Micro-perforated sheets as day-light ceilings

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ABSTRACT

The theory of microperforated panel sound-absorbing constructions has been introduced by D.-Y. Maa in 1975. Many different applications of micro-perforated sound absorbing materials have been introduced. Materials that have been used to be micro-perforated have been metal, wood, plastics and many others.
Stretched sheets used as ceilings, wall coverings and other set-ups have been applied for more than 40 years. In modern buildings ceilings often need to combine different functions, e.g. thermally activated and sound absorptive or sound absorptive and light emitting. With the micro-perforated sheets absorptive day-light ceilings can be built. 3D-shapes as well as printed sheets can be used for architectural or design purposes. Also the fully transparent micro-perforated sound absorber offers new design possibilities.
In this contribution measured sound absorption coefficients of various set-ups with micro-perforated materials as well as combinations with different porous materials will be presented.

Keywords: microperforation, absorption
I-INCE Classification of Subjects Number(s): 32.1, 35.5, 35.7, 35.3

1. INTRODUCTION

The first publication (1) by D.-Y. Maa on the theory and design of micro-perforated panel absorbers (MPA) has been published in 1975. Further developments of the theory and applications are presented in various other papers (2-7). The potential of MPA is shown in a publication (8) together with some possible applications. The calculation and measurement of MPA in so-called random incidence of diffuse sound fields has been investigated in two publications (9,10). Other aspects and further investigations on micro-perforated structures are still under described for example in (11,12, 13).

Stretched ceiling systems have been introduced around 45 years ago. A stretched membrane ceiling consists of a special foil, which is mounted in-situ by clamping it to a frame construction. The sheet is heated before mounting, and the membrane acquires its final tension after cooling. Nearly any shape might be built by this technique.

Over the last 45 years this kind of ceiling and wall covering has become a popular product with regard to modern architecture and design. However, so far only optical and other aspects of the product were generally of interest. After first experiences with a micro-perforated polycarbonate foil (13), micro-perforation of the foil used for the stretched ceiling was seen as an innovative feature. This new acoustic property may open another range of applications for stretched ceilings. In November 1999, the first micro-perforation of a stretched ceiling has been introduced and successfully been applied for room acoustic purposes. The first application of micro-perforated stretched ceilings was carried out at the Modern Art Museum in Vaduz in 2001.

Commercially available is a range of more than 200 colors. For day-light ceilings different translucent sheets can be fitted with a micro-perforation. As the micro-perforation also has optical effects it is suggested to use double layer set-ups. The visible layer consists of a classical unperforated stretched sheet and is backed by an translucent or fully clear micro-perforated sheet.

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2. SHORT REVIEW OF THEORY

A micro-perforated sound absorber consists of small orifices spaces regularly in a surrounding material, see Fig. 1 for round orifices on a square grid. The geometry of micro-perforated panel absorber with round wholes on a square grid is fully defined by the four geometrical parameters:

d – diameter of the wholes,
b – distance between the wholes,
t – thickness of the panel and
D – air cavity depth

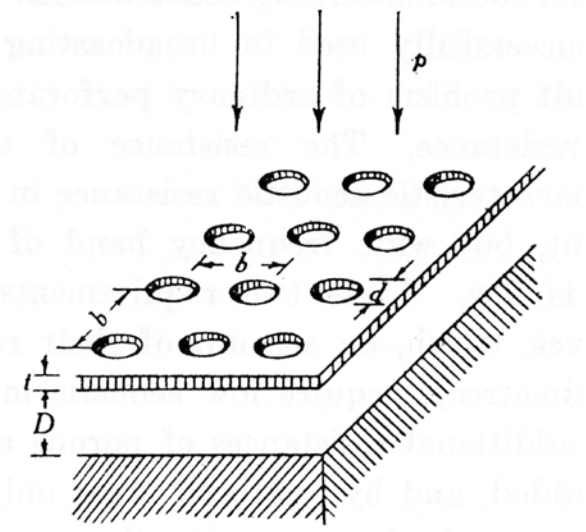


Figure 1 –Sketch of micro-perforated panel absorber (MPA) from (1) with diameter d of orifice, spacing b between orifice, thickness t of panel and air cavity depth D between panel and backing wall.

