# CHARACTERIZATION OF MULTI-LAYERED PANELS MECHANICAL PROPERTIES

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## INTRODUCTION

With the advancement of science and technology, materials with high damping capabilities and high modulus of elasticity are increasingly popular as they reduce vibration and noise. However, most of the time, there is a lack of tools that allow quick and easy characterization of the effective materials properties when used in 2D structures. Usually, prediction is made using Finite Element Method (FEM) and in most cases, these FEM codes require input data that cannot be easily obtained. This is particularly true when the material is a "home made" composite sandwich material (glass fibers with polyester resin, etc.), in a procedure that cannot ensure a rigorous control on thickness, density, etc. This paper presents a method which uses a simple experimental setup (clamped at the corners) and a fast numerical code running on a personal computer. It allows extraction of equivalent properties of small rectangular composite panels in terms of "young modulus", "density" and "damping factor" versus frequency. A dedicated numerical code (based on hierarchical finite element method) is used to fit parameters in order to match measured and simulated data. It is shown that this method allows to quickly extract useful equivalent properties for composite materials.

## 1 - HIERARCHICAL FINITE ELEMENT FORMULATION

The simulation part of this hybrid method is based on the hierarchical finite element formulation [1,2] of a rectangular Love-Kirchoff plate. The normal displacement of the plate is given by:

$$w(\xi,\eta)=\sum_{r=1}^{p}\sum_{s=1}^{p} q_{rs} Q_r(\xi) Q_s(\eta),$$

where $\xi$ and $\eta$ are defined such that $x = \frac{(1+\xi)a}{2}$ and $y = \frac{(1+\eta)b}{2}$

*a* and *b* are the length and width of the plate.

The $\{Qr\}$ basis functions set is presented in fig.1.

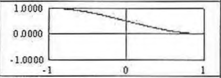
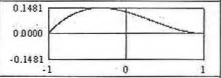
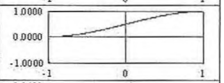
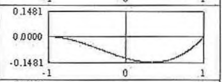
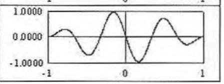
| Function order | Equation | Hybrid set $Q_r(\xi)$ |
|---|---|---|
| r=1 | $Q_1(\xi)=\frac{1}{2}-\frac{3}{4}\xi+\frac{1}{4}\xi^3$ |  |
| r=2 | $Q_2(\xi)=\frac{1}{8}-\frac{1}{8}\xi-\frac{1}{8}\xi^2+\frac{1}{8}\xi^3$ |  |
| r=3 | $Q_3(\xi)=\frac{1}{2}+\frac{3}{4}\xi-\frac{1}{4}\xi^3$ |  |
| r=4 | $Q_4(\xi)=-\frac{1}{8}-\frac{1}{8}\xi+\frac{1}{8}\xi^2+\frac{1}{8}\xi^3$ |  |
| r>4<br>For example here r = 10 | $Q_{10}(\xi)=\sin(3\pi\xi+3\pi)\sin(5\pi\xi+5\pi)$ |  |

Fig. 1 Hierarchical Hybrib Basis Functions Set

This basis functions set is built from polynomial functions [1] for the first four functions and from trigonometric functions [2] for the rest. This functions set allows to easily define cinematic boundary conditions (free, simply supported, clamped, rigid point) on each edge and on each corner of the plate, simply by removing appropriate functions from the complete set.

## 2 - VALIDATION OF THE FORMULATION

Validation of the formulation is obtained by comparing the developed code results to those of well known codes.

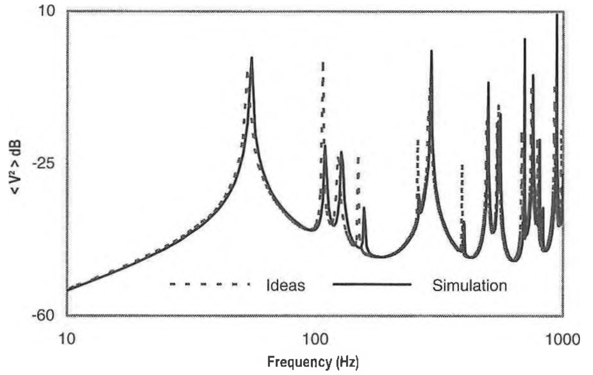


Fig. 2 <$V^2$> of an Aluminum plate: Ideas versus Simulation

Figure 2 shows a comparison of the developed code and ***SDRC-IDEAS Vibroacoustics*** results (mean quadratic velocity of a plate excited by a shaker) in the case of a "Four corners pin clamped" case (see figure 4) for an Aluminum plate. This figure shows that the boundary conditions are well mastered by the developed code. Figure 3 shows a comparison of the developed code and **MNS/ADNR**$^{\mathbf{I}}$ results in the case of a "simply supported plate" case for a viscoelastic plate (Young modulus and damping factor are frequency dependent). This figure shows that the developed code allows to efficiently simulate viscoelastic plates.

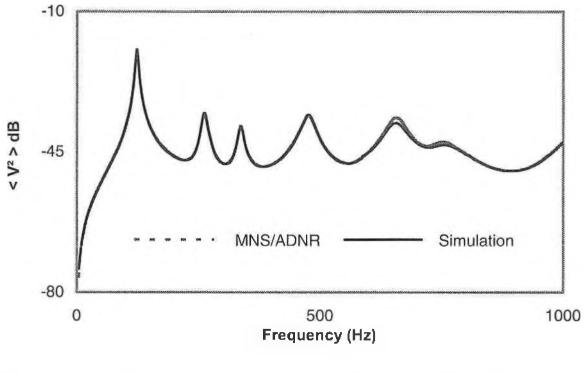


Fig. 3 <$V^2$> of a Viscoelastic plate: ADNR versus Simulation

## 3 - EXPERIMENTAL SETUP

The measurement part of this hybrid method consist on a clamp fixture presented in figure 5 which allows to set "Four corners pin clamped" boundary conditions. This type of fixture has two advantages: (*i*) Easy mounting set-up (*ii*) Low vibration energy losses at the boundaries, allowing a better characterization of the intrinsic panel damping. The plate is excited by an electro-dynamic shaker and its mean quadratic velocity is measured using a scanning laser vibrometer coupled to a PC.

