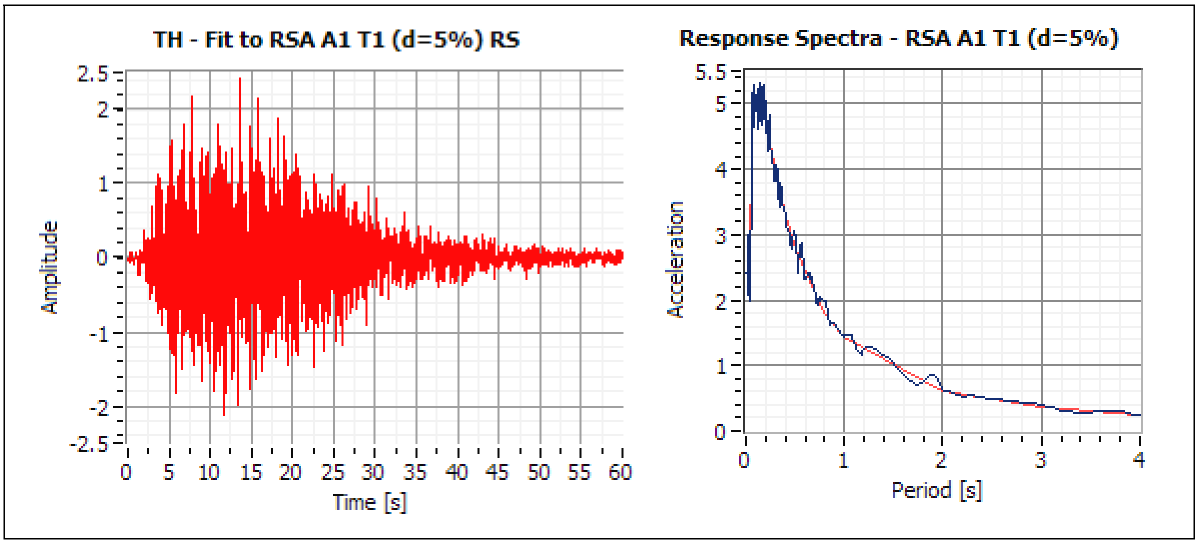


Figure 3.8: Time history from Figure 3.6 after fitting to RSA Response Spectra (A1, T1, damp=5%).

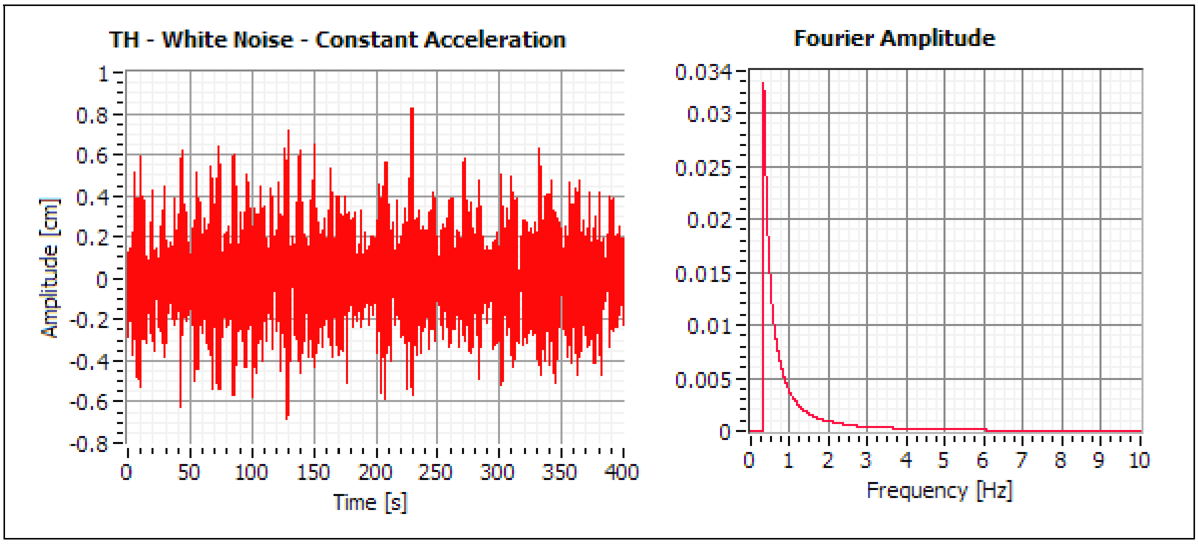


Figure 3.9: White noise TH with constant acceleration and with spectral variance reduction.

3.4 Acquisition and Output Tools

3.4.1 Acquisition Master Module

This module is used control network computers (stations) using TCP-IP Protocol, which are running terminal modules (*Acquisition & Output Terminal*, *Acquisition Terminal* or *Output Terminal* Modules). It is also possible to edit the channel configuration of a previous made acquisition (e.g. change the scale factor and offset). The graphical user interface is described in Figure A.9 to A.10.

Features:

- Terminal module control using TCP-IP network: sends or gets device, acquisition and channels configurations; sets acquisition/output on stand-by; starts a software triggered analog acquisition; receives data from the stations; displays the stations feedback;
- Edit the channel configurations of a pre-existing acquisition: edit the name, type, unit, scale factor, offset, etc;
- Load or save the channel configurations into files.

3.4.2 Acquisition & Output Terminal Module

This module is used to perform software or hardware triggered simultaneous analog acquisitions and outputs, with NI DAQ boards. All acquisitions and outputs are made using hardware buffers, so they are not software dependent. This module can be controlled by the *Acquisition Master Module* using a TCP-IP network and can be running in parallel with other modules (e.g. *Output Terminal*). To run properly, this module requires an installed NI DAQ board. The graphical user interface is described in Figure A.11.

Features:

- Hardware or software triggered analog acquisitions and outputs: i) continuous mode, used for equipment verification, calibration and warm ups; ii) buffered mode, used in the tests series;
- Remote control using the *Acquisition Master Module* and a TCP-IP network;
- *Define Output sub-module*, to define the output time histories;
- *Manual Control sub-module*, to manually control outputs – ideal for manual shaking table movements;

- *Quick Process sub-module*, with offset removal, Fourier filters, decimation and crop tools;
- *Channels Configuration sub-module*, to edit the configuration of the device, acquisition parameters, trigger settings and the channels configurations;
- *Transducers Calibration sub-module* (available through the *Channels Configuration sub-module*), for semi-automatic calibration of transducers.

3.4.3 Acquisition Terminal Module

This module is similar to the *Acquisition & Output Terminal Module* without the output capabilities. This module also requires an installed NI DAQ board. The graphical user interface is described in Figure A.12.

Features:

- Hardware or software triggered analog acquisitions: i) continuous mode, used for equipment verification and calibration; ii) buffered mode, used in the tests series;
- Remote control using the *Acquisition Master Module* and a TCP-IP network;
- *Quick Process sub-module*, with offset removal, Fourier filters, decimation and crop tools;
- *Channels Configuration sub-module*, to edit the configuration of the device, acquisition parameters, trigger settings and the channels configurations.
- *Transducers Calibration sub-module* (available through the *Channels Configuration sub-module*), for semi-automatic calibration of transducers.

3.4.4 Output Terminal Module

This module is similar to the *Acquisition & Output Terminal Module* without the acquisition features. To run properly, this module requires an installed NI DAQ board. The graphical user interface is described in Figure A.13.

Features:

- Hardware or software triggered analog outputs: i) continuous mode, used for equipment verification and warm ups; ii) buffered mode, used in the tests series;
- Remote control using the *Acquisition Master Module* and a TCP-IP network;
- *Define Output sub-module*, to define the output time histories;

- *Manual Control sub-module*, to manually control outputs - ideal for manual shaking table movements;
- *Channels Configuration sub-module*, to edit the configuration of the device, acquisition parameters, trigger settings and the channels configurations.

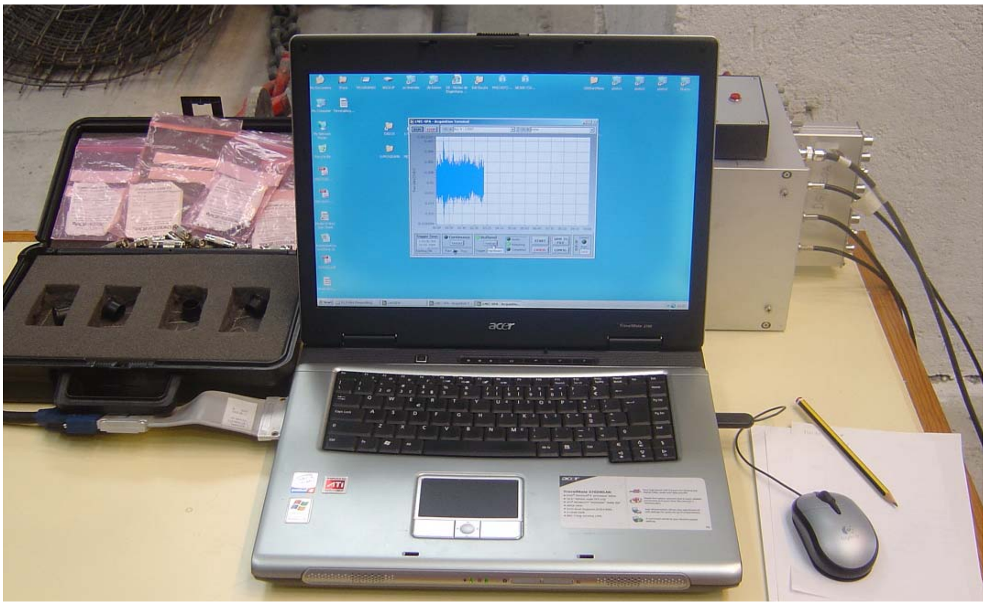


Figure 3.10: Laptop computer running the Acquisition Terminal Module in a system identification test.

3.5 System Control Tools

3.5.1 Slow Motion PID Control Module

The *Slow Motion PID Control Module* is used to control active systems with digital PID algorithms. The slow motion constraint is due to non real-time capabilities of the software and hardware, so this module is not useable in dynamic test, but it can be used in cyclic or pseudo-dynamic tests. This module requires an installed NI DAQ board and the graphical user interface is described in Figure A.14.

Features:

- Control of active systems with digital PID algorithms: i) direct output mode, used to compute the system's input/output basic characteristics, e.g scale factor and offset; ii) controlled output mode, used for digital PID control of one input channel with one output channel;
- PID settings defined at run time;
- *Define Output sub-module*, to easily define the time histories to use as output;

- *Manual Control sub-module*, to manually control outputs - ideal for manual shaking table movements;
- *Channels Configuration sub-module*, to edit the configuration of the device, acquisition parameters, trigger settings and the channels configurations.

3.6 Processing Tools

3.6.1 Analysis Module

This module is used to edit and process time histories. An extensive group of time domain and frequency domain functions are available. The *Analysis Module* has multi-channel support for the calculations and implements a command queue to process the commands (see §2.1). The graphical user interface is described in Figure A.15 to A.18.

Features:

- Multi-channel support in the calculation loop;
- Basic time domain functions: offset removal, scale, clip, crop, absolute value, zero padding, add values before, add values after, add DC value;
- Trends and fit functions: linear fit, exponential fit and polynomial fit;
- Auto and manual re-sampling and decimation functions;
- Time windows: hanning; hamming; blackman-harris; exact blackman; blackman; flat top; 4 term b-harris; 7 term b-harris; low sidelobe; cosine tape (10%); general cosine tape; force window; exponential window;
- Fourier filters;
- IIR filters: butterworth; chebyshev; inv. chebyshev; bessel; filter elliptic;
- FIR filters;
- Time and frequency domain integration and differentiation;
- Time history and function peak detector;
- Basic frequency domain functions: response spectra; Fourier amplitude and phase spectra; power spectrum and power spectral density;
- Histogram graphs;
- Channels info table: maximum; time of maximum; minimum; time of minimum; range; absolute maximum; time of absolute maximum; last value; arithmetic mean and standard deviation;

- Reduce spectral variance function: used to reduce the spectral variance of TH using an amplitude correction procedure.

More information about some of these functions are available at [Carvalhal et al. 1989].

3.6.2 Math Channels Module

The *Math Channels Module* is used to create run-time defined math channels from other channels. An extensive group of algebraic operations and engineering functions are supported. Each operation can be applied to an individual channel (e.g. add scalar, remove offset) or between a group of channels (e.g. add channels, average channels).

This module uses the math channels file type (*.mc) to load and save the data structure data (see §2.3). The graphical user interface is described in Figure A.19.

Features:

- Run-time defined math channels (code change not necessary);
- Operations on individual channels: add, subtract, multiply, divide by scalar, multiply by cosine, sine, tangent and cotangent of angle, apply atan, convert rad to degrees, convert degrees to rad, remove offset, low pass filter, hanning time window, absolute value;
- Operations between channels: add and subtract channels, average channels, calculate displacement & rotation of a 3 dof system, calculate the dissipated energy;
- Loads and saves the data structure into files;
- Data structure automatic ASCII report;
- Math channels preview.

3.7 Engineering Tools

3.7.1 System Identification Module

The *System Identification Module* is used to access the dynamic characteristics of structures in laboratory or in-situ tests (e.g. using shaking table white noise excitations or ambient vibrations). This module supports free vibrations analysis, basic frequency domain functions and other input/output and output-only methods, e.g. frequency response functions (FRF) peak picking and curve fit and the ANPSD method (see Figure 3.11). The module graphical user interface is described in Figure A.20 to A.25.

Features:

- Free vibrations analysis: used to estimate the frequency and damping from displacements records of systems with one predominant vibration mode;
- Basic frequency domain functions: Fourier spectrum's amplitude and phase, auto spectrum and cross spectrum's amplitude, phase and coherence);
- Computing FRF estimations;
- FRF peak picking;
- FRF curve fit;
- Half-power method;
- Averaged Normalized Power Spectral Density (ANPSD) method;
- Time frames to reduce spectral variance.

More information about these methods are available at [Bendat et al. 1986; Clough et al. 1993].

3.7.2 MDOF Model Module

The *MDOF Model Module* allows computing an estimation of the global forces developed during shaking table tests on specimens that can be considered as lumped mass systems (e.g. RC structures with rigid floors), using a simplified model that assumes that the inertia forces are equal to the restoring forces (neglecting damping forces):

$$\begin{cases} \{F_i\} + \{F_d\} + \{F_k\} = 0 \\ \{F_d\} \approx 0 \end{cases} \Rightarrow \{F_i\} \approx -\{F_k\}. \tag{1}$$

This model gives only approximated values, with more accuracy when the velocities are small (viscous damping hypothesis), but enables computing global forces and moments estimations using only cinematic values.

The inertia forces and torque (IF, IT), the story inertia forces and torque (SF, ST), the base shear (BS) and the base overturning moment (BOM) are computed as defined in Figure 3.12.

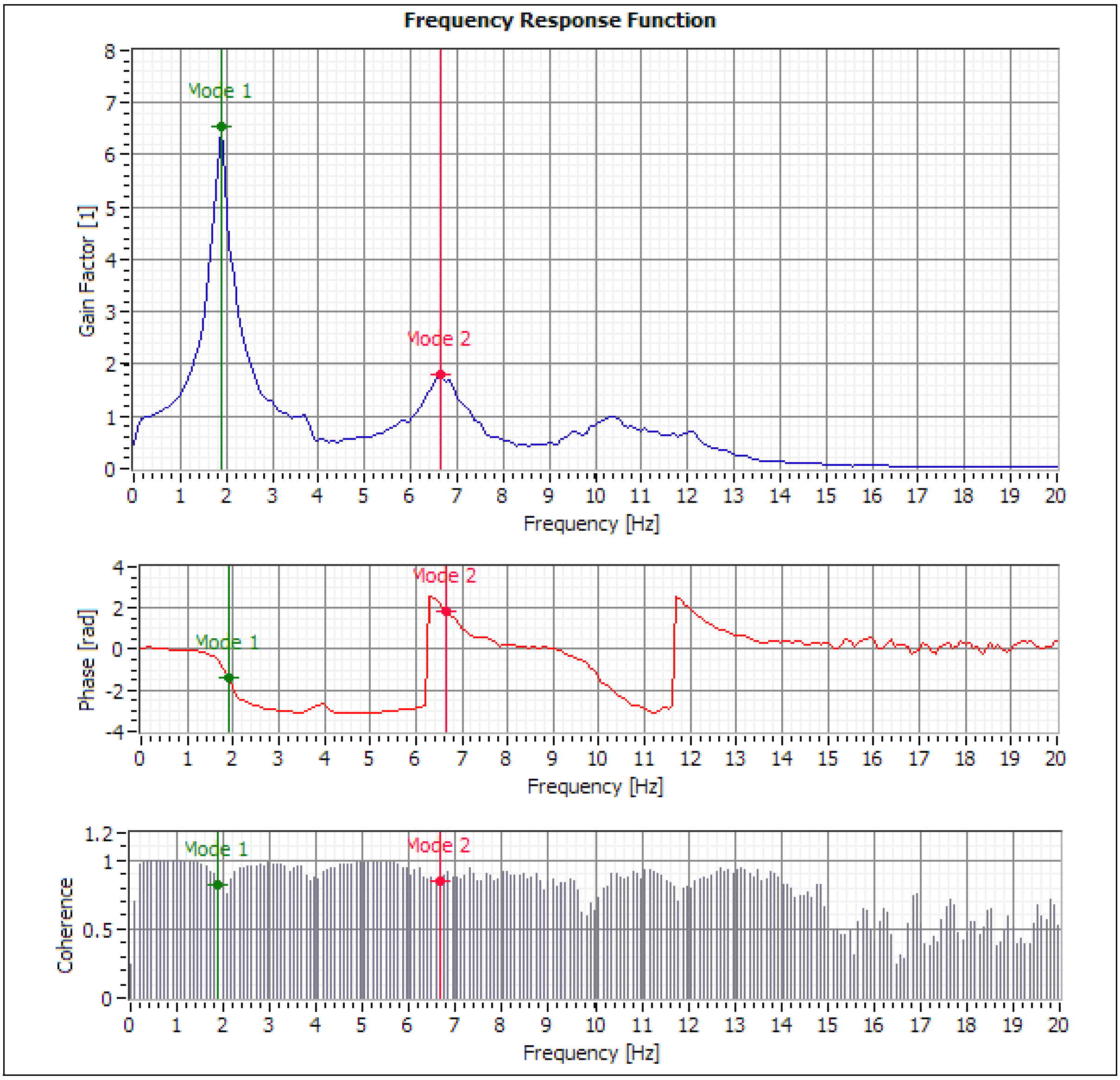
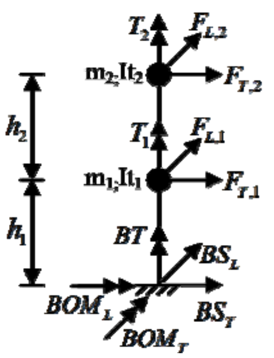


Figure 3.11: Example of the peak picking method applied to a FRF estimation.



$$IF_{T,i} = m_i \; a_{T,i} \;\; ; \;\; IF_{L,i} = m_i \; a_{L,i} \;\; ; \;\; IT_i = It_i \; a_{Tor,i}$$

$$SF_{T,i} = \sum_{k=i}^{ns} IF_{T,k} \;\; ; \;\; SF_{L,i} = \sum_{k=i}^{ns} IF_{L,k} \;\; ; \;\; ST_i = \sum_{k=i}^{ns} IT_k$$

$$BS_T = \sum_{i=1}^{ns} IF_{T,i} \;\; ; \;\; BS_L = \sum_{i=1}^{ns} IF_{L,i} \;\; ; \;\; BT = \sum_{i=1}^{ns} IT_i$$

$$BOM_T = \sum_{i=1}^{ns} IF_{T,i} \, h_i \;\; ; \;\; BOM_L = \sum_{i=1}^{ns} IF_{L,i} \, h_i$$

ns	–	Number of storeys	SF	– Story inertia force
m	–	Story mass	ST	– Story inertia torque
It	–	Story torsion inertia	BS	– Base shear
IF	–	Inertia force	BOM	– Base overturning moment
IT	–	Inertia torque		

Figure 3.12: Simplified global model.

