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UNILAstic: Equipment and software to evaluate mechanical properties of materials by acoustic test

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Abstract. The complete system consists of a support unit, a measurement unit and software. The equipment was designed to perform non-destructive tests on small and medium cylindrical samples of different materials. The support consists of a light but strong aluminum structure for the location of the sample to be tested. The measuring unit consists of a microphone and a ball hammer. To perform the test, the sample is located in the support unit where wires serve as support. With the ball hammer, the sample is hit several times and the sound is recorded with the microphone. The UNILAstic software performs a vibration analysis based on samples of sound records to establish mechanical properties of the materials (modulus of elasticity, poison ratio and shear modulus) based on natural frequencies of the specimen (flexural, torsional and longitudinal frequencies). The UNILAstic software was coded in MATLAB®. This article shows details of the construction of the support unit in order that it can be replicated by anyone, in addition, the software features are presented showing its simplicity to obtain material properties through some tests performed on concrete specimens. As a conclusion, the work presents an equipment that can be replicated in a simple way and at very low cost in the universities of Brazil.

Keywords: Acoustic test; elastic modulus; natural frequency.

1 Introduction

UNILAstic is the result of equipment and software developed in the MATLAB® language, which aims to help determine the mechanical properties of concrete through an economical and efficient tool. The first stage of the study consisted of surveying the theoretical framework, covering bibliographies on different existing methods to identify and calculate the mechanical properties of materials. The second stage was based on the survey of the quantities and budget of the materials, in order to build with affordable materials. In the last step, a test and validation of the software operation was carried out. Below, the methods behind the software programming are presented.

2 Materials and methods

2.1 Measurement principle

Non-destructive testing (NDT) is used as a non-invasive indirect testing technique to assess structural conditions economically and efficiently way [8], according to Davis [3], the impulse excitation technique (IET) stands out , due to its speed and ease of excitation of a structure in order to obtain the response, which aims to quickly identify regions within the structure that present problems for further investigation, resulting in considerable economic benefits and heightened confidence for engineers and owners. IET is a fully recognised standard test method to determine dynamic material modules according to ASTM E1876-01 [1] by measuring the fundamental resonance (or natural) frequency (f_r) from the vibration of a sample after it has been excited by a slight mechanical impulse (touch). A microphone located under the sample receives the sound waves and transmits its signals to a computer for analysis [4]**.**

2.2 Procedure to identify mechanical properties

In order to identify the mechanical properties of the material, it is first necessary to support the sample properly in its resonance nodes (0.224L at each end, where L is the length of the sample) [5]. Soon after the test is finished, the data is collected and, converted the signal acquired in the time domain to the frequency domain applying the fast Fourier transform, hence determining an approximate set of resonance frequencies (f_r) of the material (monolithic, single geometry isotropic) tested [2]. Calculating the elastic modules of the material (with high precision and reproducibility) is possible because the resonance frequencies (f_r) depend on the mass, dimensions and elastic properties of the tested sample [6].

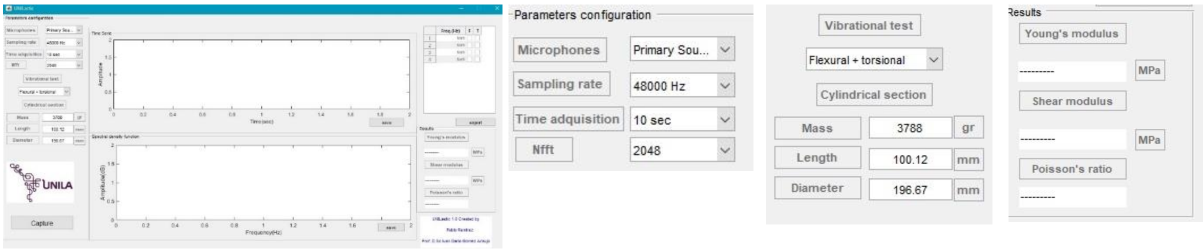
The procedures of ASTM E1876-01 [1] and the method proposed by Kolluru, Popovics and Shah [9] were the methodologies implemented in the UNILAstic software to determine the elastic properties of cylindrical concrete specimen. The application of the ASTM E1876-01 method [1] to estimate the modulus of dynamic elasticity requires defining the fundamental flexural resonance frequency. In contrast, the estimation of the shear modulus and the Poisson coefficient is an iterative process, starting from the fundamental torsional frequency. Likewise the method of ASTM E1876-01 [1], the method proposed by Kolluru, Popovics and Shah [9], makes it possible to determine the mechanical characteristics from the longitudinal frequencies. Based on the method proposed by Kolluru, Popovics and Shah [9], it is possible to determine the modulus of elasticity from the first longitudinal frequency and the shear modules and the Poisson coefficient from the first two longitudinal frequencies. This last method constitutes a direct procedure to determine the shear modulus and the Poisson's ratio.

