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SURFACE SOUND ACOUSTICAL ABSORPTION PROPERTIES OF MULTILAYER PANELS

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ABSTRACT
This paper extends and unifies the analysis of the application of multilayer panels composed of two envelopes, one metallic and one plastic, and porous granular material. Various types of screens to contain the porous material were studied. The available literature on the acoustic impedance of the various layers was reviewed. The acoustic behaviour of the single components and of the entire structure was measured in a reverberant room. The results obtained show the reliability of the proposed solution.

1 - INTRODUCTION
In recent years, in addition to important factors related to the growing demands regarding the human environment and diversification of life styles, noise has become an increasingly complex and serious problem. For this reason, the development of low-cost panels and acoustic barriers that are weatherproof and resistant to chemical agents is gaining importance. Accordingly, the authors have turned their attention to multilayer sound $-$ absorptive structures containing loose foamed clay. In some cases, such structures are able to resist high temperatures: up to $600-700$ °C.

2 - ACOUSTIC IMPEDANCE THEORY
In order to define the acoustic behaviour of the entire panel, composed of three different layers, the specific acoustic-impedance ratio Z of the absorptive structure was evaluated as:

$$Z = Z_c + Z_f + Z_p \tag{1}$$

in which Z_c, Z_f and Z_p are the specific impedances of the different layers: the foamed clay, the perforated facing and the microdrilled plastic, respectively.
As already described in a previous work [1], Z_c was calculated, by means of the Hamet Model. Z_f and Z_p were determined in accordance with the Maha theory, which will be described below.

2.1 - Crandall theory
The perforated panel may be regarded as a lattice of short narrow tubes, separated by distances much larger than their diameters, but small compared with the wavelength of impinging sound waves. The propagation of sound waves in narrow tubes was treated by Rayleigh [2] and a simplified version was given by Crandall [3], for tubes much shorter than the wavelengths of the sound waves. The equation of air motion in a tube compared with the wavelength is:

$$j\omega\rho_0 u - \frac{\eta}{r_1}\frac{\partial}{\partial r_1}\left(r_1\frac{\partial}{\partial r_1}u\right) = \frac{\Delta p}{t} \tag{2}$$

where Δp is the sound pressure difference between the ends of the tube, t the length of the tube (equal to the thickness of the panel), ρ_0 is the density of air, η its coefficient of viscosity, and r_1 the radius vector of cylindrical coordinates inside the tube.
These formulas have since been used by Zwikker and Kosten [4] in the theory of absorbing materials.

2.2 - Maha theory

Maha [5, 6] found a simple approximate formula for the specific acoustic impedance of the perforated panel, which yields:

$$Z = \frac{32\eta t}{pd^2}\left(\sqrt{1+\frac{x^2}{32}}+\frac{\sqrt{2}}{8}x\frac{d}{t}\right)+j\frac{\omega\rho t}{p}\left(1+\frac{1}{\sqrt{9+\frac{x^2}{2}}}+0.85\frac{d}{t}\right) = R + j\omega M \tag{3}$$

where $j=\sqrt{-1}$, η is the dynamic viscosity of air, ρ is the density of air, t is the thickness of the plate, p is the perforation ratio of the plate (ratio of the perforated area to the area of the panel), d the diameter of the holes, $x = d/2\sqrt{\varpi\rho/\eta}$, ω is the angular frequency of sinusoidal air motion, and R and M are acoustic resistance and acoustic mass, respectively.

2.3 - Bolt theory

According to Bolt [7], the impedance of facing commonly met in practice is determined largely by two factors: the effective mass of the air moving in the holes and the mass of the facing material. Only these two factors, which give rise to parallel mass reactances, are included in his design chart. In this case:

$$Z = jX = j\left(\frac{X_h}{1+\frac{X_h}{X_m}}\right) \tag{4}$$

in which $X_m = \omega m$ is the specific reactance of the facing material, which has a mass per unit area of m grams/cm^2, and $\omega = 2\pi f$ and X_m is the effective mass of the air moving of radius r in a plate of d thick.

3 - APPLICATION CONDITIONS

In a previous work [1], the behaviour of granular clay beds of different diameters positioned in layers of various thicknesses was studied in a reverberant room where the granular clay was exposed to impact sound without any protection. In order to construct a panel for practical reason, this means in a vertical position, a boundary containing structure was needed. Two envelopes, one of perforated metal and one of microdrilled plastic, were chosen.

Therefore, the absorbing structure here investigated (Fig. 1) was made in a tough and durable form to withstand blast forces and the weather. The two envelopes were chosen in order not to influence the absorption characteristics of the porous material.