This module uses the MDOF Model file type (*.mm) to load and save the model information (see §2.3). The graphical user interface is described in Figure A.26.

Features:

- Computing an estimation of the global forces developed on lumped mass systems, namely the inertia force and torque, the story inertia force and torque, the base shear and base overturning moment.
- Loads and saves the model data into files;
- Model data automatic ASCII report;
- MDOF channels preview.

3.7.3 2D Visualization Module

Visualization is a tool that can enhance significantly the presentation of results, but can also help the researcher to understand the structural behaviour. *The 2D Visualization Module* allows creating 2D animations using moving nodes (motion defined by time histories) connected by lines.

This module uses the visualization data file type (*.vis) to load and save the data necessary to define the visualizations (see §2.3). The graphical user interface is described in Figure A.27 to A.29.

Features:

- Creation of 2D visualizations with lines connecting moving nodes (motion defined by time histories);
- Infinite number of nodes and lines;
- Automatic insertion into frames of a title, a user-defined text, the elapsed time and the movement scale factor;
- Storing and retrieving the visualization data from files;
- Export to AVI file.

3.7.4 Graph Animation Module

The *Graph Animation Module* can produce XY graphs animations with data collected from tests (e.g. polar diagrams and hysteretic loops, etc). The graphical user interface is described in Figure A.30.

Features:

- Animation of XY graphs using time history data;
- User defined time scope and frames per second;
- Export to AVI file.

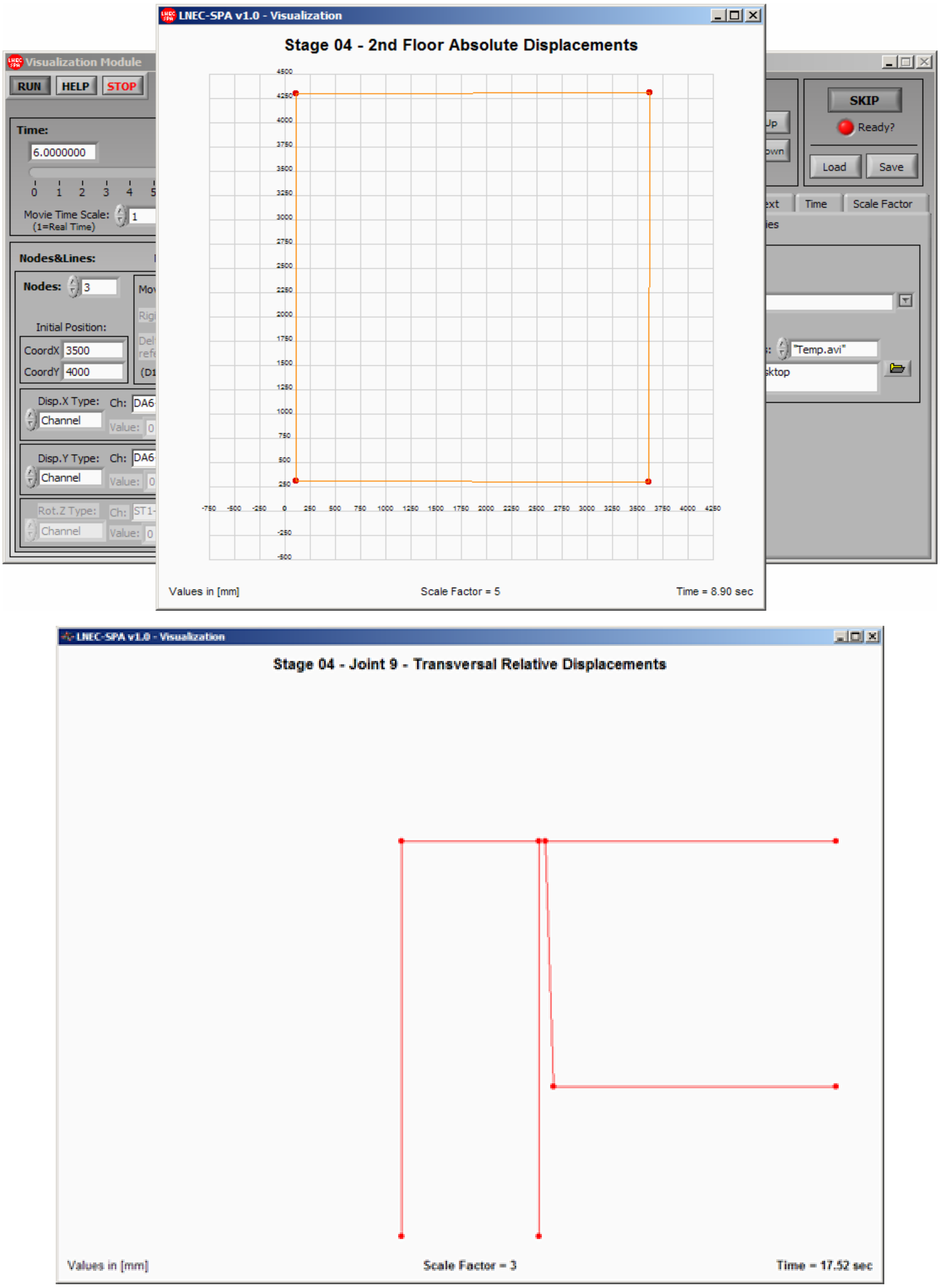


Figure 3.13: Examples of snap-shoots of 2D visualizations.

3.8 Other Tools

3.8.1 Strong Ground Motion Module

Figure 3.14: GEOSIG's Seismic Recorder

The *Strong Ground Motion Module* is used to analyse the data form strong ground motions measured by seismic recorders (e.g. GSR files, see Figure 3.14), but it can also be used with other sources of data (e.g. earthquake scenario analysis of shaking table tests). This module enables the automatic calculation of the acceleration, velocity and displacement time histories from the source data using signal processing functions (filters and baseline corrections). A group of strong ground motion parameters can be computed from those TH. These parameters are defined in Table 3.1. Most of the implemented parameters were inspired in the excellent software *SeismoSignal* from *SeismoSoft* [SeismoSoft 2004]. It is possible to create, automatically, a standard report from the current data. An example of a report is presented in the Annex B.

This module is unit dependent, so the time histories have to be defined with coherent units (accelerations time histories in acceleration units, etc, see §2.1). The graphical user interface is described in Figure A.31.

Features:

- Automatic calculation of the acceleration, velocity and displacement TH from the source data using signal processing tools (filters and baseline corrections);
- Computing several frequency domain functions: response spectra, Fourier amplitude and phase, power spectrum, power spectral density, Husid plot and the energy flux plot;
- Computing several strong ground motion parameters: PGA; PGV; PGD; Peak velocity and acceleration ratio; Arias Intensity; A95 parameter; t05 parameter; t95 parameter; Significant duration; Characteristic intensity; Predominant period; Mean period; Sustained maximum acceleration; Acceleration Spectrum Intensity; Velocity Spectrum Intensity;
- Automatic report generation;
- Automatic unit conversion.

Name of the parameter:	**How is calculated:**
Peak ground acceleration (PGA)	$PGA = \max\lvert a(t)\rvert$
Peak ground velocity (PGV)	$PGV = \max\lvert v(t)\rvert$
Peak ground displacement (PGD)	$PGD = \max\lvert d(t)\rvert$
Peak velocity and acceleration ratio (Vmax/amax)	$v_{max}/a_{max} = \frac{\max\lvert v(t)\rvert}{\max\lvert a(t)\rvert}$
Arias Intensity (Ia)	$I_a = \frac{\pi}{2g}\int\left[a(t)\right]^2 dt$
A95 parameter (A95)	Is the maximum value of acceleration that corresponds to 95% of the Arias intensity value.
t05 parameter (t05)	Is the time where 5% of the Arias intensity is reached.
t95 parameter (t95):	Is the time where 95% of the Arias intensity is reached.
Significant duration (SD)	$SD = t_{95} - t_{05}$
Characteristic intensity (Ic)	$I_c = (a_{rms})^{\frac{3}{2}}.\sqrt{t_{tot}},\quad a_{rms} = \sqrt{\frac{1}{t_{tot}}\int\left[a(t)\right]^2 dt}$
Predominant period (Tp)	Is the period where is reached the maximum spectral accelerations in an acceleration response spectra (damping=5%)
Mean period (Tm)	$T_m = \frac{\sum C_i^2/f_i}{\sum C_i^2}$ where: C_i are the Fourier amplitudes at f_i frequencies between 0.25 and 20 Hz.
Sustained maximum acceleration (SMA)	Is the third maximum acceleration measured.
Sustained maximum Velocity (SMV)	Is the third maximum velocity measured.
Acceleration Spectrum Intensity (ASI)	$ASI = \int_{0.1}^{0.5} S_a(\xi = 5\%, T)\,dT$
Velocity Spectrum Intensity (VSI) (also known as Housner Intensity)	$VSI = \int_{0.1}^{2.5} S_v(\xi = 5\%, T)\,dT$

Table 3.1: Strong ground motion parameters.

3.8.2 Web-Shaker Module

The goal of the *Web Shaker Module* is to make available on the internet, for educational purposes, a small electric SDOF shaking table with an analogue PID control system (see Figure 3.15). Several types of specimens can be tested, from SDOF to more complex MDOF specimens.

This module allows the remote control of the shaking table with input definition, view the test through a web-cam and explore the output data (e.g. shaking table displacements and several measurements on the specimens). It is also possible to turn on a light to execute the test at night. The graphical user interface is described in Figure A.32.

Features:

- Control a SDOF electric shaking table: several output signals are available (sine, square, triangle and sawtooth waves, uniform white noise, Gaussian white noise):
- Up to 16 acquisition channels;
- Light switch control;
- Acquired data chart;
- Movie window to watch the test.

Figure 3.15: General view of the Web Shaker

4 FUTURE DEVELOPMENTS

After publishing this report, the LNEC-SPA software will engage a testing phase, with the purpose of correcting bugs and improving the graphical interfaces with information from users. This phase will last at least to the first semester of 2007 and no new improvements are scheduled in this period. After this phase, a short-term goal is to improve the *System Identification Module* to release a new version of the software as part of the LNEC participation in the *Lessloss - Risk Mitigation for Earthquakes and Landslides* research project (Sub-Project 5: In-situ assessment, monitoring and typification). Another goal, in a long-term scope, is to create a 3D visualization module, which will require more complex graphic tools like *OpenGL* or *DirectX*.

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Lisboa, Laboratório Nacional de Engenharia Civil, February of 2007,

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ANNEXES

Annex A – GRAPHICAL USER INTERFACE

Annex B - STRONG GROUND MOTION REPORT

A GRAPHICAL USER INTERFACE

FIGURE INDEX

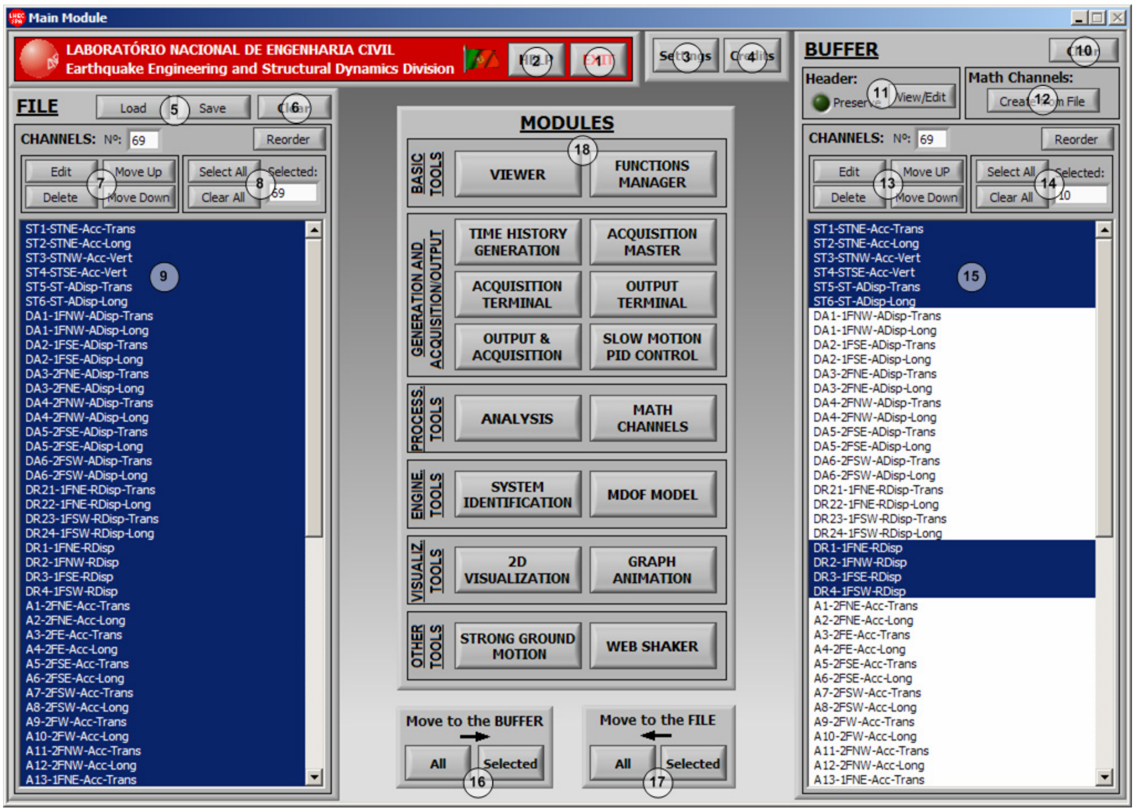
A.1 Start Module

Legend

1. Program version, build number and date;
2. User validation;
3. Switch to the *Main Module* or exit the software;
4. Displays the *Licence Agreement* page;
5. Lists all available modules.

Figure A.1: Start Module.

A.2 Main Module

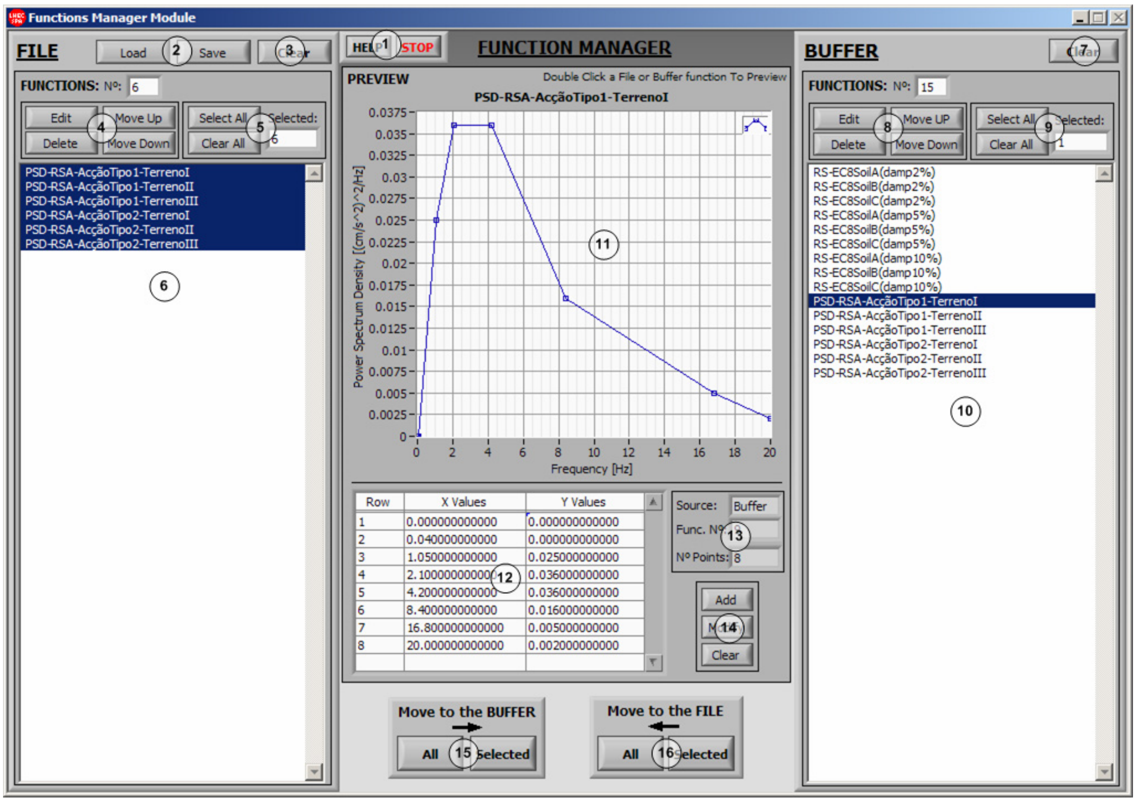


Legend

1. Exit the software;
2. Displays the module help;
3. Displays the *Settings sub-module*;
4. Displays the *Credits sub-module*;
5. Loads or Saves compatible files types into the File memory area;
6. Clears the File memory area;
7. Displays the *TH Edit sub-module* (name, type, units, etc.), orders and deletes the time histories in File;
8. Selects all or none TH in File;
9. Selects individual channels in File;
10. Clears the Buffer memory area;
11. View and edit the Buffer Header;
12. Creates the math channels defined in a file (MC format);
13. Displays the *TH Edit sub-module* (name, type, units, etc.), orders and deletes the channels in Buffer ;
14. Selects all or none TH in Buffer;
15. Selects individual channels in Buffer;
16. Move all or the selected time histories from File to the Buffer memory areas;
17. Move all or the selected time histories from Buffer to the File memory areas;
18. Starts other modules.