2.3 Software and equipment

The software along side the equipment was developed in the MATLAB® Guide and the program runs on Microsoft Windows®, the user interface is shown in Figure 1a, and is divided into simple modules which are presented below,

- Parameter setting panel: as shown in Figure 1b covers (i) the selection of the microphone that connects to the computer; (ii) selection of the sampling frequency; (iii) definition of the test time in seconds; and (iv) size of the Fourier transform (Nfft). Acoustic test: the user selects the type of test to be performed, the mass, length and diameter of the test body is defined (Figure 1c);
- Results panel: the results of Young's modules, shear module and Poisson coefficient are presented (Figure 1d);

To run the program, the user first defines the test configuration parameters, then the Capture button must be pressed to start the test. The microphone is placed opposite from the excitation position in order to identify the natural frequencies properly, according to the type of test to be performed.Within the time determined in the program, the microphone initially acquires the ambient sound, followed by the sound coming from the specimen due to the impacts given on it with the test hammer. Upon completion of the test, the program automatically identifies the peaks in the spectrum of the acquired signal, shown them in a table. The user must select from this table the natural frequencies that he/she considers fundamental, either flexural or longitudinal, depending on the type of test defined in the initial configuration. By selecting these frequencies, the software automatically calculates the mechanical properties of the specimen.



(a) (b) (c) (d)

Figure 1. UNILAstic: (a) graphical program opening interface; (b) initial settings panel; (c) acoustic test type and material properties definition panel; (d) results panel.

For the acoustic test a support unit had to be built based on the specifications of Sonelastic® model SA-BC, as shown in Figure 2.

Figure 2. UNILAstic support unit

The following materials were used for the construction of the UNILAstic support unit:

Table 1 – List of materials and quantities

Description of the materials	Unit	Quantities	Total cost
Front Closing Cover - Square - 4 un	set	2	12,6
Surface Finishing - Side Strip for Channel 8	m	10	26,2
Aluminum Structural Profile 30x30 Center M8 - Channel 8	m	3	117,6
Base Levelling Foot 40 - w/ Hexagon Nut - 2 un	set	2	13,4
Angle Kit 38x38x28mm for Base Profile 30 - with Nuts and Bolts	set	2	17,7
Desandador - Male Turner	un	1	87,5
Long Allen Key with Dome Point - 5mm	un	1	12,96
Male Machine - M8	un	1	81
Allen Screw Head Flap M8 x 16mm - Connector 30 Screw - 10 un	set	2	18,7
Screw slot round head 3/16 mm	un	1	0,48
Solid stainless-steel round bar 1/2 "	m	1,66	129,48
Galvanized steel cable 1/16"	m	1	0,89
25 mm x 3/4" short thread PVC fittings	un	6	3,96
3/16" Wire Rope Stretchers	un	4	10,4
1/8" Wire Rope Clamps	un	4	2,2
Pedestal mini Ask Bumbo microphone holder (table+bong)	un	1	103,55

Microphone Shure	un	1	0
Total			**638,62**

It should be noted that the microphone for the time being is low-cost Shure brand, with the following features:

- Type of microphone: dynamic;
- Frequency response: 50 Hz to 15kHZ;
- Polar pattern: cardioid;
- Sensitivity: -52 dBV/Pa at 1 kHz;
- Impedance: 600 Ω;
- Cable type: XLR to ¼" of 4.57 m;

Table 1 shows that the total cost of the product is R$ 638.62 excluding cutting and welding services and the cost of the microphone, thereby making feasible the reproduction of the product when compared to the SA-BC model support marketed by ATCP Physical Engineering with a price of R$ 109,000 together with the software offered by the company [7].

A number of tests were carried out in a cylindrical concrete specimen in order to evaluate the functioning of the software in conjunction with the microphone. Besides this evaluation, a comparison of both the instruments to excite (Figure 3) and the sound pickup instruments is summed up, in this sense two types of microphones were used, the Shure and the acoustic sensor CA-DP.

(a) (b)

Figure 3. Excitation tools: a) Light Manual Impulse Device (DIML); b) Ball type hammer

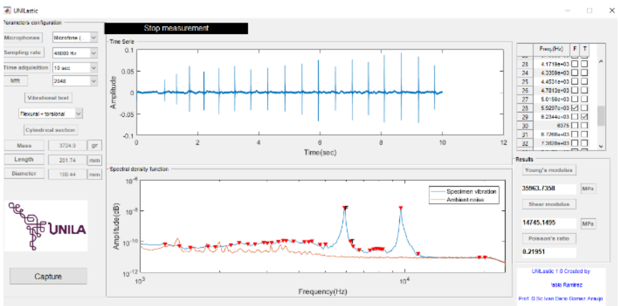


Figure 4. UNILAstic window finalized the test

The specimen was excited by the above mentioned tools. The preliminary results of the software are shown in Table 2, according to the test performed with mass equal to 3724.9 gr and average dimensions of D=99.866 mm and L=201.433 mm, the following initial configurations were adopted: sampling rate of 72000 Hz, time acquisition of 10 sec and Nfft equal to 2048. It should be highlighted that the values of modulus of elasticity are similar when compared to commercial software, on the other hand, the results of shear modulus and the Poisson ratio differentiate in the results, by the methods used in the calculation by UNILAstic.