The theory of the micro-perforated panel absorbers as presented in 1 is based on the classical treatment of sound propagation in short tubes. The derivation by Maa first delivers an approximation for the specific acoustic impedance ZMPP for a micro-perforated panel of thickness t as

$$Z_{MPP} = r + j\ \omega\ m \quad (1)$$

The formulae for r and m are given in several publications, see for example (1,9). A micro-perforated panel in front of an air cavity forms a resonant system. The impedance of this system made of the micro-perforated panel and the air cavity can be calculated using the impedance $Z_{AIR}(\theta)$ of the air cavity of depth D at an angle θ to the normal of the surface given by

$$Z_{AIR}(\theta) = -j\cot(\omega D / c_0 \cos\theta) \quad (2)$$

With this the impedance $Z_{MPA}(\theta)$ the impedance of the micro-perforated panel absorber (MPA) can easily be calculated according to

$$Z_{MPA}(\theta) = Z_{MPP}\cos\theta + Z_{AIR}(\theta) \quad (3)$$

With this impedance $Z_{MPA}(\theta)$ the absorption coefficient α(θ) for a plane wave incident at a certain angle θ can be calculated according to

$$\alpha(\theta) = \frac{4\,\mathrm{Re}\{Z_{MPA}(\theta)\}}{[1+\mathrm{Re}\{Z_{MPA}(\theta)\}]^2 + [\mathrm{Im}\{Z_{MPA}(\theta)\}]^2} \quad (4)$$

This equation for α(θ) can now be used for the calculation of the so-called statistical or random incidence sound absorption coefficient according to the well-known Paris' formula

$$\alpha_{stat} = \int_{0^\circ}^{90^\circ} \alpha(\theta)\sin 2\theta\ d\theta \quad (5)$$

This formula for α_{stat} represents the limiting case for equally distributed angels of incidence and can also be obtained from an exact analysis of normal modes in a room (9).

3. RESULTS FROM LABORATORY

During the last 15 years various measurements on micro-perforated sound absorber have been carried out and reported elsewhere (9,10,13). It is well known that the theoretical predictions agree well with corresponding measurements.

In the following section the results of reverberation chamber measurements of various assemblies using micro-perforated stretched ceilings with double layer set-ups are presented. All measurements have been carried out according to the procedure described in DIN EN ISO 354 (14). The micro-perforated sheets hat the following perforations (named typ A15, A20, A30, A40 by the manufacturer BARRISOL):

diameter of the wholes: d = 0.1 mm, 0,15 mm, 0,20 mm, 0,5 mm
number of wholes per square meter: 500.000, 400.000, 300.000, 50.000
thickness of panel (stretched foil): t = 180 µm

The cavity depths and the distance between the sheets have been varied.

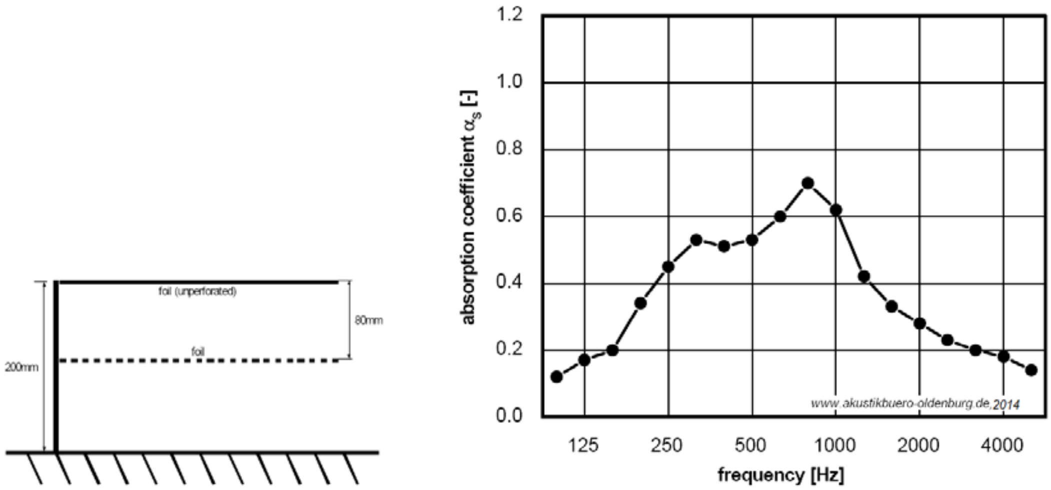


Figure 2 – Sketch of set-up and corresponding result for absorption coefficient

In Figure 2 the frequency-dependent sound absorption coefficient according to ISO 354 for the 200 mm double layer set-up with an unperforated and a micro-perforated sheet behind at a distance of 80 mm is depicted. The maximum value of 0.70 is reached at 800 Hz. The NRC-value according to ASTM C 423-01 is NRC = 0.50, the SAA-value is SAA = 0.46.

The installation of fluorescent tubes or LED lighting in the backing cavity does not change the acoustic performance. Using the front layer as unperforated sheet yields homogenous and diffuse lighting. The absorption comes from the second micro-perforated layer

Another possible set-up is shown in figure 3.