Figure A.2: Main Module.

A.3 Functions Manager Module

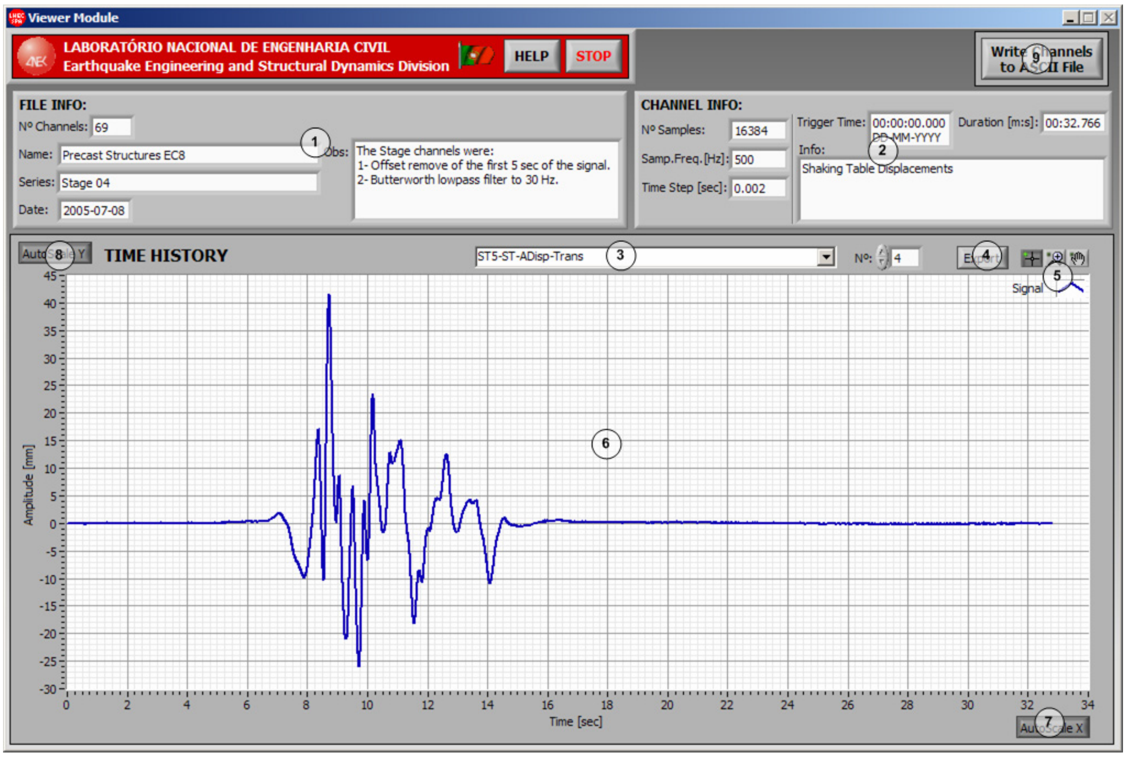


Legend

1. Help/Stop buttons;
2. Loads or Saves compatible functions files types into the File memory area;
3. Clears the File memory area;
4. Displays the *Functions edit sub-module* (name, type, units, etc.), orders and deletes the time histories in File;
5. Selects all or none functions in File;
6. Selects individual functions in File;
7. Clears the Buffer memory area;
8. Displays the *Functions edit sub-module* (name, type, units, etc.), orders and deletes the channels in Buffer ;
9. Selects all or none functions in Buffer;
10. Selects individual functions in Buffer;
11. Preview chart;
12. Editable table;
13. Function details;
14. Add/change to source or clear table's data;
15. Move all or the selected functions from File to Buffer memory areas;
16. Move all or the selected functions from Buffer to File memory areas;

Figure A.3: Functions Manager Module.

A.4 Viewer Module

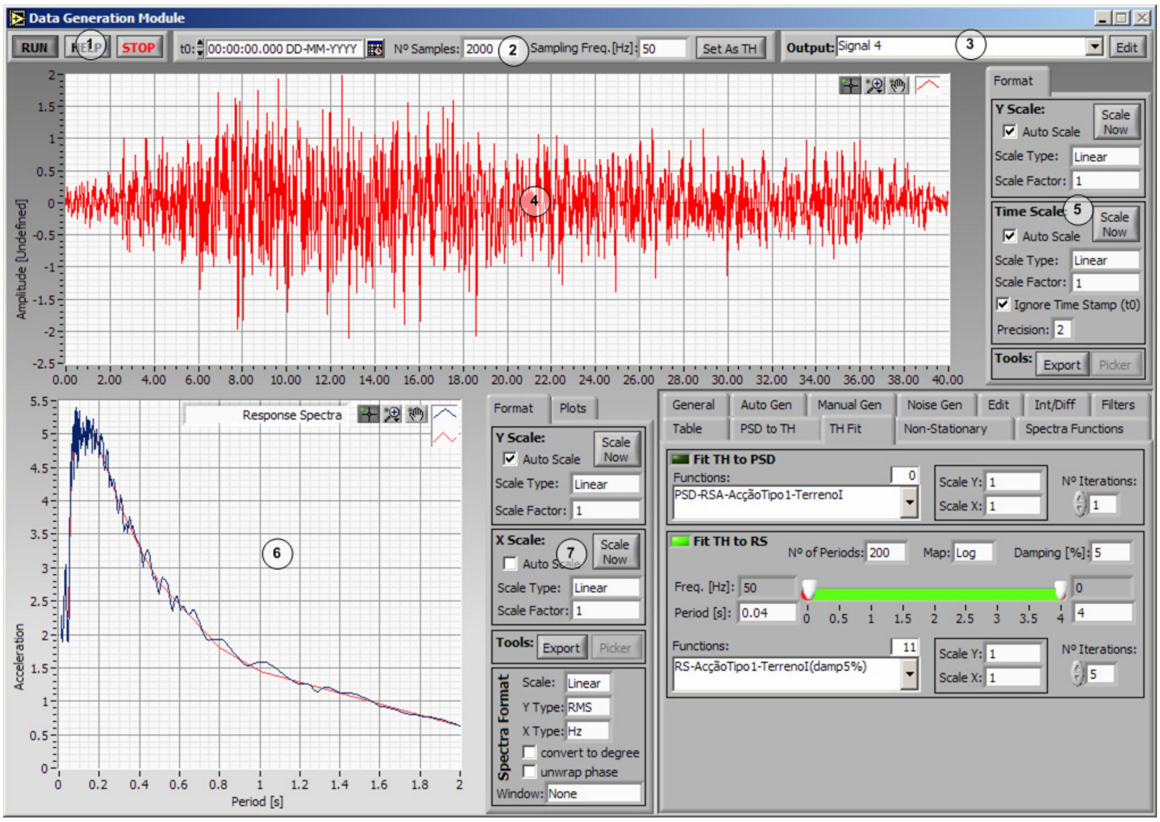


Legend

1. Header data;
2. Selected channel information;
3. Channel selector;
4. Displays the *Export sub-module*;
5. Plot settings;
6. Time history graph;
7. Sets X axis auto scale on or off;
8. Sets Y axis auto scale on or off;
9. Exports all the channels to a column ordered ASCII file.

Figure A.4: Viewer Module.

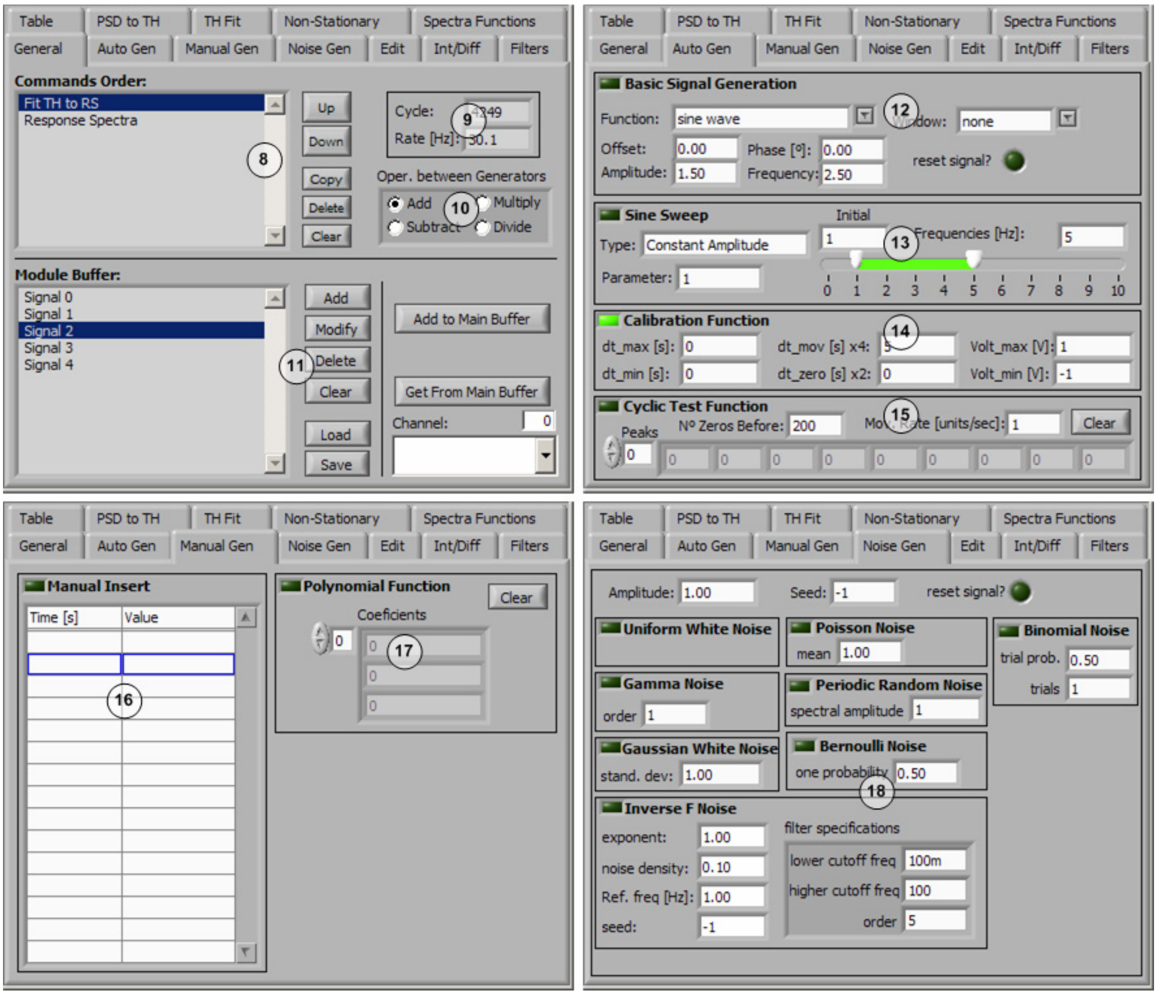
A.5 Time History Generation Module



Legend

1. Run/Help/Stop buttons;
2. Generation settings;
3. Time history selector;
4. Time history graph;
5. Time history graph settings;
6. Functions graph;
7. Functions graph settings;

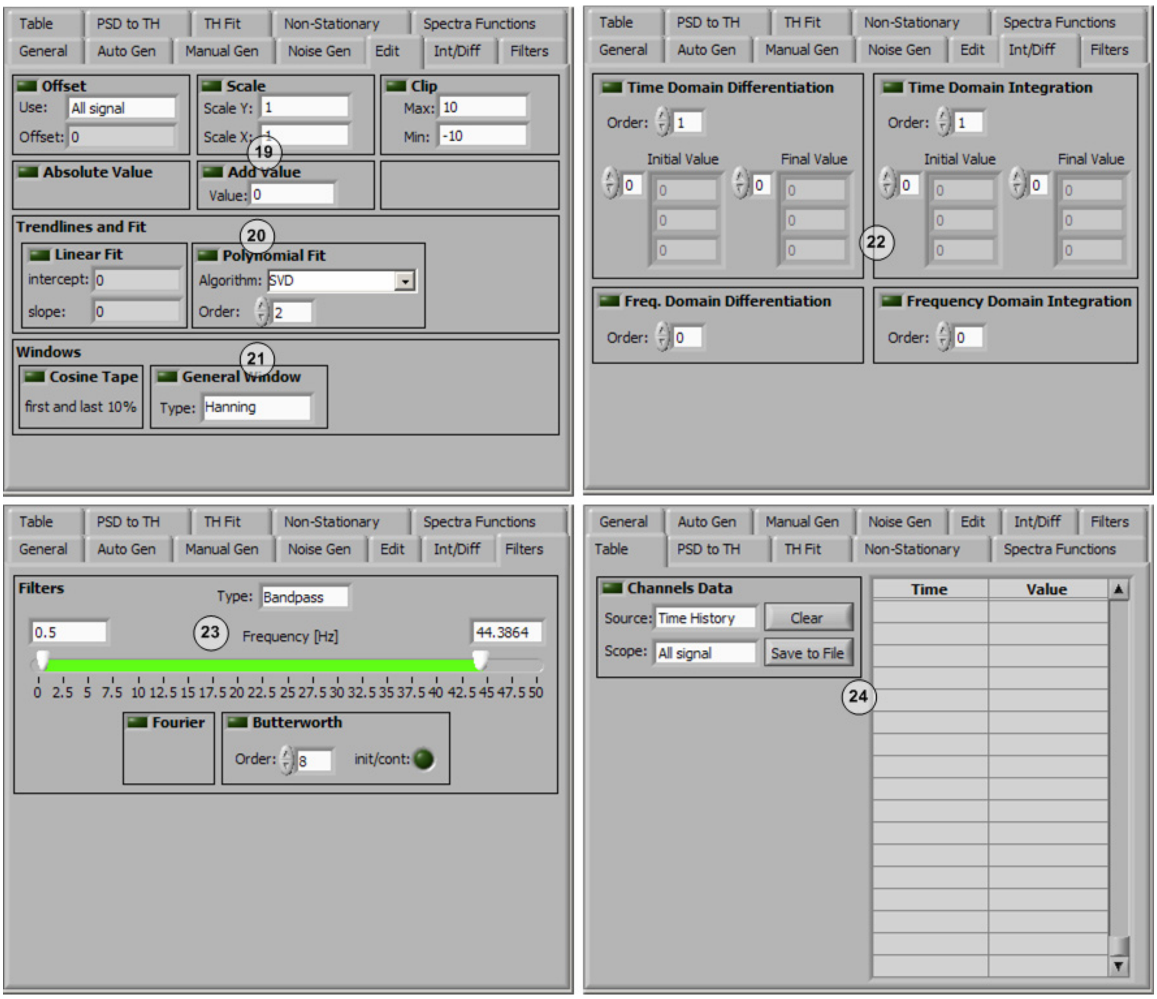
Figure A.5: Time History Generation Module.



Legend

8. Operations and functions queue;
9. Cycle and cycle rate display;
10. Operations between generators selector;
11. Time histories buffer;
12. Basic signal generation (sine, triangle, square, and sawtooth waves);
13. Sine sweep generator;
14. Calibration TH generator;
15. Cyclic test TH generator;
16. Manually defined TH generator;
17. Polynomial function generator;
18. Noise generators;

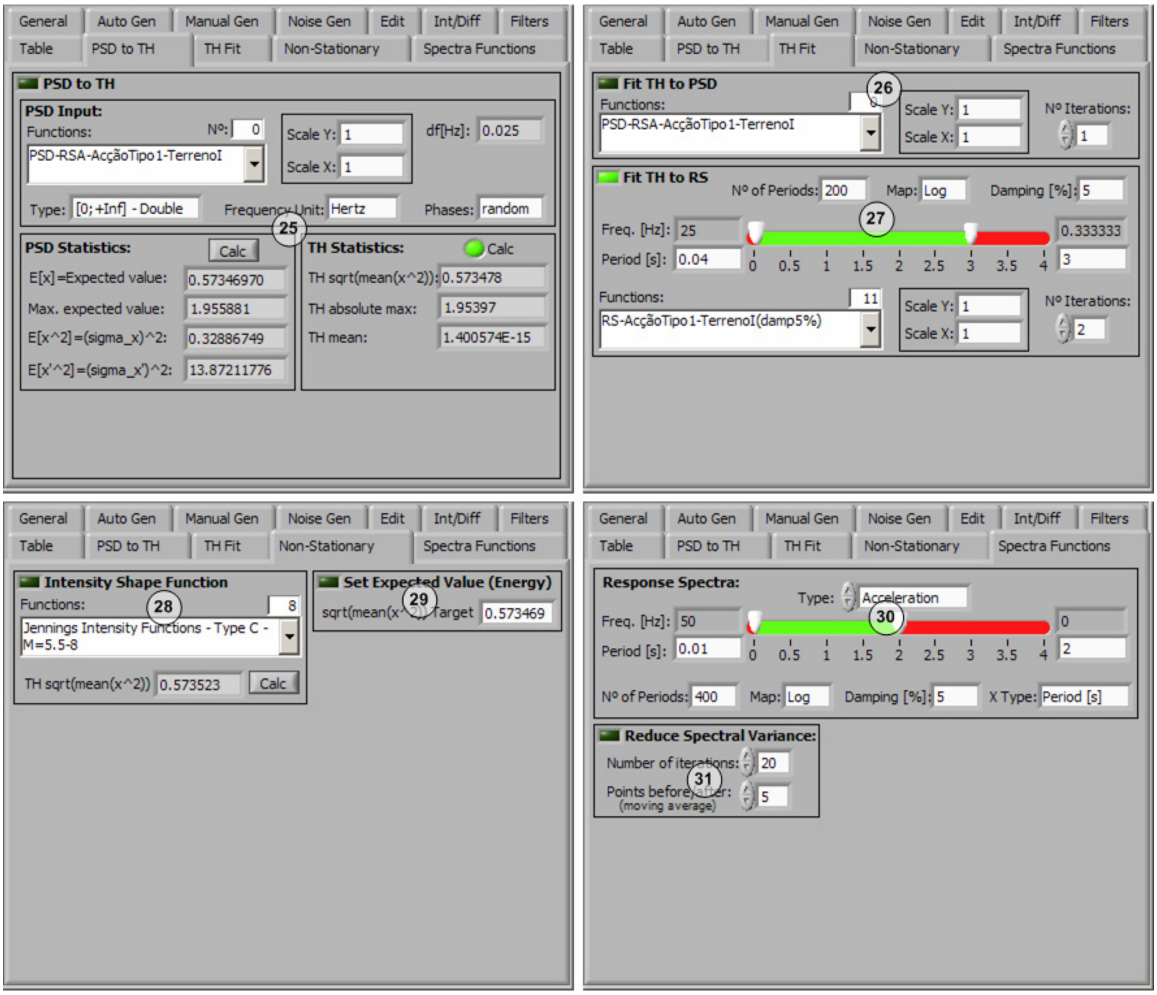
Figure A.6: Time History Generation Module (cont.).