Table 2 – Results

Test type	E (MPa)	G (MPa)	ν
Flexional + torsional w/ use of the SV 200 and DIML microphone (Fig. 4)	35963.7358	14754,1495	0,21951
Longitudinal w/ use of CA-DP and DIML microphone	35754.3516	14771,6048	0,21024
Longitudinal w/ use of CA-DP microphone and ball type hammer	35629.4955	14845,6231	0,2
Longitudinal w/ use of SV 200 and DIML microphone	35880.7129	15175,1894	0,18222
Longitudinal w/ use of CA-DP and DIML microphone	35745.7128	14768.0357	0.21024
Flexional + torsional w/ use of CA-DP and DIML microphone	35506.1208	14856.2237	0,19499

[1]Longitudinal w/ use of Sonelastic and SA-BC support	35900±0.207	-	0.20±0.05
[1]Flexional + torsional w/ use of Sonelastic and SA-BC support	35788±0.207	961	0.20±0.05

[1]The approximate Poisson's ratio should be informed in the commercial software.

3 Conclusion

As an immediate result, a simple method of building an equipment to obtain the mechanical properties of materials by the excitation impulse technique is presented, using economic materials and reused from other parts. The partial results presented by the software allow to conclude the mechanical properties of the material, emphasizing that the type of microphone affects the data collection as well as the excitation instrument. Thus, the following main conclusions were drawn:

- In the different tests performed, the light manual impulse device stands out as the most efficient instrument to excite the specimen, managing to excite high frequencies. It was found that the microphone is a fundamental tool in the identification of natural frequencies, the acoustic sensor CA-DP is able to better identify both high frequencies, as well as longitudinal and low amplitude and torsional frequencies, when compared with the model SV 200 microphone.
- The maximum frequency of 48 kHz is optimal for the cylindrical concrete specimen with the characteristics used in this article.

As a future research activity, add to the software the calculation for obtaining a damping curve versus amplitude. And the elaboration of a practical manual that describes the step for the construction of the equipment. Finally, we have to say that the software and the equipment developed in this research is not commercialized and is used exclusively for academic purposes of learning and research.

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References

[1] AMERICAN SOCIETY FOR TESTING AND MATERIALS. ASTM E1876-01, Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Impulse Excitation of Vibration. [S. l.: s. n.], 2009.
[2] CUNHA, Álvaro; CAETANO, Elsa. Experimental Modal Analysis of Civil Engineering Structures. Journal of Sound and Vibration, [S. l.], p. 12-20, 1 jun. 2006.
[3] DAVIS, A. G. The nondestructive impulse response test in North America: 1985-2001. NDT&E International, [s. l.], v. 36, p. 185-193, jun. 2003.
[4] HERITAGE, Kevin; FRISBY, Clayton; WOLFENDEN, Alan. Impulse excitation technique for dynamic flexural measurements at moderate temperature. Review of Scientific Instruments, [S. l.], p. 973-974, 29 fev. 1988.
[5] ROEBBEN, G. et al. Impulse excitation apparatus to measure resonant frequencies, elastic moduli, and internal friction at room and high temperature. Review of Scientific Instruments, [S. l.], p. 4511-4515, 12 dez. 1997.
[6] ROEBBEN, G. et al. The innovative impulse excitation technique for high-temperature mechanical spectroscopy. Journal of Alloys and Compounds, [S. l.], p. 284-287, 28 set. 2000.
[7] UNIVERSIDADE FEDERAL DA INTEGRAÇÃO LATINO-AMERICANA. Gabinete do Reitor. Extrato de Inexigibilidade de Licitação nº 7/2015 – UASG 158658, de 15 de abril de 2015. Aquisição do equipamento "Medidor não-destrutivo dos módulos elásticos e do amortecimento de materiais" para a estruturação do Laboratório de caracterização, análise e desenvolvimento de materiais - LACADEM. Diário Oficial da União, Brasília, DF, 22 abr. 2015. p. 30.
[8] LORENZI, Alexandre et al. Emprego de ensaios não destrutivos para inspeção de estruturas de concreto. Revista de Engenharia Civil IMED, [s. l.], p. 3-13, 2016.
[9] KOLLURU, S.; POPOVICS, J.; SHAH, S. Determining Elastic Properties of Concrete Using Vibrational Resonance Frequencies of Standard Test Cylinders. Cement, Concrete and Aggregates, [*s. l.*], p. 81-89, 1 dez. 2000.