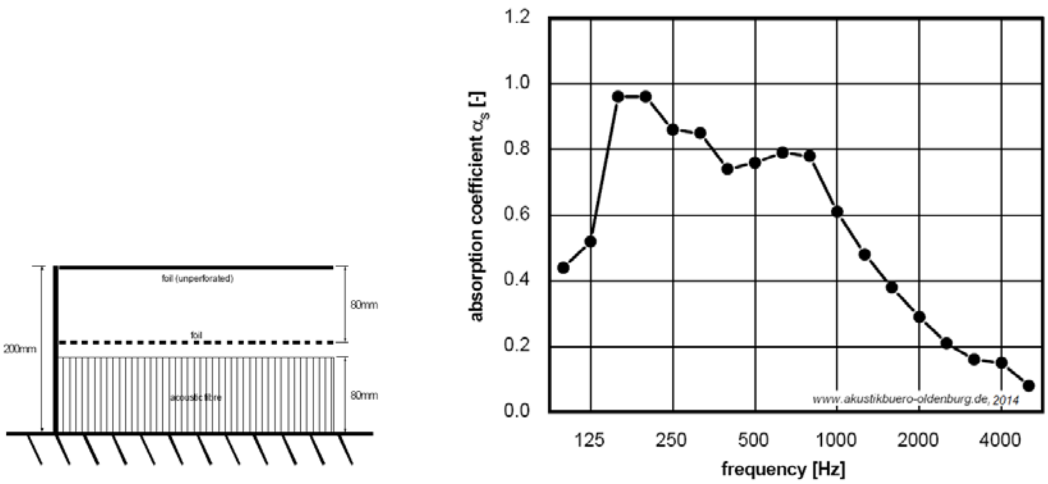


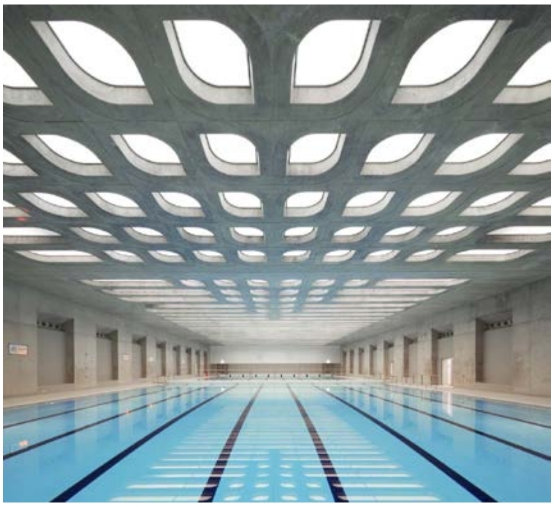
Figure 3 – Sketch of set-up and corresponding result for absorption coefficient

In Figure 3 the frequency-dependent sound absorption coefficient according to ISO 354 for the set-up with a porous sound absorber in the cavity is depicted. The maximum value of 0.96 is reached at 200 Hz. The NRC-value according to ASTM C 423-01 is NRC = 0.65, the SAA-value is SAA = 0.64. This set-up is a good low frequency sound absorber.

4. PROJECT EXAMPLES

The set-up shown in figure 2 has been used as a sound absorbing day-light ceiling in the training hall of the Olympic Aquatic Center in London, see Figure 4. The room shows many concrete surfaces at the walls and the ceilings. The lighting orifices in the ceiling are made with a backing micro-perforated sheet. The specification for the acoustic properties have been given by the acoustic consultants and could be reached with the set-up described.

A second project example is shown in the right picture of figure 4. A double layer set-up mad of two fully clear micro-perforated sheets is used as a kind of baffle sound absorber.



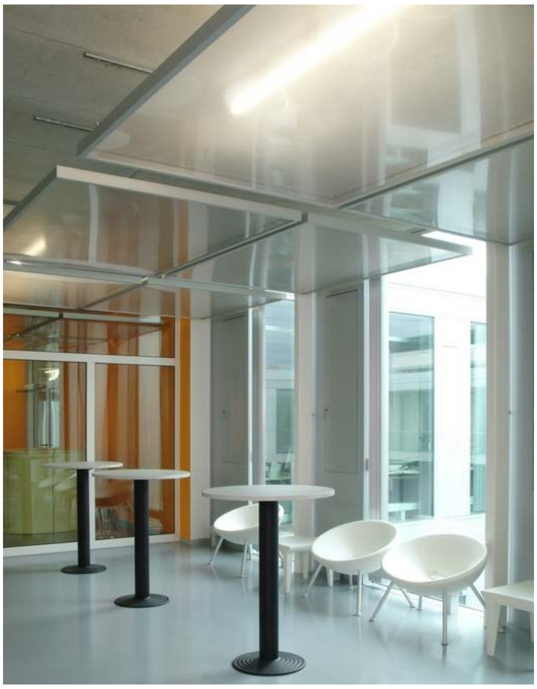


Figure 4 – Photograph of two projects:

left – Olympic Aquatic Center, London; right: University lounge, Stuttgart

5. CONCLUSIONS

Two projects have briefly been shown and described where double layer set-ups with micro-perforated stretched have been applied. Using a micro-perforated sheet in the backing cavity behind an unperforated sheet gives a NRC of 0.50 for a 200 mm thick set-up. The absorption can be increased especially in the low frequency range by adding a porous sound absorber material in the backing cavity.

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