Legend

19. Basic time domain edit (offset removal, scale, clip, absolute value and add value functions);
20. Trends and fit functions;
21. Time windows;
22. Time and frequency domain integration and differentiation;
23. Fourier and Butterworth filters;
24. Data table;

Figure A.7: Time History Generation Module (cont.).

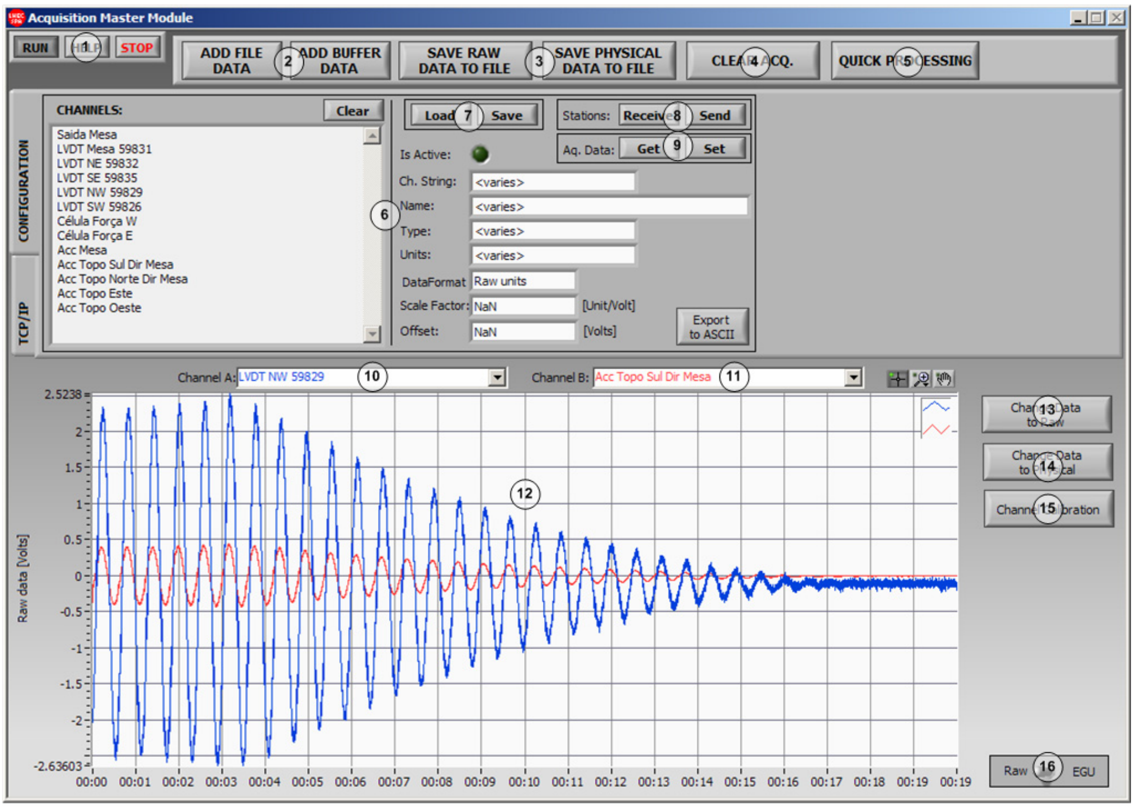


Legend

25. Power spectral density to time history generator;
26. Fit time history to power spectral density function;
27. Fit time history to response spectra function;
28. Intensity shape functions (for creating non-stationary signals);
29. Energy corrections;
30. Response spectra settings (functions graph);
31. Reduce spectral variance function;

Figure A.8: Time History Generation Module (cont.).

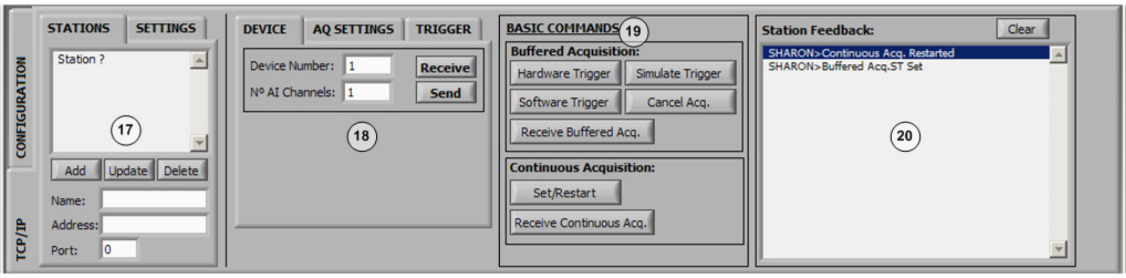
A.6 Acquisition Master Module



Legend

1. Run/Help/Stop buttons;
2. Retrieves data from a supported file type or from the buffer;
3. Save current data in a raw or processed (EGU) data file;
4. Clears the acquisition buffer;
5. Displays the *Quick Process sub-module*;
6. Channels data edit;
7. Loads or saves the channels configurations into a file;
8. Receives or sends channels configuration froms or to stations;
9. Gets or Sets the current channels configurations from or to the loaded data;
10. Channel A selector (plot in blue);
11. Channel B selector (plot in red);
12. Graph;
13. Sets the loaded data to raw units format;
14. Sets the loaded data to EGU units format;
15. Displays the *Transducers Calibration sub-module*;
16. Switch between raw units and engineering units (EGU);

Figure A.9: Acquisition Master Module.

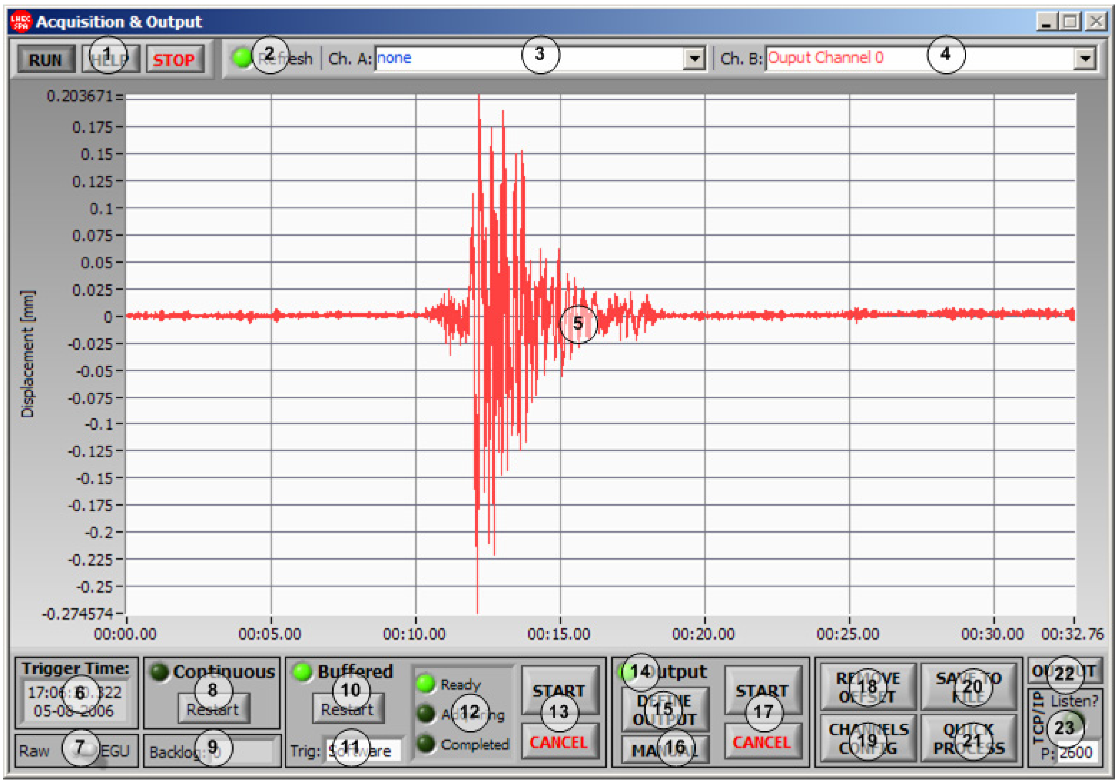


Legend

17. Configuration and selection of network stations;
18. Receives or sends the device, acquisition and trigger settings from or to stations;
19. Sends commands to the stations;
20. Displays the station's feedback;

Figure A.10: Acquisition Master Module (cont.).

A.7 Acquisition & Output Module

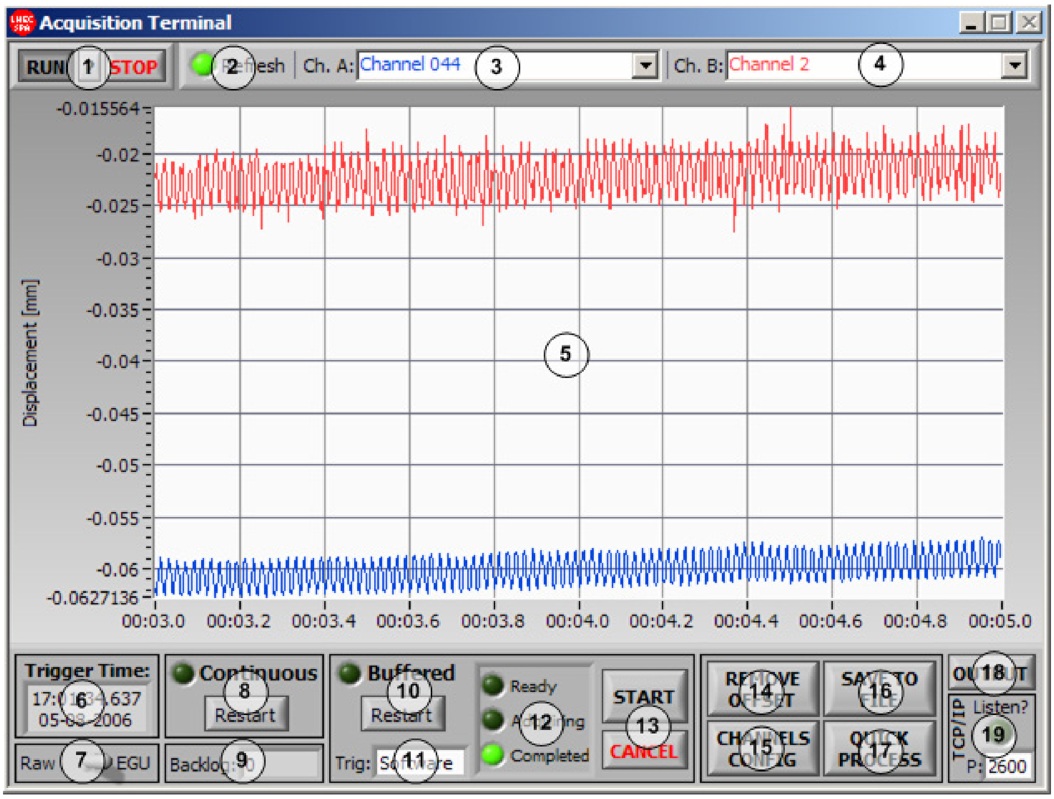


Legend

1. Run/Help/Stop buttons;
2. Refresh the chart switch;
3. Channel A selector (plot in blue);
4. Channel B selector (plot in red);
5. Chart;
6. Trigger time of the current acquisition/output;
7. Switch between raw units and engineering units (EGU);
8. Set and restart a continuous acquisition/output;
9. Current acquisition backlog display;
10. Set and restart a buffered acquisition/output;
11. Trigger type selector;
12. State display of the buffered acquisition;
13. Start-Stop buffered acquisition;
14. Enable output switch;
15. Displays the *Define Output sub-module*;
16. Displays the *Manual Control sub-module*;
17. Start/Stop the buffered output;
18. Remove offset of all active channels;
19. Displays the *Channels Configuration sub-module*;
20. Save current acquisition to one of the supported file types;
21. Displays the *Quick Process sub-module*;
22. Starts the *Output Terminal Module*;
23. Listen to TCP-IP network commands switch and port selector.

Figure A.11: Acquisition & Output Module.

A.8 Acquisition Terminal Module

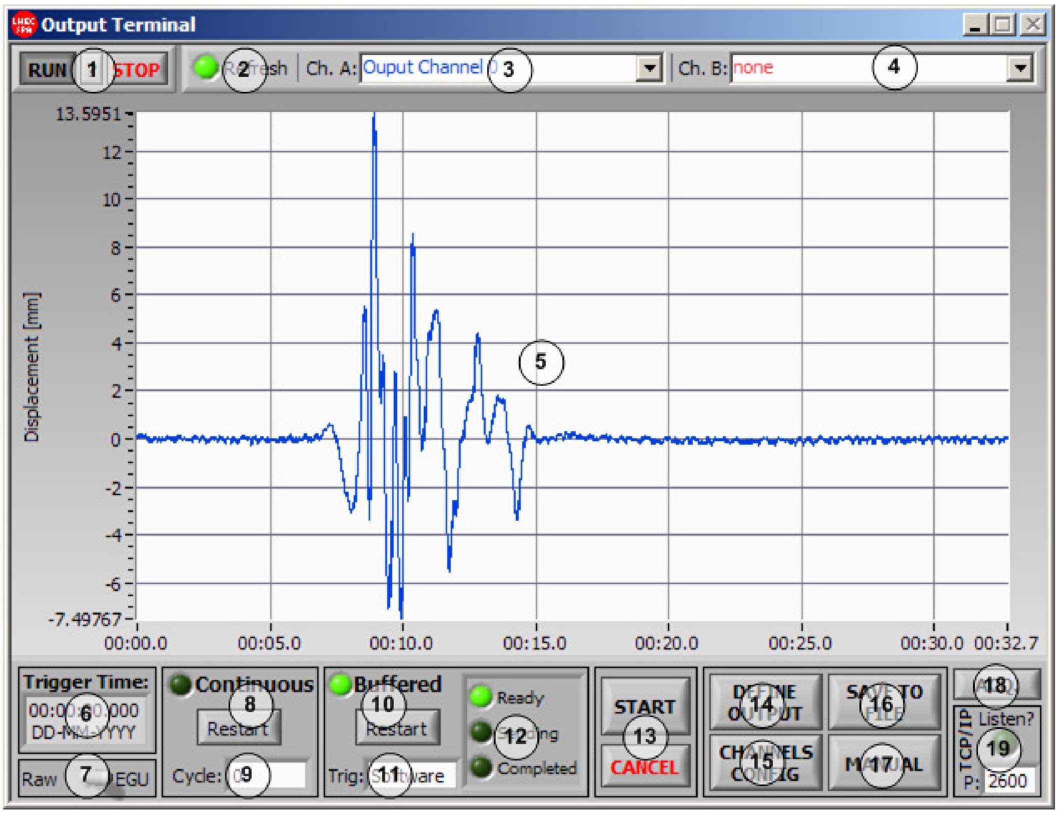


Legend

1. Run/Help/Stop buttons;
2. Refresh the chart switch;
3. Channel A selector (plot in blue);
4. Channel B selector (plot in red);
5. Chart;
6. Trigger time of the current acquisition;
7. Switch between raw units and engineering units (EGU);
8. Set and restart a continuous acquisition;
9. Current backlog display;
10. Set and restart a buffered acquisition;
11. Trigger type selector;
12. State display of the buffered acquisition;
13. Start/Stop buffered acquisition;
14. Remove offset of all active channels;
15. Displays the *Channels Configuration sub-module*;
16. Save current acquisition to one of the supported file types;
17. Displays the *Quick Process sub-module*;
18. Starts the *Output Terminal Module*;
19. Listen to TCP-IP network commands switch and port selector.

Figure A.12: Acquisition Terminal Module.