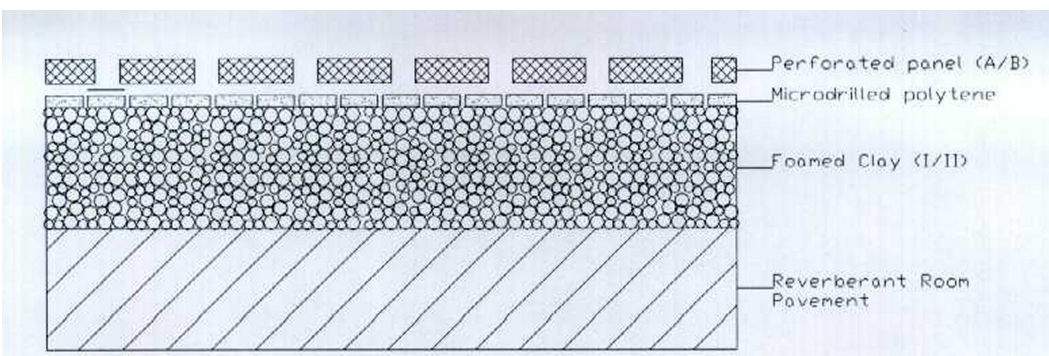

Figure 1: Multilayer panel scheme.

4 - EXPERIMENTAL MEASUREMENTS

Measurements of the absorption coefficient were carried out in a reverberant room operating in accordance with the standard ISO 354, 1985 [8]. A metal case with an area of 10 m^2 with horizontal and vertical stiffeners was positioned on the floor. Then all the materials, both separately and in a combined structure were measured.

4.1 - Materials used in experiments

Acoustic tests were carried out on two types of foamed clay: type I, diameter 2-3 mm and density of 500 Kg/m^3, type II. Moreover the microdrilled plastic and two perforated facings: type A used for sample I and type B for sample II, having different parameters as specified in table 1. The physical characteristics of the screens were suggested by the foam clay's diameters.

Screens			Metal Type A	Metal Type B	Microdrilled Plastic
Samples			Type I	Type II	Type I/II
Thickness of panel	t	(mm)	1	0.75	0.1
Percentage perforation	p	(%)	78	22	10
Diameter of holes	d	(mm)	6	1.2	1
Mass per unit area	ρ	(Kg/m^2)	2.5	3	0.025

Table 1: Physical characteristics of the screens.

4.2 - Experimental results

Figure 2 shows absorption coefficients at different third-octave frequencies between 100 and 5000 Hz for a layer of loose foamed type I clay of 0.005 m of thickness, for the same clay covered with a sheet of microdrilled plastic bag and for the clay covered with both the plastic bag and the type A perforated facing. Data obtained with sample II and perforated facing B present similar characteristics to those of sample I and perforated facing A.

5 - DISCUSSION

Figure 2 shows that the plastic, as well as the two microperforated panels, have little influence on the absorption coefficient of the foamed clay. Regarding the plastic this is in agreement with the findings of Campanella [9]. The absorption coefficient of the type A perforated panel was calculated by means of the Bolt and Maha theories. The coefficient calculated with the approximate formula of the Bolt theory is less accurate than that calculated with Maha.

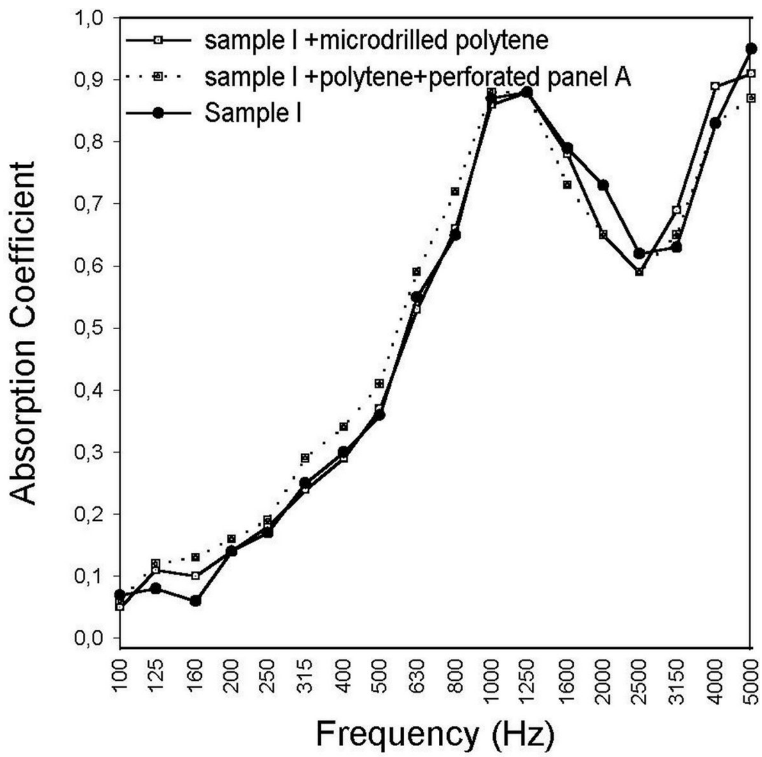

Figure 2: Experimental values.

