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THE ESTIMATION OF DYNAMIC PROPERTIES OF A FIXED BEAM USING EXPERIMENTAL MODAL TESTING

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Abstract: *Complex and ambitious civil structures, like large cable-stayed or suspension bridges, dams, tall residential buildings , or other special structures compelled structural engineers to create new experimental methods to enable the accurate identification of the most relevant static and dynamic properties. This paper presents some general aspects regarding modal analysis and experimental methods for the estimation of the modal frequencies of a structure, followed by an experimental modal testing of a fixed beam, conducted in order to calibrate the computer finite element (FE) model.*
Key words*: experimental modal analysis, vibrations, frequencies response function, dynamic behavior.*

1. INTRODUCTION

Modal analysis has become a widespread means of finding the natural modes of vibration of a machine or structure. In every development of a new or improved mechanical product, structural dynamic testing on product prototypes is used to assess its real dynamic behavior.

Essential dynamic parameters such as the modal frequencies, modal shapes and damping coefficients are required in finite element modeling to predict the response of the structure to a variety of dynamic loadings.

The interaction between the inertial and elastic characteristics of the materials within a structure causes the phenomenon called resonant vibration. Structures can resonate and damage can be induced even by small dynamic forces, thus giving abnormally large vibrations.

Experimental modal testing is based on estimating a set of frequency response function (FRF) relating the applied force and corresponding response at several points along the structure. The measured time data is transformed from time domain to frequency domain using Fast Fourier Transform algorithm. [1]

The Fourier transform accomplishes this by breaking down the original time-based waveform into a series of sinusoidal terms, each with a unique magnitude, frequency, and phase. This process, in effect, converts a waveform from the time domain into a more manageable series of sinusoidal functions that when added together, exactly reproduce the original waveform. Plotting the amplitude of each sinusoidal term versus its frequency creates a power spectrum, which is the response of the original waveform in the frequency domain. Fig. 1 illustrates this time to frequency domain conversion concept.

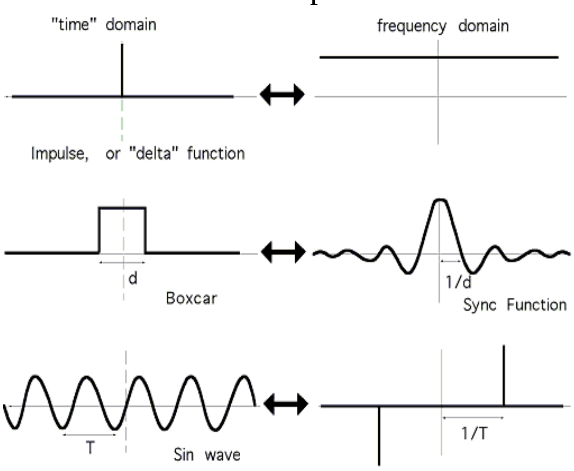

Fig. 1 The Fourier transform illustrated

2. OBJECTIVES

Measured time data is transformed from the time domain to the frequency domain using a Fast Fourier Transform algorithm found in any signal processing analyzer and related computer software packages.

Due to this transformation, the functions end up being complex valued numbers; the functions contain real and imaginary components or magnitude and phase components to describe the function.

One could evaluate a simple freely supported plate (Fig.2) subjected to a dynamic force with constant peak and changing rate of oscillation in sinusoidal fashion [2].

There are peaks in this function which occur at the resonant frequencies of the system. And we notice that these peaks occur at frequencies where the time response was observed to have maximum values corresponding to the rate of oscillation of the input excitation (Fig. 3 and 4).

We can use either the time trace to determine the frequency at which maximum amplitude increases occur or the frequency response function to determine where these natural frequencies occur.

Experimental modal analysis obtains the modal model from measured FRF data or measured free vibration response data. Thus, it is a path from response data to modal model. Once the modal model is derived, a number of applications can be investigated. Some applications of modal analysis involve direct use of modal data from measurement while others use these data for further analysis. Troubleshooting using experimental modal analysis is to gain an insight into a dynamic structure which is problematic [3].

An essential approach is to take a measurement of the structure, derive its modal model and use it to correlate with the existing FE model in order to update it. The philosophy behind this model correlation is that the modal model derived from measurement, though incomplete due to lack of sufficient numbers of vibration modes and measured locations, truly represents the structure's dynamic behavior. Thus, it can be used to 'correct' the FE model, should any discrepancies occur between them.