A.9 Output Terminal Module

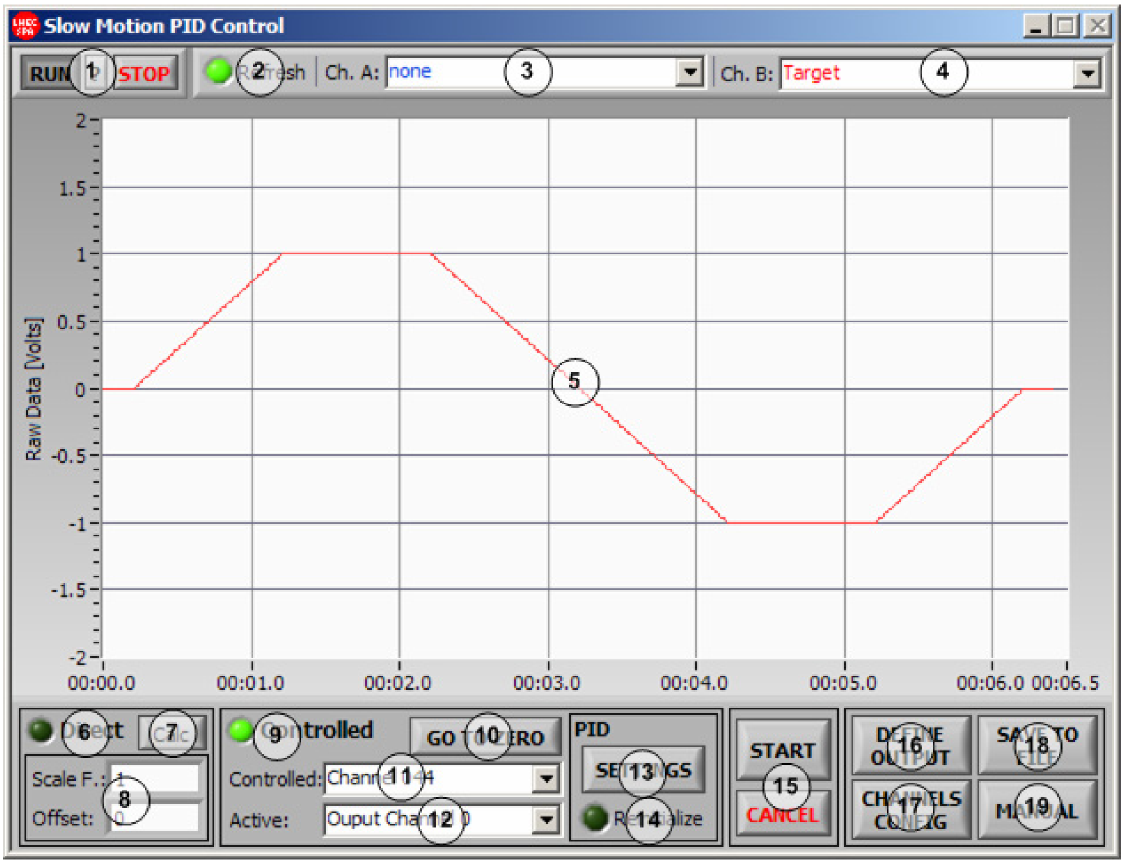


Legend

1. Run/Help/Stop buttons;
2. Refresh the chart switch;
3. Channel A selector (plot in blue);
4. Channel B selector (plot in red);
5. Chart;
6. Trigger time of the current output;
7. Switch between raw units and engineering units (EGU);
8. Set and restart a continuous output;
9. Counter of outputs cycles display;
10. Set and restart a buffered output;
11. Trigger type selector;
12. State display of the output;
13. Start/Stop buffered output;
14. Displays the *Define Output sub-module*;
15. Displays the *Channels Configuration sub-module*;
16. Save the current output data to one of the supported file types;
17. Displays the *Manual Control sub-module*;
18. Starts the *Acquisition Terminal Module*;
19. Listen to TCP-IP network commands switch and port selector.

Figure A.13: Output Terminal Module.

A.10 Slow Motion PID Control Module

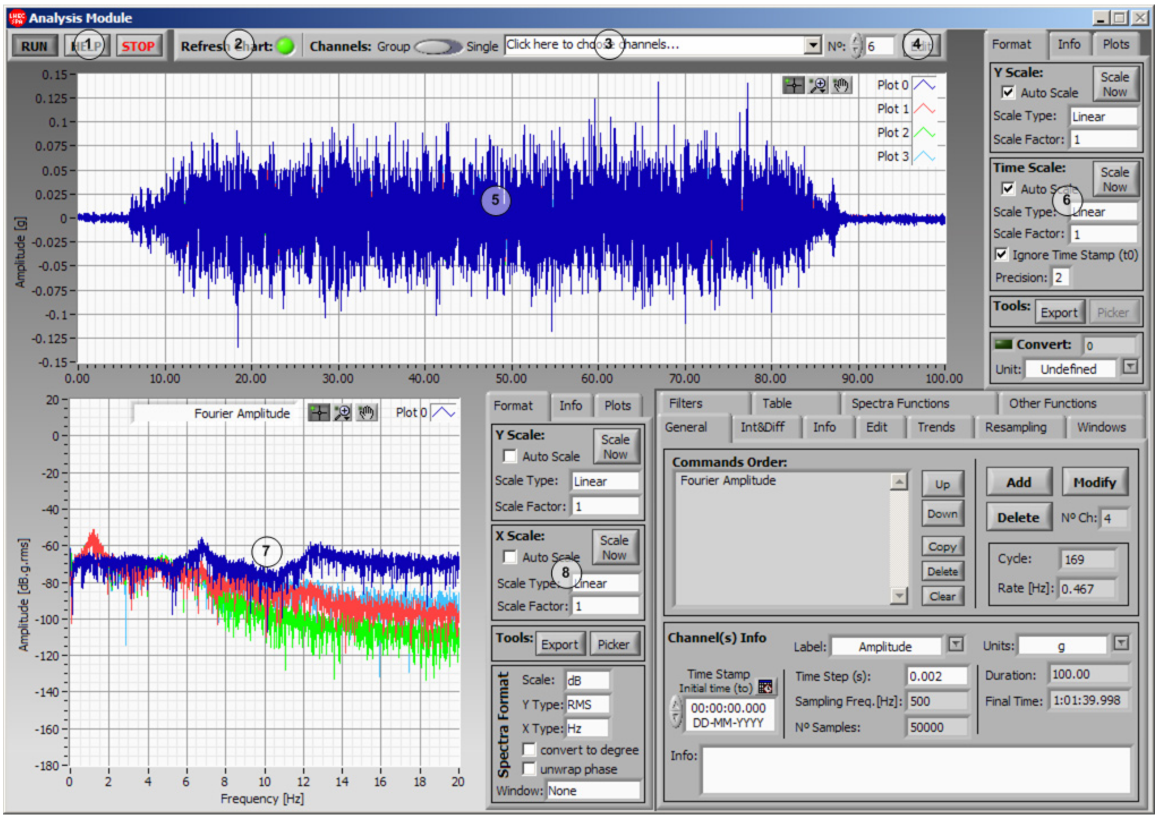


Legend

1. Run/Help/Stop buttons;
2. Refresh the chart switch;
3. Target/Measured/Output selector (plot in blue);
4. Target/Measured/Output selector (plot in red);
5. Chart;
6. Set a direct output (No PID control);
7. Calculate scale factor and offset from last data;
8. Scale factor and offset controls;
9. Set a controlled output/input (with digital PID control);
10. Set the system to its zero position;
11. Input channel to control selector;
12. Output channel selector;
13. Displays the *PID settings sub-module*, to set proportional gain, integral time, derivative time and other settings;
14. Reinitialize the PID Algorithm;
15. Start/Stop a direct or control procedure;
16. Displays the *Define Output sub-module*;
17. Displays the *Channels Configuration sub-module*;
18. Save current output data to one of the supported file types;
19. Displays the *Manual Control sub-module*.

Figure A.14: Slow Motion PID Control Module.

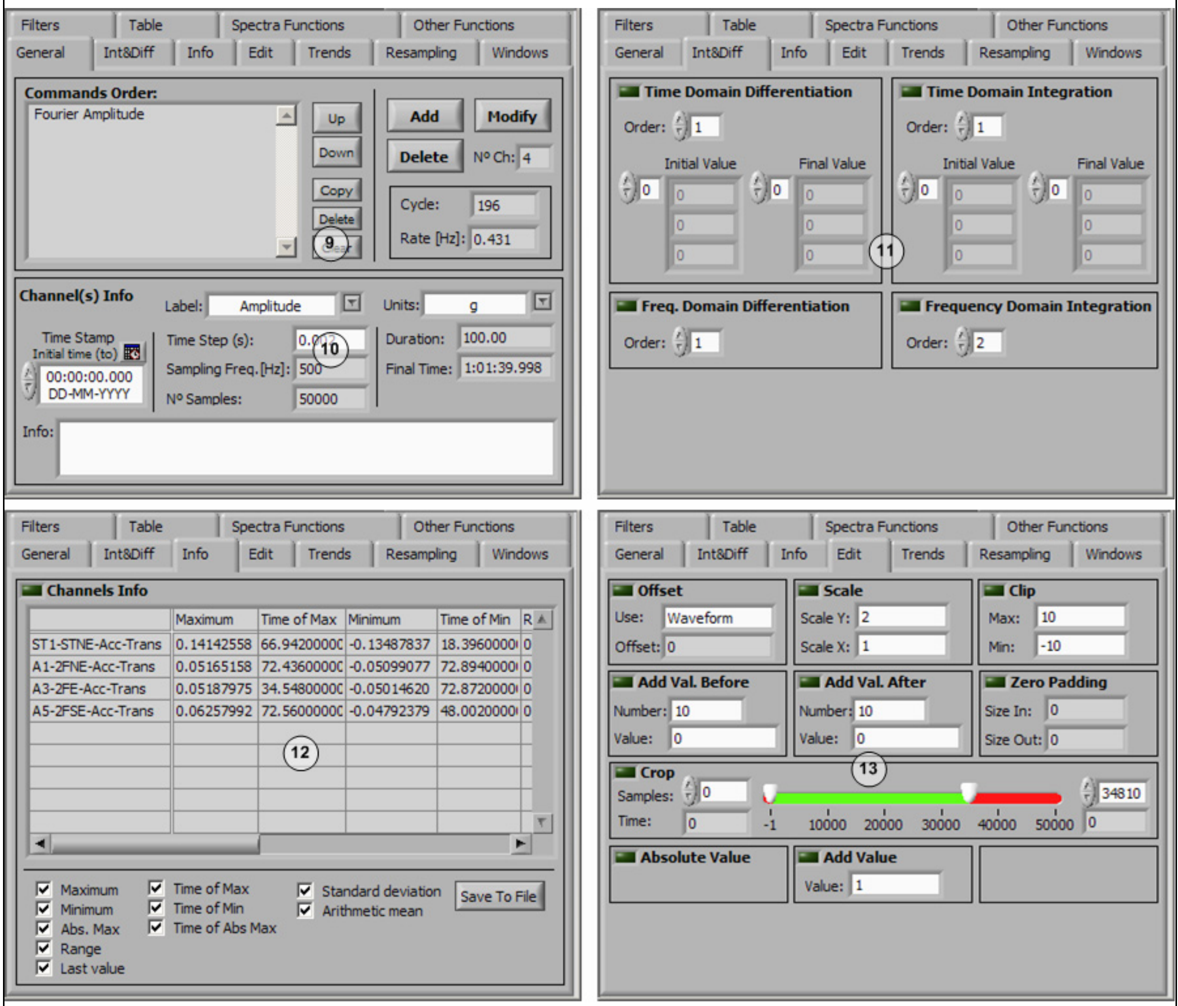
A.11 Analysis Module



Legend

1. Run/Help/Stop buttons;
2. Refresh chart control;
3. Single channel or multi-channel selectors;
4. Channels settings editor;
5. Time history graph;
6. Time history graph settings;
7. Functions graph;
8. Functions graph settings;

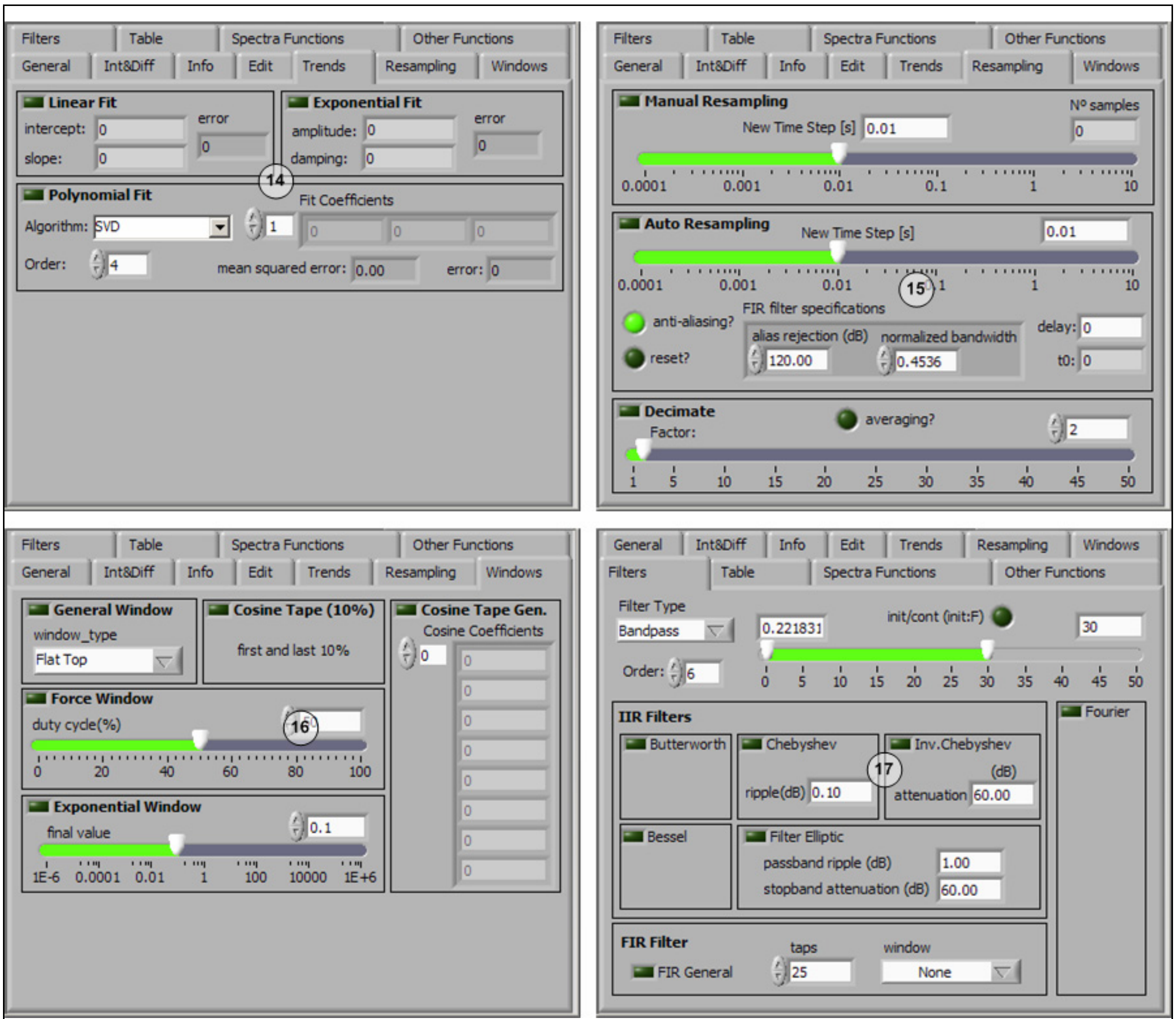
Figure A.15: Analysis Module.



Legend

9. Operations and functions queue;
10. Basic channels info (time step, sampling frequency, etc);
11. Time and frequency domain integration and differentiation;
12. Channels info table;
13. Basic time domain functions;

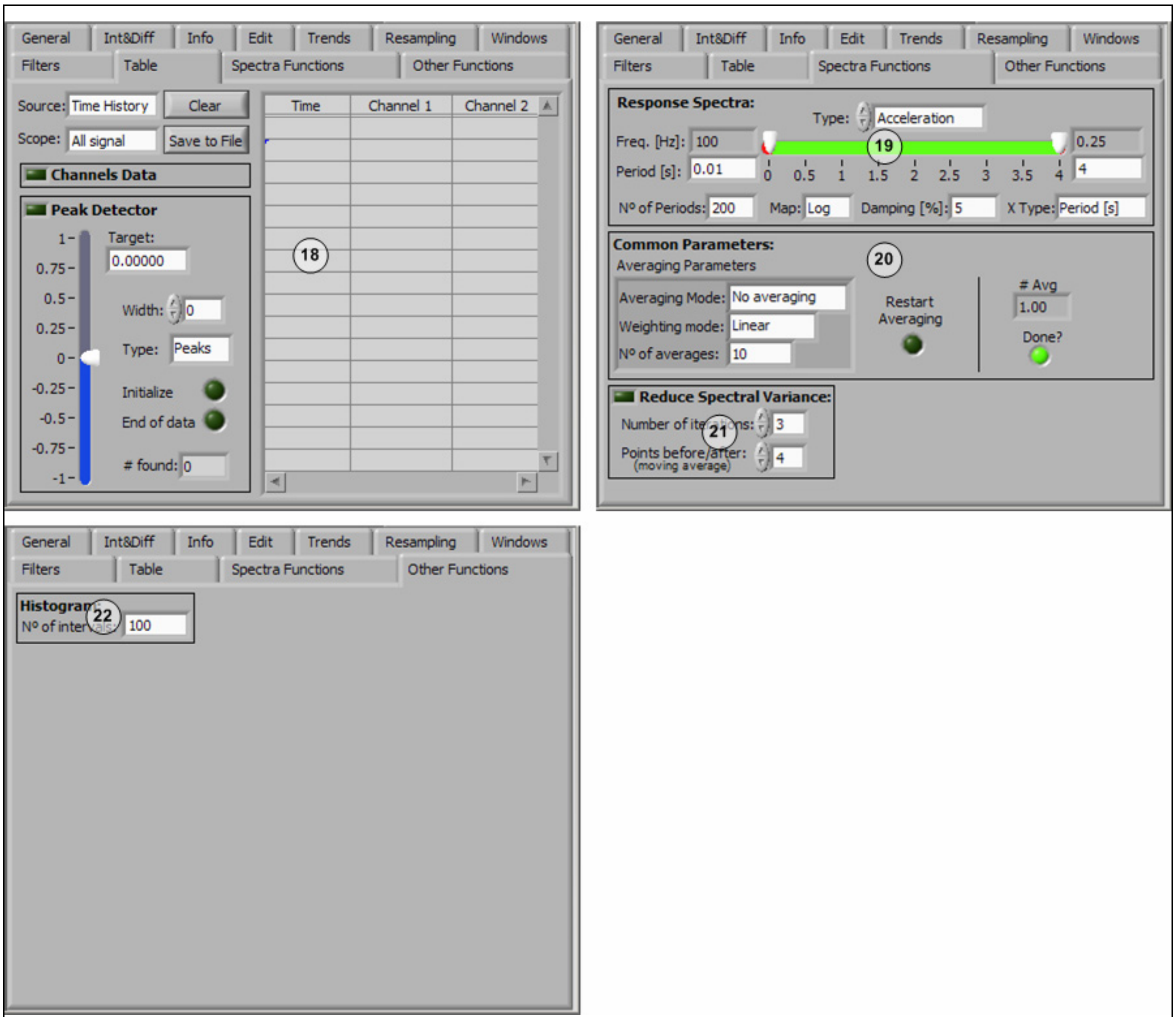
Figure A.16: Analysis Module (cont.).