Figure 3 shows the evaluation of the absorption coefficient of the different components: the type A perforated facing (calculated according to Maha), the microdrilled plastic bag. They both have very low absorption coefficient values. This is in accordance with the experimental results.

6 - CONCLUSIONS

By means of the Maha theory, which was found to be the most accurate among the others, a study of the acoustic impedance of an orifice and, hence, of the screens, here presented, shows that the acoustic resistance as well as its resistance to mass reactance ratio of both the perforated facings and the microdrilled plastic have very low values.

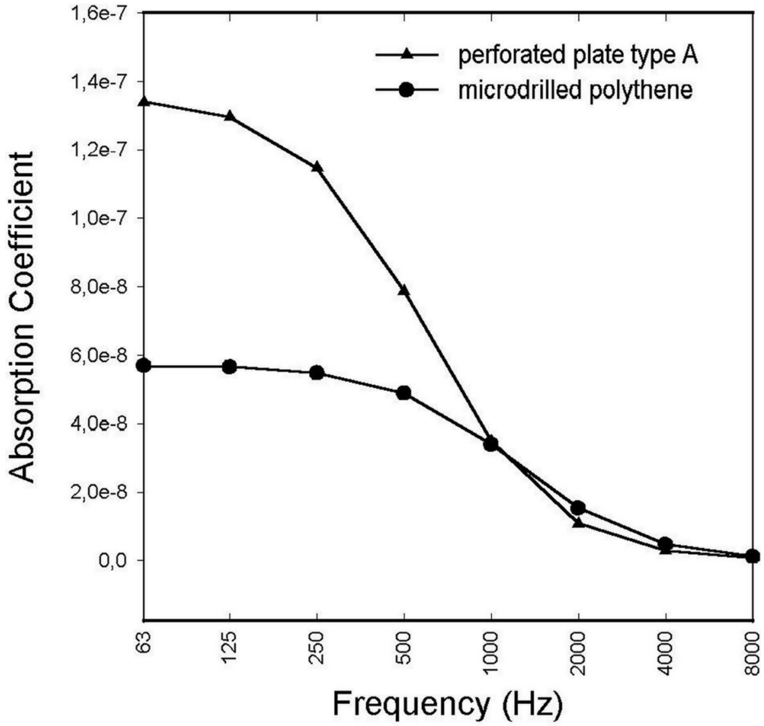

Figure 3: Evaluation by means of the Maha theory.

This is in accordance with the experimental data. Therefore, the perforated panels as well as the microdrilled plastic beg, play the role of protective face only.
In conclusion the obtained results show a good reliability of the absorptive structure here presented which is low cost and has the technical characteristics to be applied in external applications.

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REFERENCES

1. **P. Ricciardi, M. Bertucci, A. Di Bella, U. Magrini, R. Zecchin**, Proprietà acustiche di materiali inerti porosi a struttura sferica-Analisi teorica e prove sperimentali, In *XXVII Convegno Nazionale AIA*, pp. 120-124, 1999

2. **L. Rayleigh**, *Theory of sound*, Mc Millan, London, pp. 130-160, 3794

3. **I. B. Crandall**, *Theory of vibrating systems and sound*, Van Nostrand, New York, pp. 229, 1926

4. **C. Zwikker, C.W. Kosten**, *Sound absorbing materials*, Elsevier press, New York, pp. 25-52, 1949

5. **D.Y. Maha**, Microperforated-Panel Wideband absorbers, *Noise Control Engineering Journal*, Vol. 29 (3), pp. 77-84, 1987

6. **D.Y. Maha**, Potential of microperforated panel absorber, *J. Acoust. Soc. Am.*, Vol. 105 (5), pp. 2861-2866, 1998

7. **R.H. Bolt**, On the design of perforated facings for acoustic materials, *J. Acoust. Soc. Am.*, Vol. 19 (5), pp. 2861-2866, 1947

8. **International Standard Iso 354**, *Acoustics- Measurements of sound absorption in a reverberant room*, 1985

9. **A. Campanella**, *Private conversation*, 1998