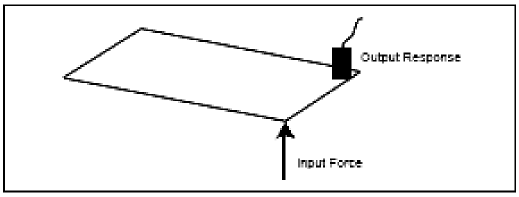

Fig. 2 - Excitation/response testing

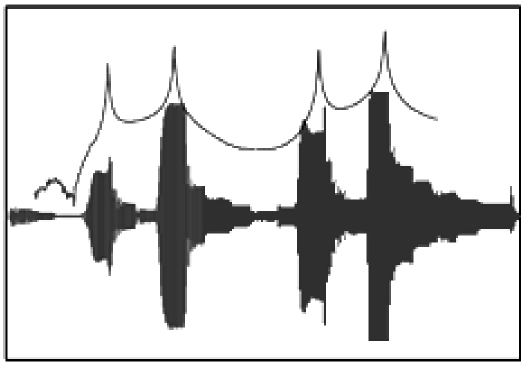

Fig.3 Overlay of time and frequency response functions

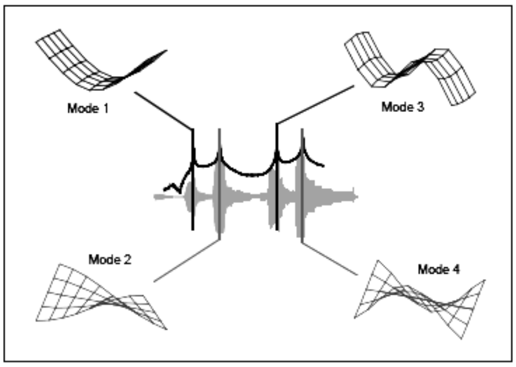

Fig.4 Simple plate sine dwell responses

Structural modification analysis, sensitivity analysis, response prediction, substructure coupling, structural damage detection and active vibration control are the other applications of modal parameters and the derived model from thereof.

3. EXPERIMENTAL METHOD

Conventional modal analysis is based on estimating a set of frequency response functions relating the applied force and corresponding response at several pairs of points along the structure. The construction of FRFs requires use of an instrumentation chain for structural excitation, data acquisition, and signal processing.

Remarkable technological progress in transducers and analog-to-digital converters has supported experimental modal analysis of large structures exclusively based on measuring the structural response to ambient excitations and applying suitable stochastic modal identification methods (the operational modal analysis).

In small and medium-size structures, the excitation can be induced by an impulse hammer similar to those currently used in mechanical engineering. This device has the advantage of providing a wide-band input that is able to stimulate different modes of vibration. The main drawbacks are the relatively low frequency resolution of the spectral estimates (which can preclude the accurate estimation of modal damping factors) and the lack of energy to excite some relevant modes of vibration.

An alternative, also derived from mechanical engineering, is the use of large electrodynamic shakers, which can apply a large variety of input signals (random, multi-sine, etc.) when duly controlled both in frequency and amplitude using a signal generator and a power amplifier.

The dynamic response of a structure is usually measured with piezoelectric, piezoresistive, capacitive or force balance accelerometers, due to their relatively low cost and high sensitivity [4]. A particular feature of piezoelectric accelerometers is that they don't need a power supply and operate well over a wide frequency range. The data acquisition and storage of dynamic data requires the use of an analog-to-digital (A/D) converter in the measurement chain.

4. EXPERIMENTAL TESTING

4.1 Equipments

- Modal hammer 8206C03 – PCB Piezotronics [5]
- Accelerometer Brüel&Kjær (4507)
- Software PULSE™ Labshop
- Pulse Type 3560-C Portable Data Acquisition unit [6]
- Connectors
- Laptop Computer

The specimen tested is a S235 steel bar, type UPN80 with the following dimensions: web height h = 8cm, flange width b = 4.5cm, web thickness t_w = 0.6cm, flange thickness t_f = 0.8cm, bar length L = 126,5 cm.(see Fig. 5).

4.2 Experimental set up

The beam was divided into a grid of points along the bar axis, by 7 cross-sections and 5 points on each cross-section, thus generating 35 points on the beam that will be the nodal points. The accelerometer was fixed in one of these points, leaving his position unchanged throughout the trial (see Fig. 5).

The impact hammer was prepared so that the induced force has a common optimal value to stimulate measurable frequencies of the beam, and on this basis was chosen the hammer tip and the additional weight at the opposite end. Fig. 6 shows all selected nodal points for and the striking directions.

The member was fixed at both ends; the restraints were made by spot welding between the profile and two metal plates which were fixed by adding weights on each one. The accelerometer was fixed at one side to the beam at the test node among all the nodal points on the beam. The impact hammer was kept ready to excite the beam at each point. On each strike, the structural response was obtained in frequency domain. For each point an average of three measurements was saved, provided that good correlation between measurements was achieved.

At the time of the striking with the impact hammer, precautions were taken whether the striking should have been perpendicular to the steel beam surface. The above procedure was repeated for all the nodal points. The FRF plots were saved after assigning the direction and the position of extracted data from the nodal points.