Legend

14. Trends and fit functions;
15. Re-sampling functions (manual, auto) and decimation;
16. Time windows;
17. Filters;

Figure A.17: Analysis Module (cont.).

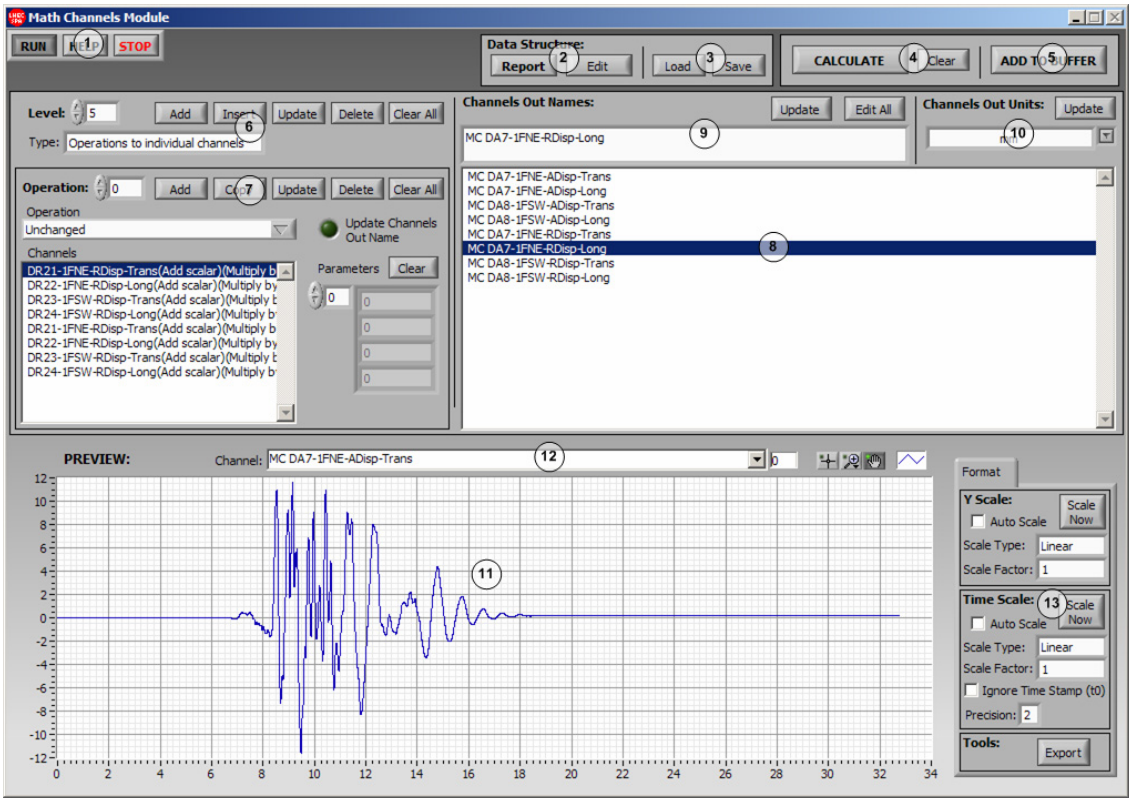


Legend

18. Data table and peak detector;
19. Response spectra settings (Functions graph);
20. Common parameter for multi-channel functions;
21. Reduce spectral variance function;
22. Histogram function.

Figure A.18: Analysis Module (cont.).

A.12 Math Channels Module

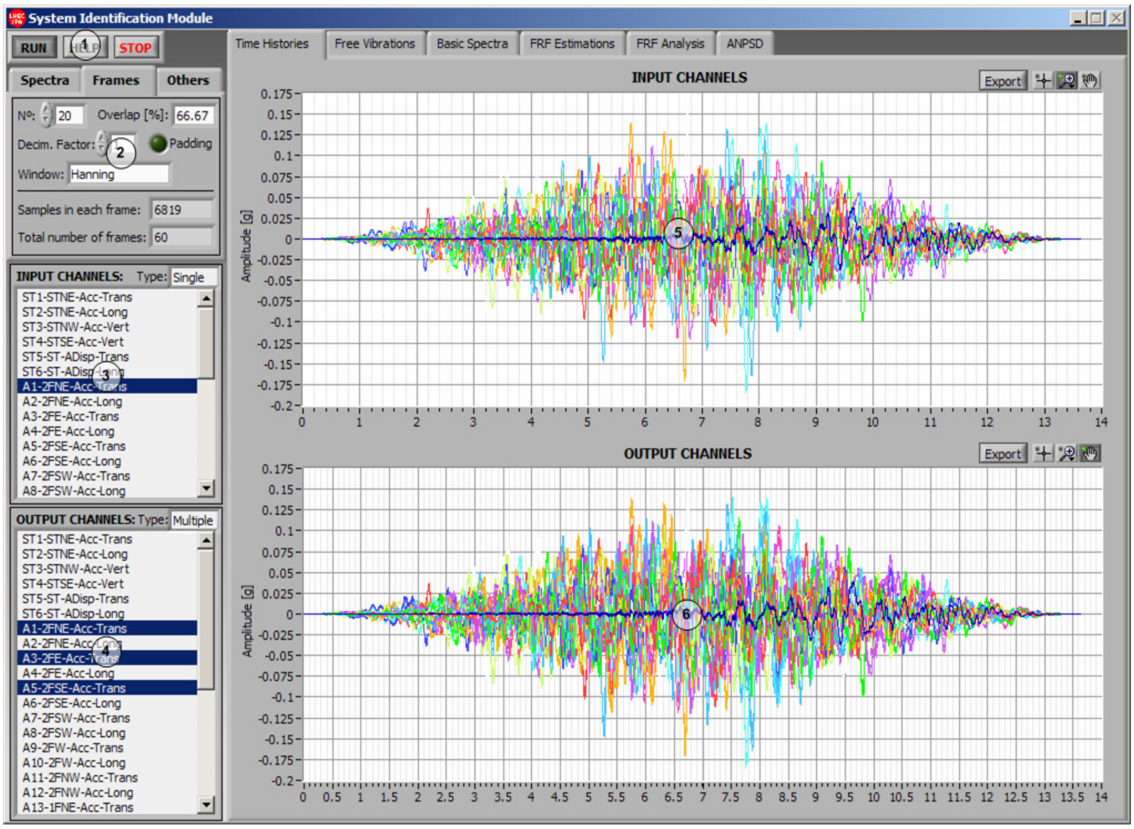


Legend

1. Run/Help/Stop buttons;
2. Data structure edit and ASCII report creation;
3. Load or save the data structure (mc file type);
4. Calculate or clear the math channels buffer;
5. Add math channels to the global buffer;
6. Data structure's *Level* parameters;
7. Data structure's *Operation* parameters;
8. Level's resulting channels;
9. Level's resulting channels names;
10. Level's resulting channels units;
11. Preview graph;
12. Preview graph channel selector;
13. Preview graph format;

Figure A.19: Math Channels Module.

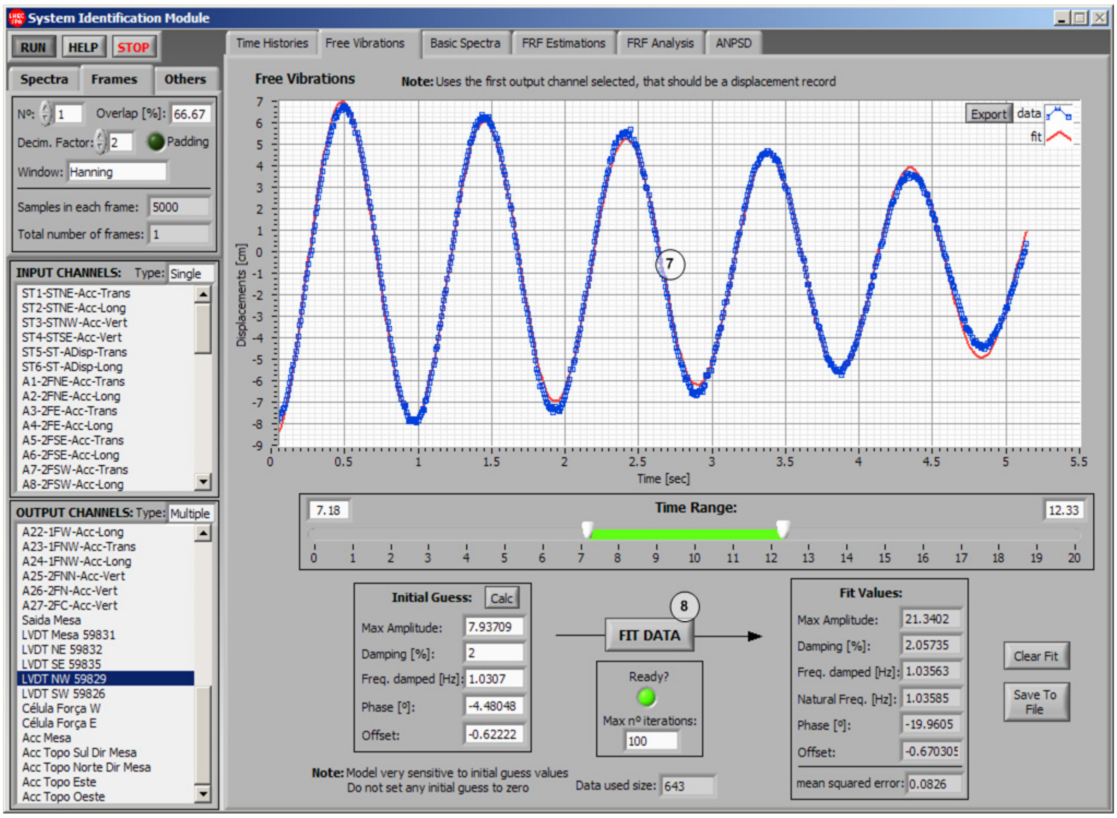
A.13 System Identification Module



Legend

1. Run/Help/Stop buttons;
2. Spectra, frames and other settings;
3. Input channels selector;
4. Output channels selector;
5. Input channels graph;
6. Output channels graph;

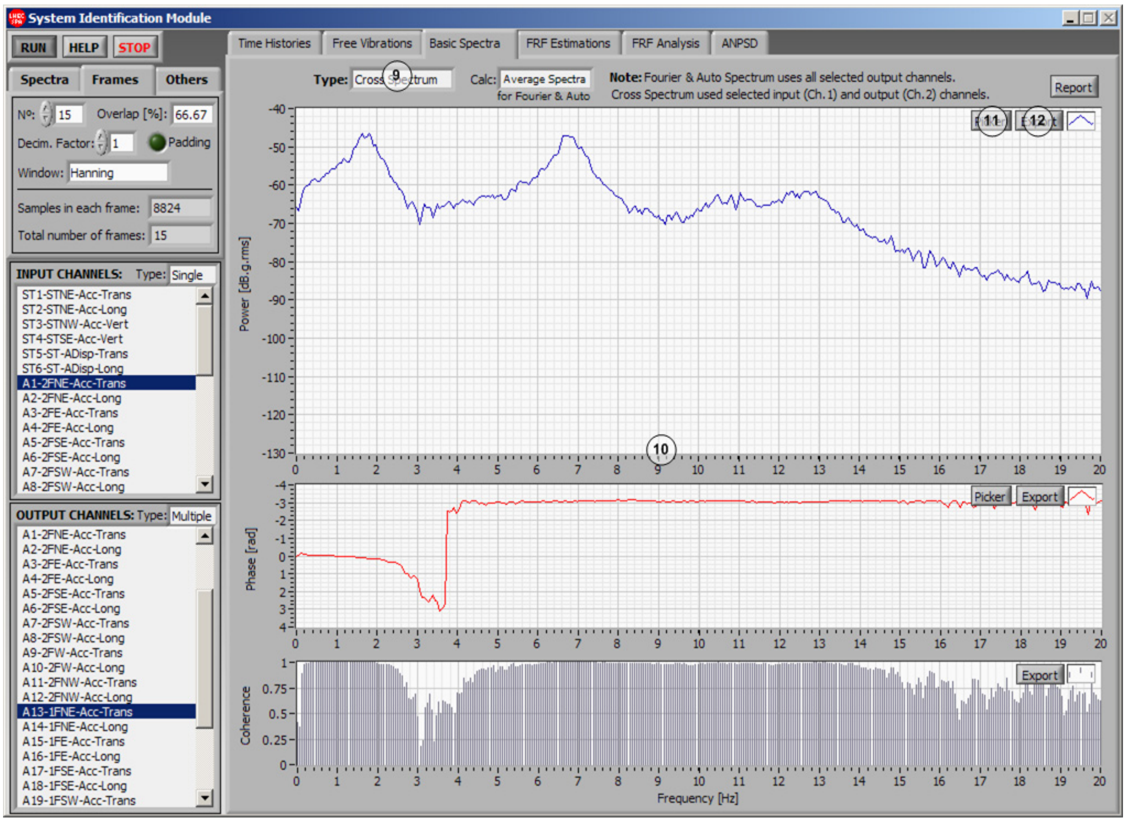
Figure A.20: System Identification Module.



Legend

7. Free vibrations graph;
8. Free vibrations fit parameters and results;

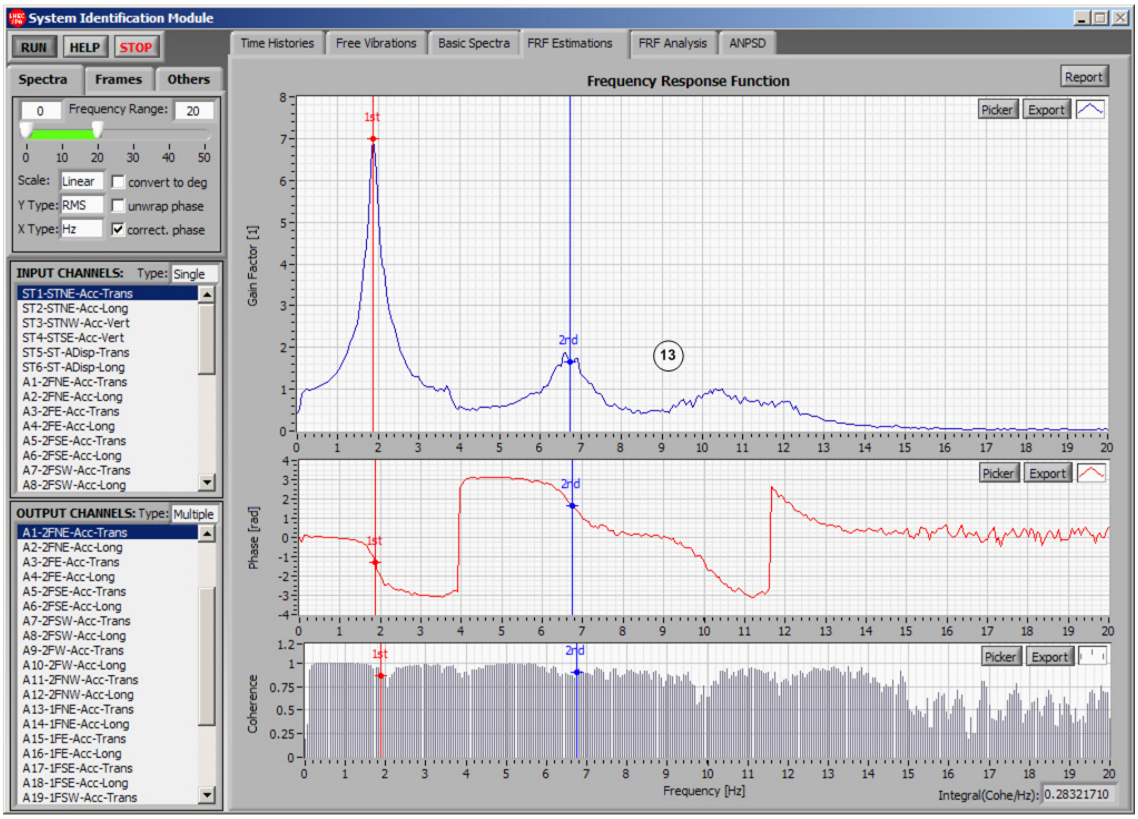
Figure A.21: System Identification Module (cont.).