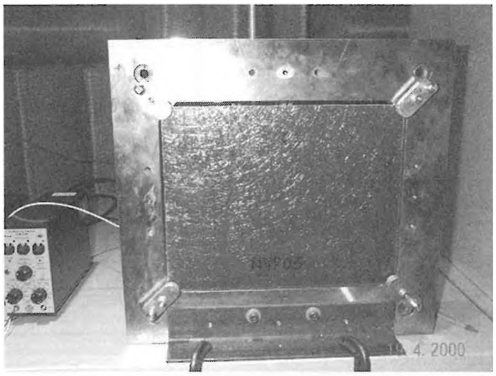


Fig. 5 Plate fixture with "Four corners clamped"

## 4 - VALIDATION OF THE EXPERIMENTAL SETUP

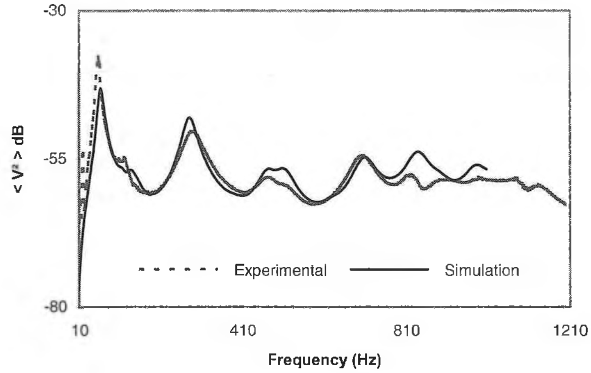


Fig. 6 $<V^2>$ of a Multi-layered Viscoelastic plate: Experimental versus Simulation

Figure 6 shows the comparison of experimental measurements versus theoretical prediction using the developed code. Good agreement is found between experimental and numerical results for the Multi-layered Viscoelastic Panel. For the case shown, the Multi-layered Panel consists of a layer of 3M ISD112 between two steel panels.

## 5 - EXPLOITATION OF THE METHOD

As example of exploitation of this hybrid method, after extracting equivalent properties in terms of Young modulus and damping factor, an untreated Glass Fiber Reinforced Plastic (GFRP) composite panel is compared to a GFRP containing a layer of 3M ISD112 and to a panel of Glass Fibers embedded in viscoelastic resin (figure 7 panels 4 mm thick).

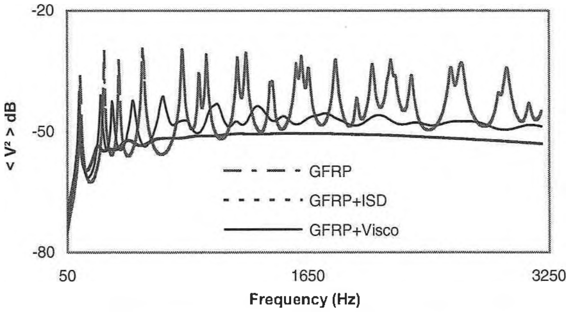


Fig. 7 Results for 4 mm Thick Composite Panels

Hence, the Hybrid method allows extraction of the properties of each 4 mm panel by fitting experimental results. The global attenuation with respect of the reference panel (GFRP) is 11.0 dB for the GFRP with 3M ISD112 panel and 6.8 dB for the GFRP with BF Goodrich VTBN panel. Although the constrained panel exhibits the highest damping level, the integrated viscoelastic panel should not be ruled out as it shows a good damping level with less manufacturing costs.

Parametric study can also be performed and figure 8 presents another exploitation of the hybrid method by implementing the extracted equivalent properties in the developed code while changing the thickness of the plate (panels 6 mm thick).

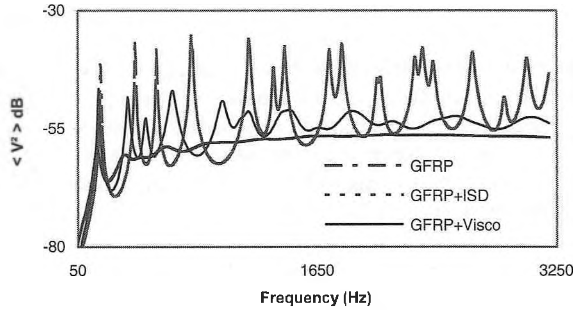


Fig. 8 Simulation Results for 6 mm Thick Composite Panels

Global attenuation is now respectively 9.6 dB and 6.4 dB for the constrained panel and the integrated viscoelastic panel.

## 6 - CONCLUSION & PERSPECTIVES

This proposed hybrid method allows to quickly extract equivalent properties of unknown materials in order to obtain input data for finite element code and to help design. The fitted results presented in this paper have been manually fitted. The authors are presently studying an automatic fitting procedure.

## REFERENCES

[1] **N. S. Bardell**, Free vibration analysis of a flat plate using the hierarchical finite element method, Journal of sound and vibration, 151, 263-289, 1991

[2] **O. Beslin, J. Nicolas**, A hierarchical functions set for predicting very high order plate bending modes with any boundary conditions, Journal of sound and vibration, 202 (5), 633-655, 1997

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[1] Structural acoustics and vibration software, MECANUM INC (http://www.mecanum.com)