The values (i.e., natural frequencies and modal shapes) obtained from the experimental modal analysis were compared with the values obtained from a FEM analysis, created in Autodesk Robot Structural Analysis Professional code [7].

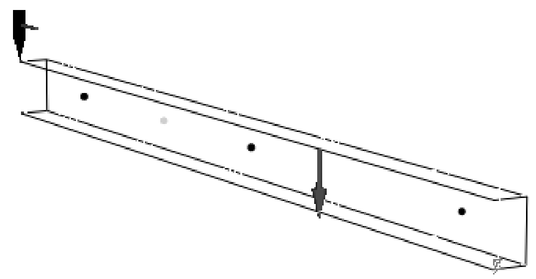

Fig.5 Accelerometer position and first striking position

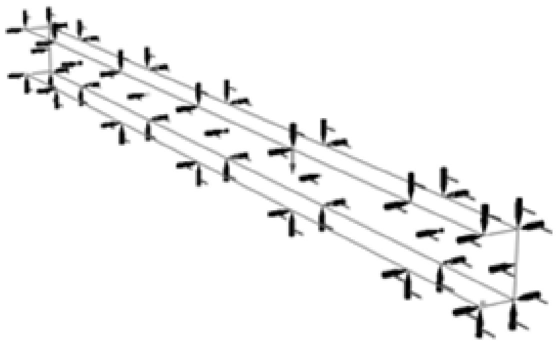

Fig.6 Establish points and directions for hammer striking

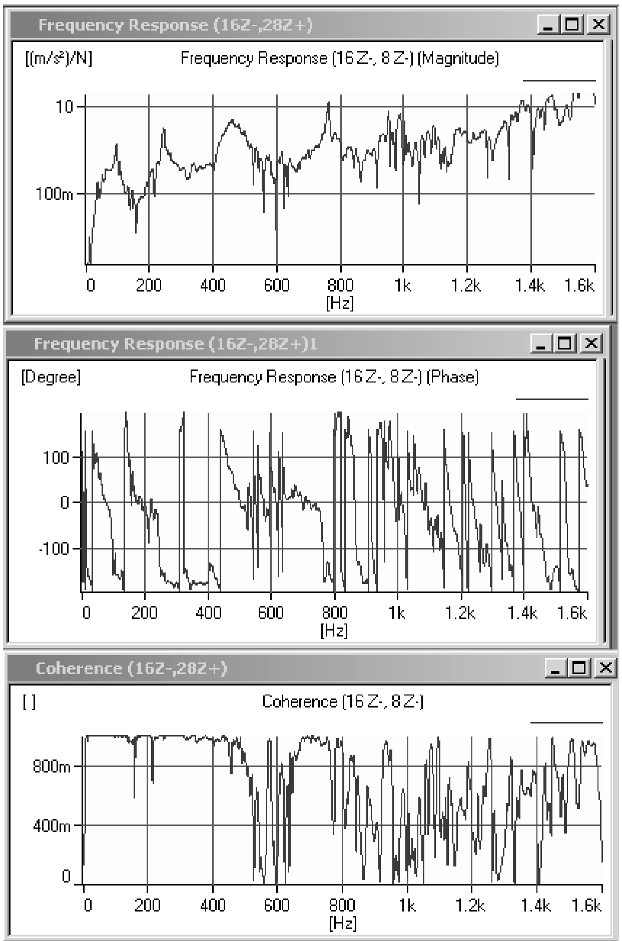

Fig.7 Frequencies Response Functions for one strike

4.3 FRF measurement

The measurement for experimental modal analysis is to acquire frequency response function data from a test structure. Experimental modal analysis is a system identification endeavor. The structure is a 'black box' that needs to be deciphered. The traditional approach is to provide the 'black box' with a known input, measure the output and proceed with the identification.

For our measurement, the authors used force input so that the FRF can be derived directly from the input force and member response information. The excitation force can be random, sinusoidal, and periodic or of impact nature. Theoretically, the type of force does not matter as the FRF is defined as the ratio between the response and force.

In practice, whenever practical one uses a force that has sufficient energy and frequency components to excite all vibration modes of interest and to allow minimum errors in signal processing, leading to the formation of accurate FRF data. The frequency response function was given by the acceleration divided by the input force.

4.4 Obtained results

The modal frequencies were estimated as the frequencies where we received maximum gain in the frequency response function plots. The results are in good compliance with those obtained from FEA.

Table 1

Modal frequencies: FEA vs. experimental test

Eigen mode	FEA modal frequencies (Hz)	Experimental modal frequencies (Hz)
1	52.93	52
2	89.33	97
3	299.65	253
4	456.27	457
5	759.65	759

Frequency range of the two analyzes are similar, but in some cases (mode 2, mode 3) there is a significant difference between FEA and experimental values, but these may be due to material imperfections of the bar.