Legend

9. Fourier, auto or cross spectrum functions selector;
10. Amplitude/power, phase and coherence graphs;
11. Displays the *Export sub-module*;
12. Displays the *Peak Picker sub-module*;

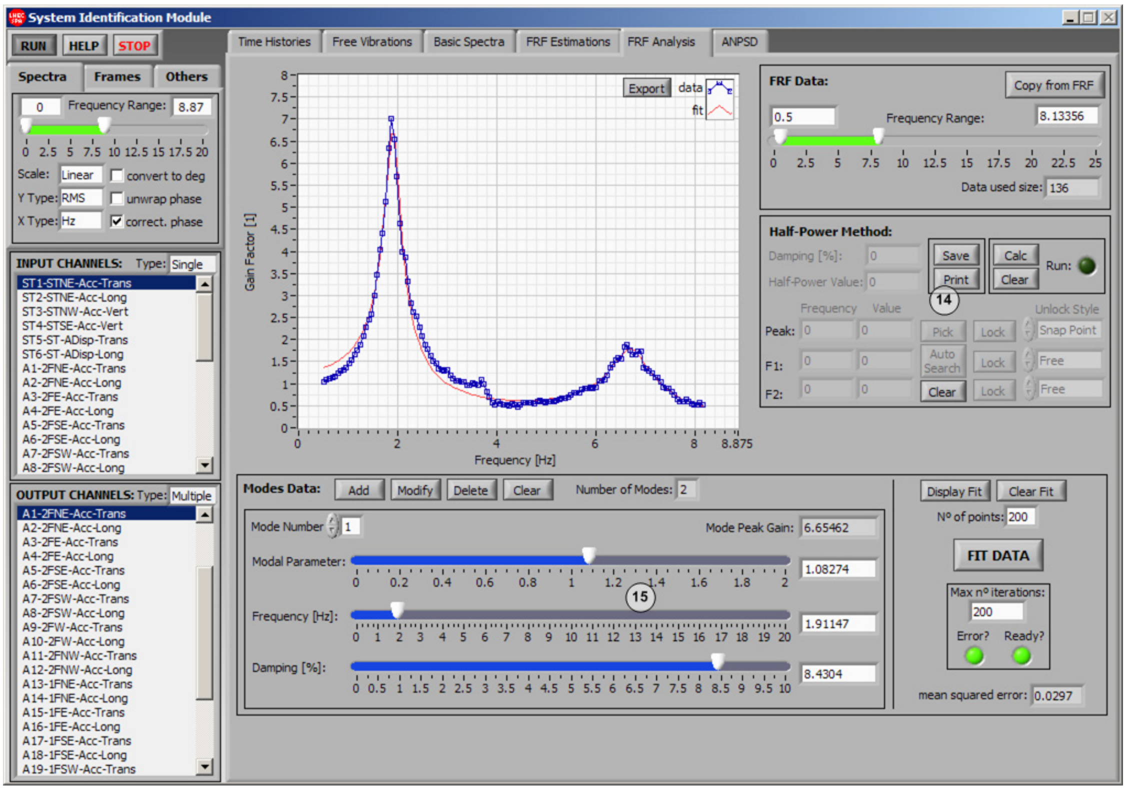
Figure A.22: System Identification Module (cont.).



Legend

13. FRF gain factor, phase and coherence graphs;

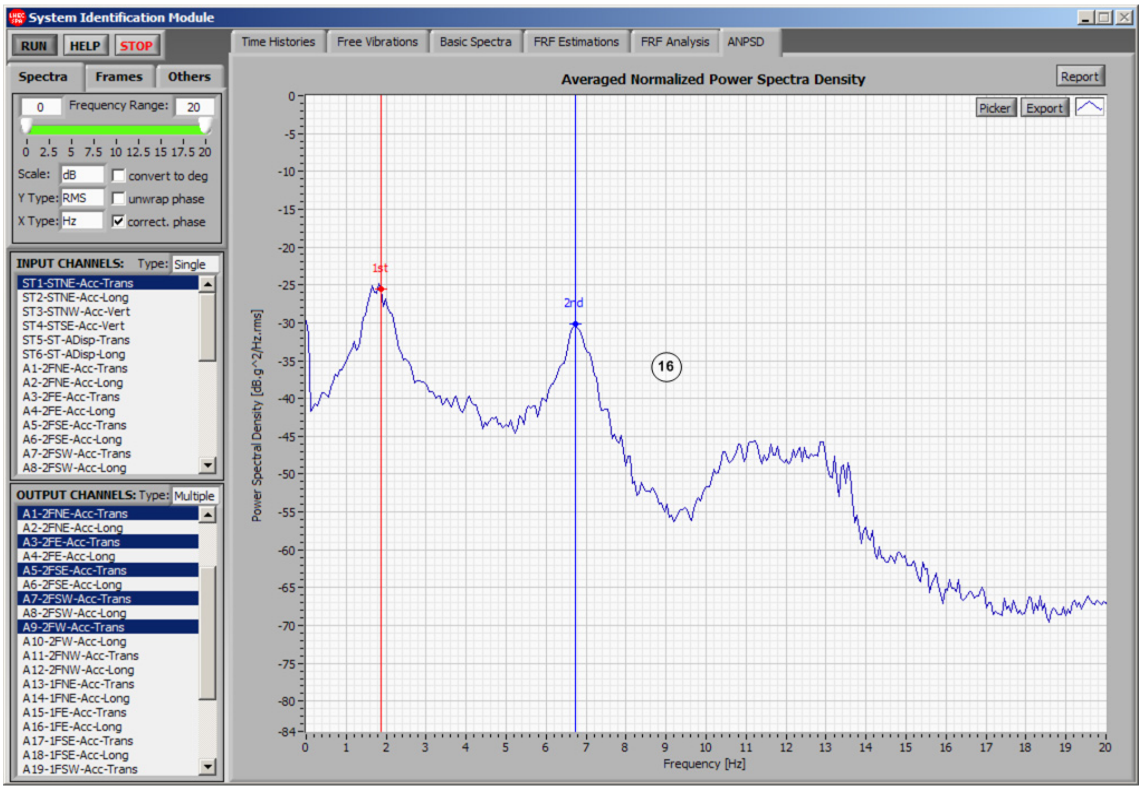
Figure A.23: System Identification Module (cont.).



Legend

14. Half-power method parameters and results;
15. FRF curve fit parameters and results;

Figure A.24: System Identification Module (cont.).

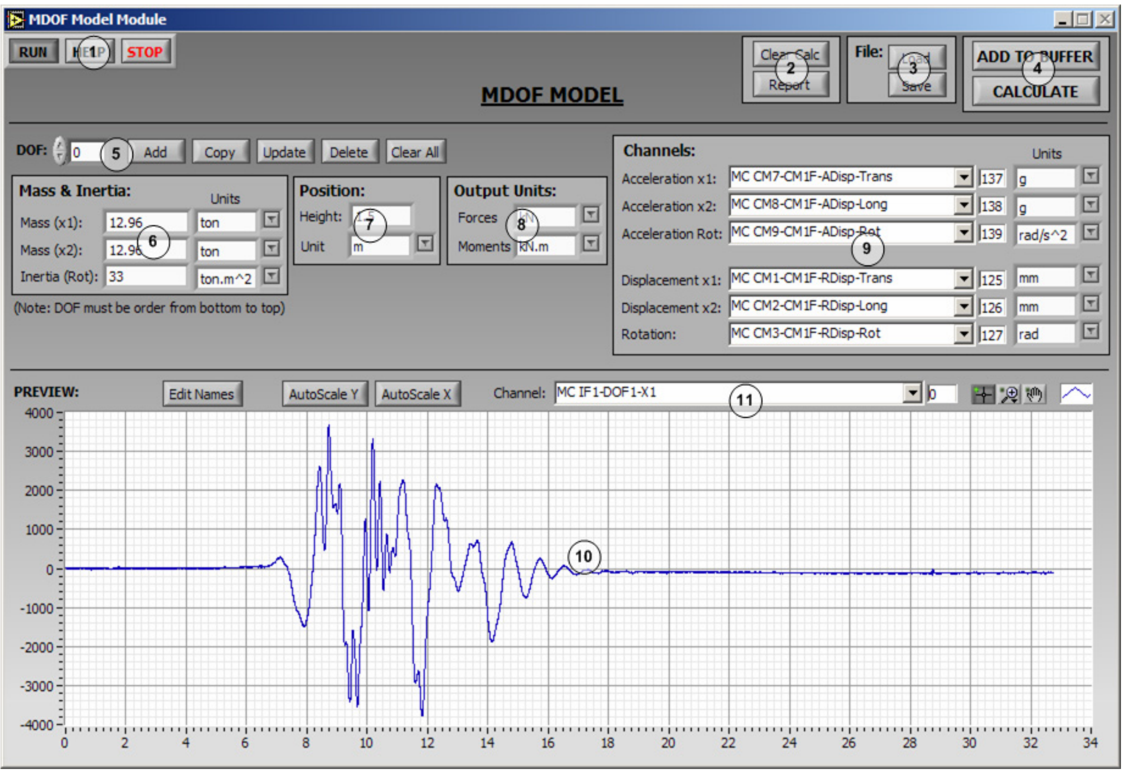


Legend

16. Averaged Normalized Power Spectral Density method graph.

Figure A.25: System Identification Module (cont.).

A.14 MDOF Model Module

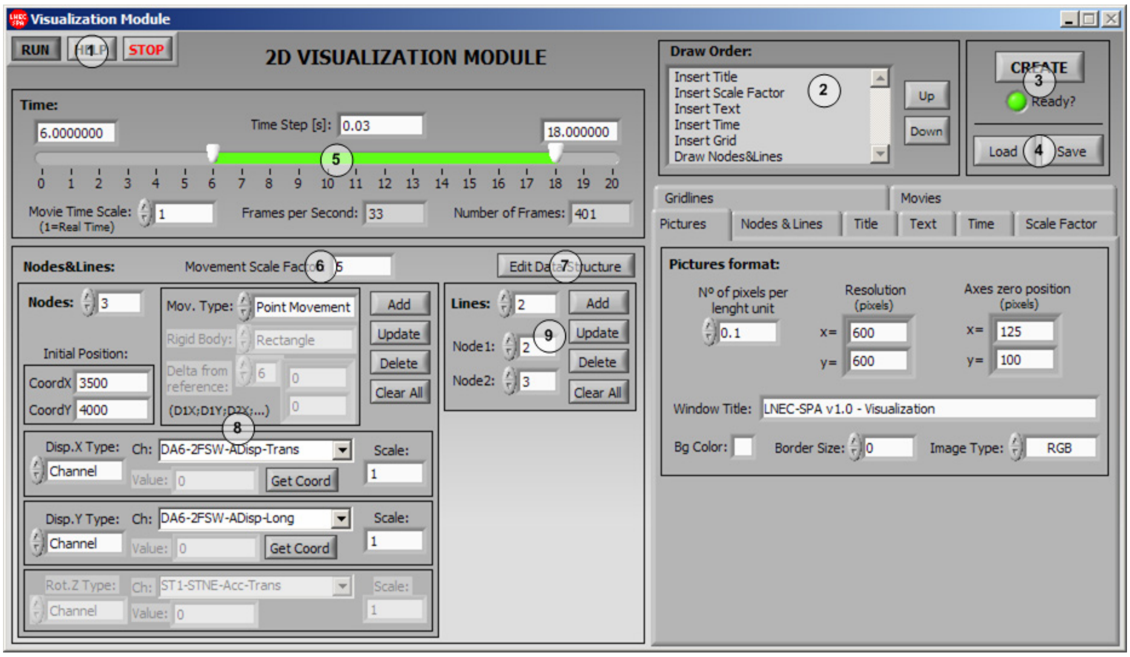


Legend

1. Run/Help/Stop buttons;
2. Clear calculation and automatic ASCII report button;
3. Load or save the MDOF model data (mm file type);
4. Add to buffer and calculate data buttons;
5. DOF's data definition;
6. DOF's mass & inertia;
7. DOF's position;
8. DOF's output units;
9. Accelerations and Displacements channels sources selector;
10. Preview graph;
11. Preview graph channel selector;

Figure A.26: MDOF Model Module.

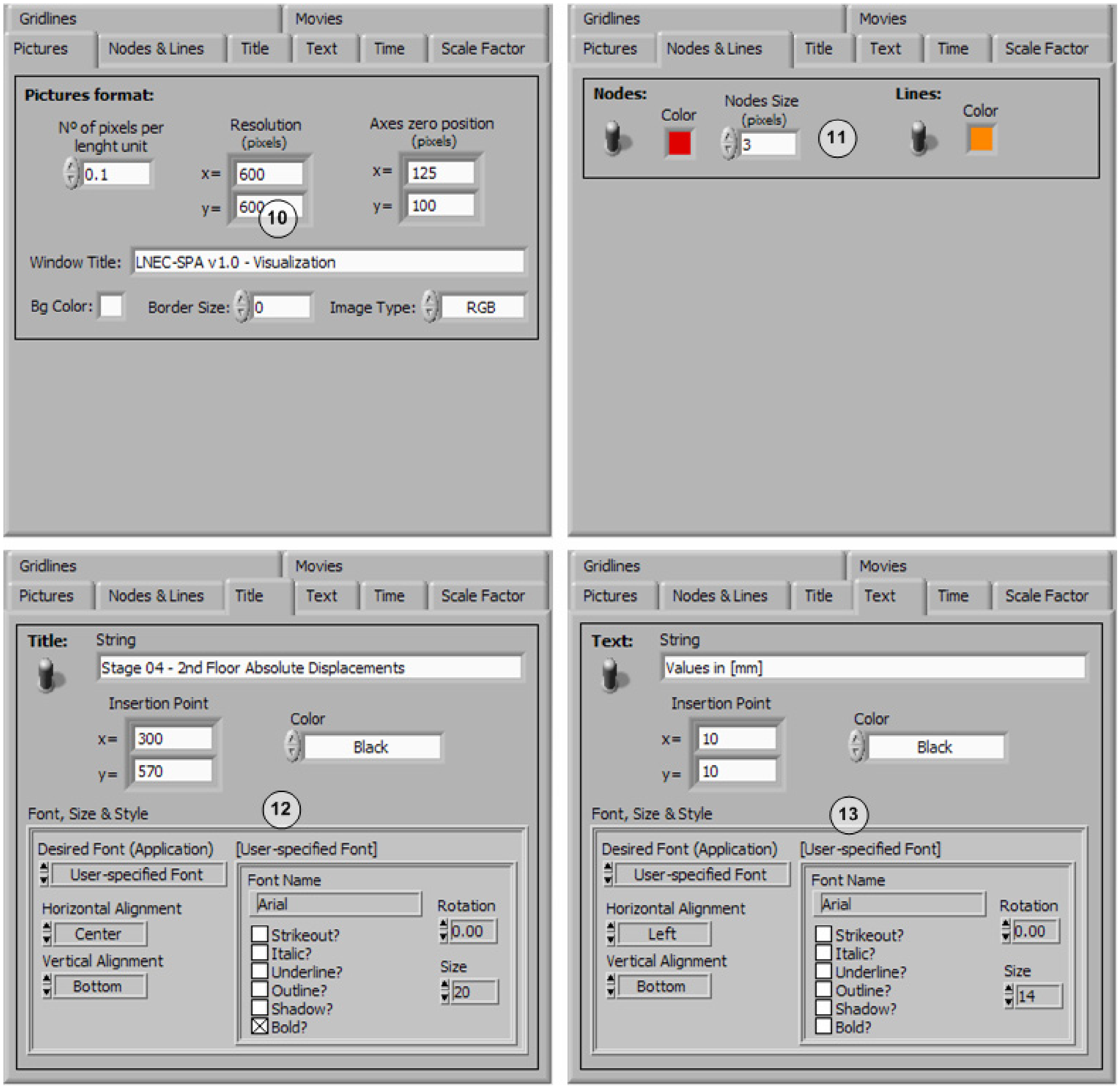
A.15 2D Visualization Module



Legend

1. Run/Help/Stop buttons;
2. Draw order queue;
3. Create/skip animation;
4. Load or save the visualization data file (vis file type);
5. Time parameters definition;
6. Movement's scale factor control;
7. Edit data structure;
8. Node's data parameters;
9. Line's data parameters;

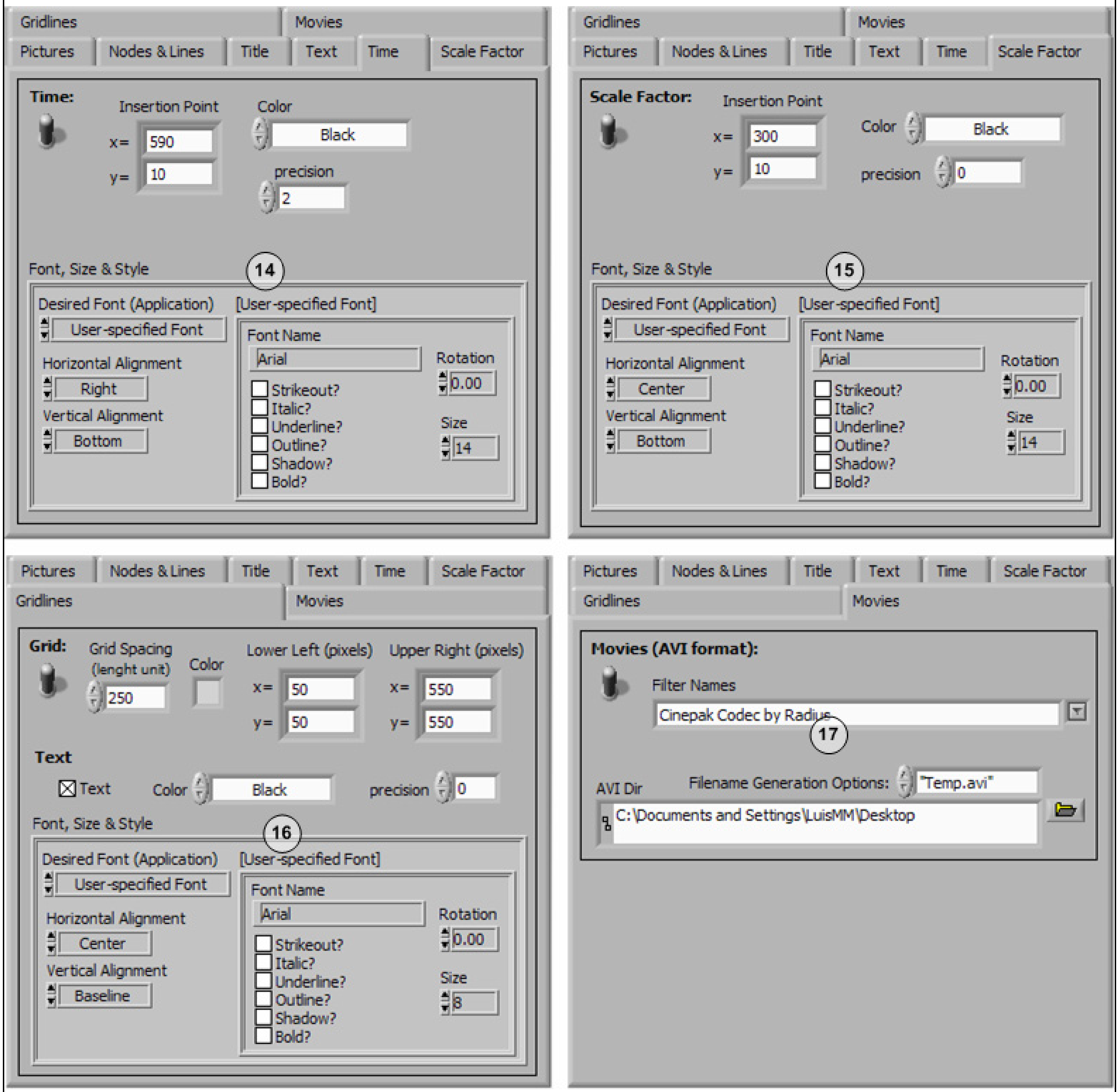
Figure A.27: 2D Visualization Module.



Legend

10. Picture/Frame parameters;
11. Nodes and Lines format;
12. Title text definitions;
13. Custom text definitions;

Figure A.28: 2D Visualization Module (cont.).

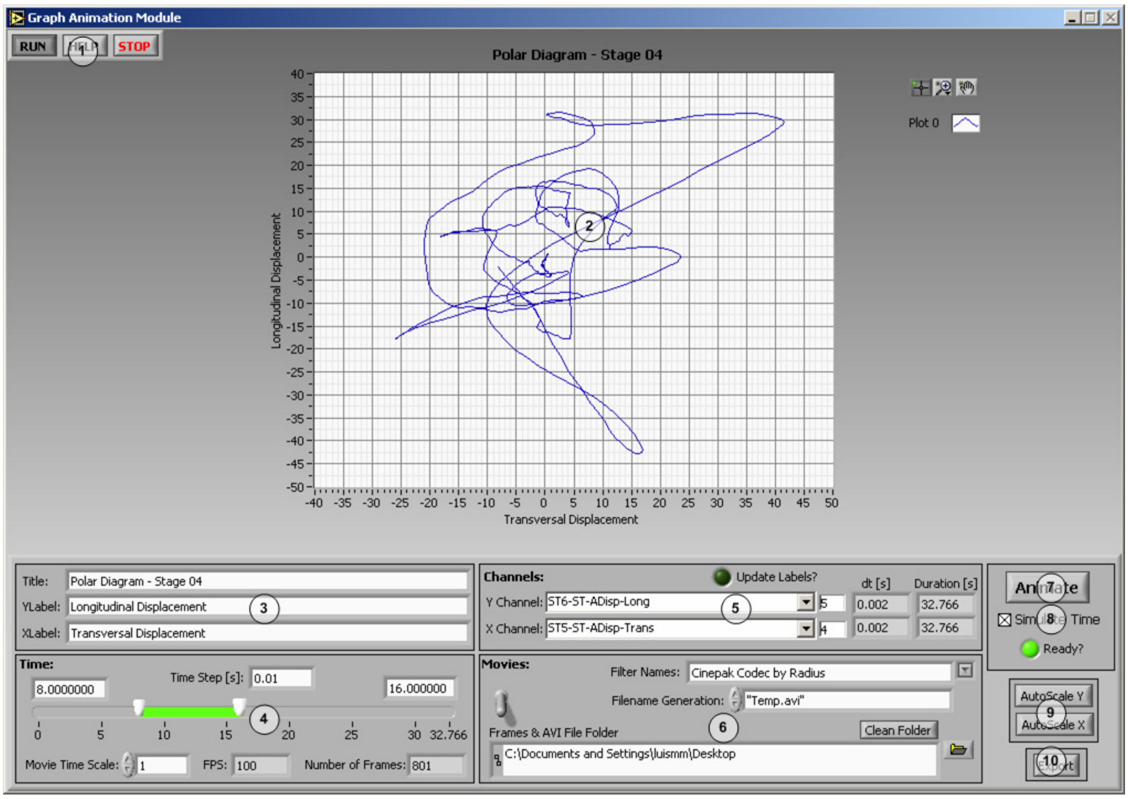


Legend

14. Time text definitions;
15. Scale factor text definitions;
16. Grid format;
17. AVI movie file parameters.

Figure A.29: 2D Visualization Module (cont.).

A.16 Graph Animation Module

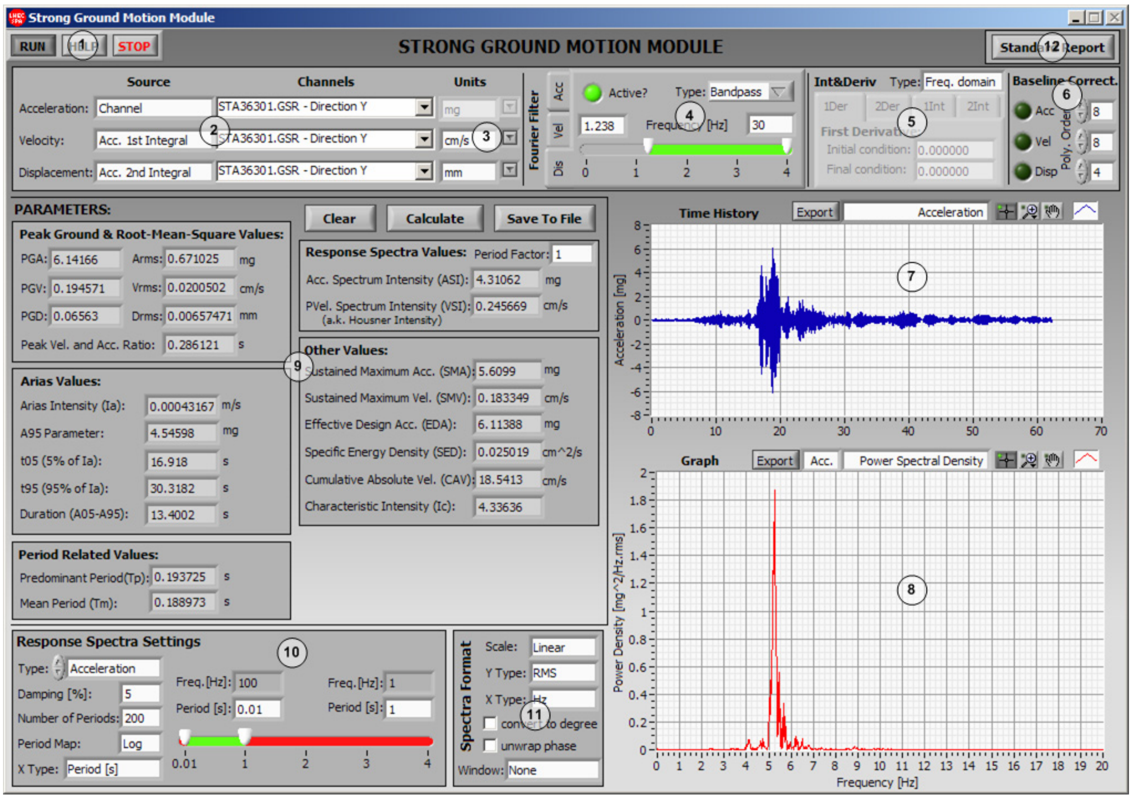


Legend

1. Run/Help/Stop buttons;
2. XY graph;
3. Title, X label and Y label definition;
4. Time scope and frames per second parameters;
5. Source channels selectors;
6. AVI movie file parameters;
7. Animate chart control;
8. Simulate time control;
9. Auto-scale X and auto-scale Y buttons;
10. Displays the *Export sub-module*.

Figure A.30: Graph Animation Module.

A.17 Strong Ground Motion Module

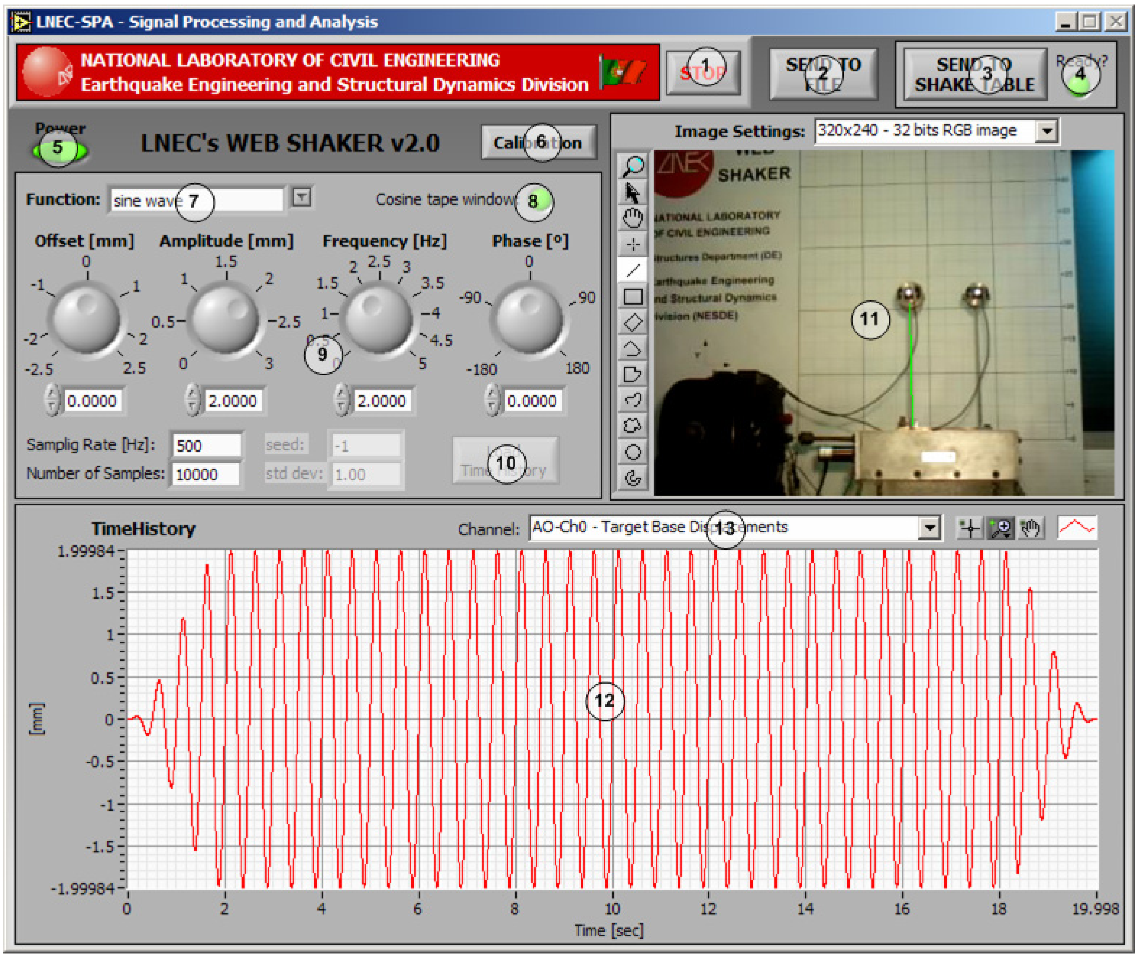


Legend

1. Run/Help/Stop buttons;
2. Source time histories definitions;
3. Time histories units selector;
4. Fourier filters;
5. Integration and derivation parameters;
6. Baseline correction using polynomial functions;
7. Calculated accelerations, velocities or displacements graph;
8. Functions graph;
9. Strong ground motion parameters;
10. Response spectra settings;
11. Common spectra parameters;
12. Standard report creation.

Figure A.31: Strong Ground Motion Module.

A.18 Web-Shaker Module



Legend

1. Stop button;
2. Save data to a supported file type;
3. Send output to the shaking table;
4. Ready state led;
5. Light power switch;
6. Calibration of the optic displacement transducers;
7. Output function selector;
8. Cosine tapper time window switch;
9. Functions parameters controls;
10. Load time history from file;
11. Images/movie captured by the web-camera;
12. Output and acquisition channels chart;
13. Channels selector;

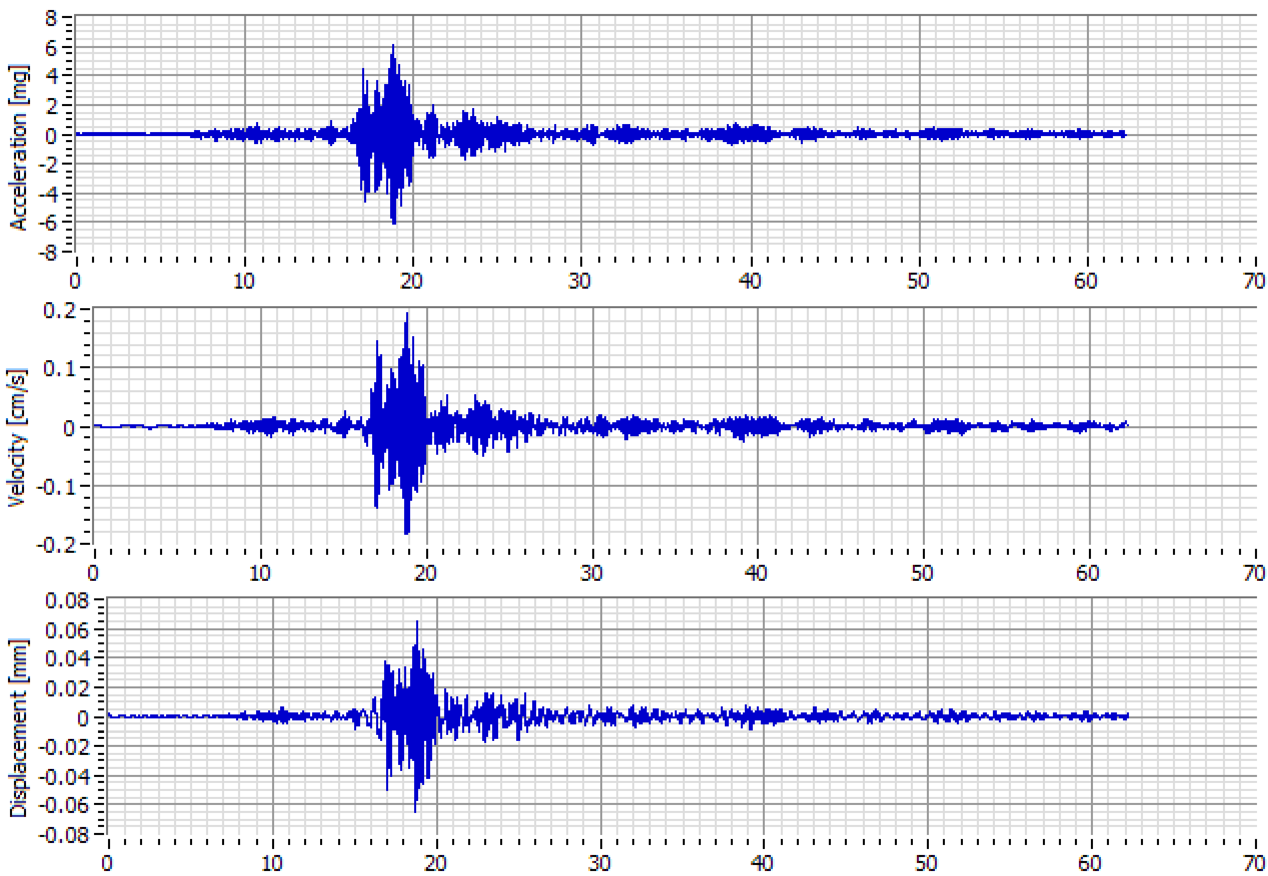
Figure A.32: Web Shaker Module.

B STRONG GROUND MOTION REPORT

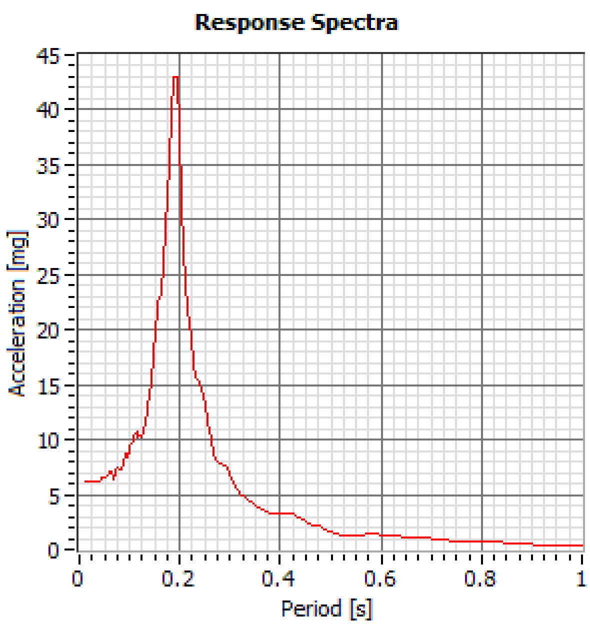
STRONG GROUND MOTION REPORT

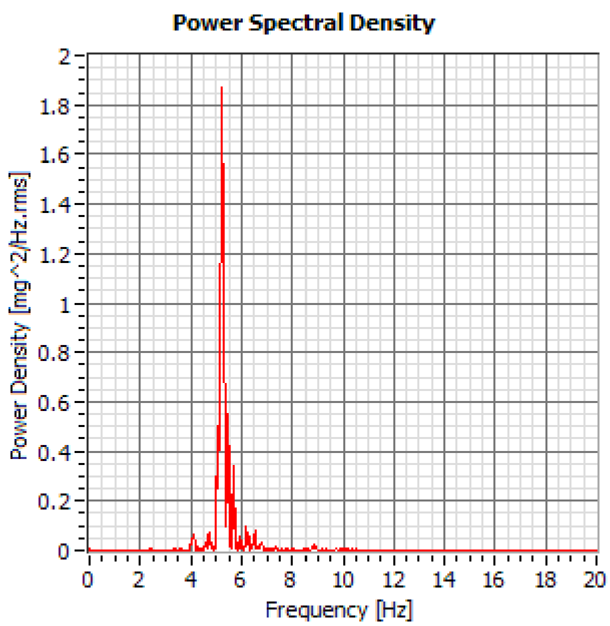
1- Time Histories

Acceleration TH: Channel - STA36301.GSR - Direction Y
Velocity TH: Acc. 1st Integral - STA36301.GSR - Direction Y
Displacements TH: Acc. 2nd Integral - STA36301.GSR - Direction Y



2- Response Spectra and Power Spectral Density - Acceleration TH





3- Parameters

Peak Values and Period Related		
PGA	6.141659	mg
PGV	0.194571	cm/s
PGD	0.065630	mm
PGV/PGA	0.286121	s
Predominant Period	0.193725	s
Mean Period	0.188973	s

Arias Related		
Arias Intensity (Ia)	0.000432	m/s
A95 Parameter	4.545981	mg
t05 (5% Ia)	16.917952	s
t95 (95% Ia)	30.318175	s
Duration (A05-A95)	13.400223	s

This report was generated by LNEC-SPA Software
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