The mode shapes look the same in both cases. An example is shown in fig.8 the modal shape of mode 4 extracted from FEA.

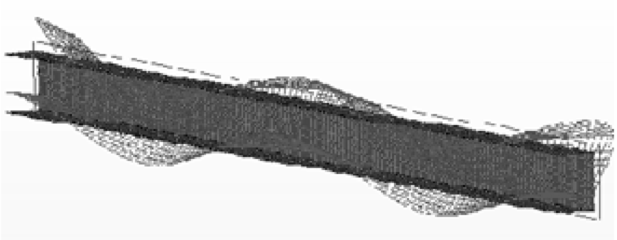

Fig.8 Modal shape of mode 4 – FEA

A vibration mode can be considered valid if the FRF plots can identify the correspondence between peaks function in all points considered to determine the experimental analysis. Thus, in figure 9 one can see the correspondence between peaks in frequency response functions, which are represented in different nodal points. All the resonance points (peaks) are separated by anti-resonance points, and must be in the same direction.

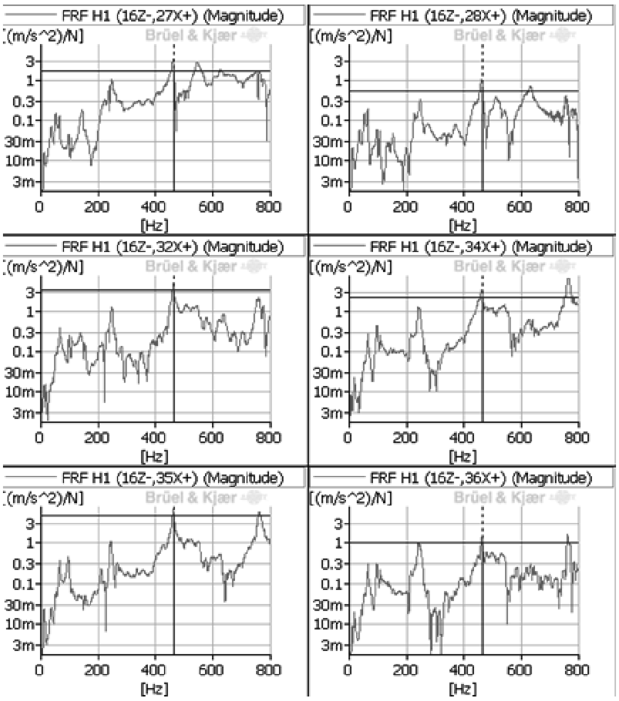

Fig.9 FRF plots

4.5 FE model calibration

The results presented were obtained only after the calibration of the model in the FE code. Because the member ends are not perfectly fixed, adjustments were made in the FEA using elastic supports. Thus, the bar's ends were partially fixed on vertical direction with a stiffness value (elastic coefficient) K_z = 180kN/m.

5. CONCLUSIONS

This paper presents an experimental test of a beam as an example of experimental modal analysis. The results were used to identify the beam dynamic characteristics and more important to calibrate the FE model. Same procedure can be made using similar equipment in order to perform structural dynamic testing of large civil engineering structures

The techniques that may be used under normal operation conditions can provide a solid basis for:

- development of FE correlation analyses
- FE updating and validation
- defining a set of dynamic properties of the initially undamaged structure that can later be used for the application of vibration-based damage detection techniques
- integrating classical or operational modal identification techniques in health monitoring systems
- implementing vibration-control devices

Civil engineering structures have peculiar characteristics (large size and relatively low natural frequencies) that make the current application of classical input-output modal identification techniques difficult. Therefore, there is presently a clear tendency worldwide to explore and improve the potential of output-only (operational) modal identification techniques.

The modal identification of bridges and other civil structures is required for validation of finite-element models used to predict static and dynamic structural behavior either at the design stage or at rehabilitation. After appropriate experimental validation, finite-element models can provide essential baseline information that can subsequently be compared with information captured by long-term monitoring systems to detect structural damage.

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TEST EXPERIMENTAL: DETERMINAREA PROPRIETATILOR DINAMICE ALE UNEI GRINZI METALICE INCASTRATE

Abstract: Construcțiile complexe şi ambițioase, precum barajele, podurile hobanate, suspendate sau alte structuri speciale au obligat pe inginerii constructori să dezvolte noi metode experimentale capabile de a identifica cu mare acuratețe proprietățile structurale statice şi dinamice. Această lucrare prezintă câteva aspecte generale privind analiza modală experimentală utilizată pentru estimarea frecvenţelor şi formelor modale proprii ale unei structuri, concentrându-se apoi pe analiza experimentală a unei grinzi dublu încastrate, analiză utilizată ulterior la calibrarea modelului numeric în element finit.

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