Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
Alberto DOMINGO and Carlos LAZARO (eds.)

Research on the combination of water and membranes as a sound insulation building material.

*Arno PRONK, Roberto MAFFEI [a], Heiko MARTIN [b]

*Building Technology, Product Development
Eindhoven University of Technology
Den Dolech 2
5612 AZ Eindhoven, The Netherlands
a.d.c.pronk@tue.nl

[a] Building Environment Science & Technology/B:E:S:T: Department
Politecnico di Milano
Via Bonardi 3, 20133 Milano, Italy
roberto.maffei@torrescalla.it

[b] Acoustics Laboratory Eindhoven University
h.j.martin@tue.nl;

Abstract
This research concerns a 200 mm thick panel filled with water. The airborne sound insulation of this panel was measured in accordance with standard ISO 140-3 [2]. Results show that the single number rating for the airborne sound insulation R_w [3] for an average water layer thickness of 200 mm is 48 dB. This value is comparable to the one of a 150 mm brick wall or 100 mm concrete panel. Predictions about sound insulation of the same system at different thickness and possible applications such as highway sound barrier or construction site sound barrier are presented in the following page

Key words: membranes, distance fabric, sound insulation.

1.introduction
Water has a higher mass compared to the one of air. This property can be useful to develop a sound insulating panel made by membrane and water only. It is well known that, nowadays, new developments in architectural free form shaped buildings lead to the design of filled multilayer membranes as façade construction (Wenmaekers *et al* [9]). The water between the membranes can collect or radiate heat or cold and transfer it to and from the

building service system (Pronk *et al* [6]). Moreover, as presented in the design competition "Create a barrier of silence" by Schiphol Airport, the design team "Silent Blue" proved that a water panel can also work as a sound barrier. The group proposed a noise barrier made by a multilayer membrane filled with water as a roof and wall structure [8]. In this context, a sound reduction of 20 dB was required in the 31,5 Hz octave band for the attenuation of ground noise by airplanes.

To understand the behaviour of water as a sound isolation material, tests were done in the Acoustics Laboratory of Eindhoven University. Results showed that water is a useful material in terms of sound insulation properties. The tests indicated that doubling the water layer, the weighted sound insulation index R_w increases 3 dB (Wenmaekers *et al* [9]).

To show the sound insulation properties of a waterpanel a mock-up was designed and tested. The measurement set-up and result of this test are presented in the following pages.

2.1 The mock-up

A panel (Figure 17) of 150 cm *125 cm *20 cm size was produced at Buitink Technology, The Netherlands. The size comes from the standardized size of the test opening for windows in the Acoustics Laboratory. The thickness of the panel follows from the distant fabric (Figure 18) used. This panel consists of two layers of membranes placed at a constant fixed distance of 20 cm. The total mass of the panel, when deflated, is 7,34 kilogram. Surface mass of one layer of membrane is therefore 1,95 kg/m^2.

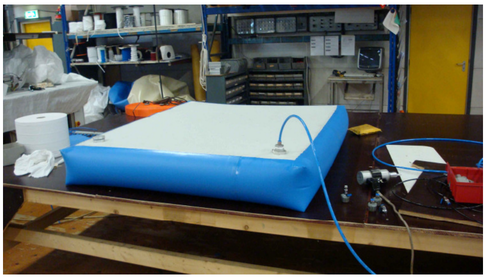

Figure 17

Figure 18

2.2 Testing

The airborne sound insulation of water was measured in accordance with ISO standard 140-3 "Laboratory measurements of airborne sound insulation of building elements" [2].

The panel was placed into the vertical opening between two highly sound insulated concrete test rooms. In the first room (source room), random pink noise is produced by an amplifier with integrated noise generator (AE Amphion) and a loudspeaker (Meyvis type M4). Meanwhile the equivalent sound pressure level Leq is measured in source and receiving room with omnidirectional microphones (Type B&K 4165) on a rotating boom (16 seconds per rotation) and software DIRAC 4.1 [1]. The sound pressure level is averaged over two different loudspeaker positions. Also, the reverberation time T has been

$$A = 0.16\frac{V}{T} \qquad [m^2]$$

measured by the impulse response method [4] using the same equipment and an exponential sweep signal generated by DIRAC 4.1. The average of 6 measurements with 2 loudspeaker positions and 3 microphone positions has been used for the determination of the average reverberation time. The equivalent absorption area in the receiving room 2 is evaluated using Sabine's reverberation formula (1). The sound reduction index R is calculated from equation (2).

(1) (1)

where:
V = the volume of the receiving room, in m^3;
T = the reverberation time in the receiving room, in s.

$$R = L_1 - L_2 + 10\log(\frac{S}{A}) \qquad [dB] \tag{2}$$

where:
R = the sound reduction index, in dB;
L_1 = the average sound pressure level in the source room, in dB re. 20 µPa;
L_2 = the average sound pressure level in the receiving room, in dB re. 20 µPa;
S = the area of the test object, in m^2;
A = the equivalent absorption area in the receiving room, in m^2.

A supporting wooden structure with almost no sound insulation was built up on both sides to keep the panel in place (Figure 19 a-b). The panel was tested for leakage of sound by the use of a stethoscope. Several gaps were detected between the membrane and the edge of the opening due to the wrinkling of the inflatable. Foam strips were used to lose the gaps and successfully close the leakage of sound (Figure 20).
Two different tests have been carried out. In the first test, the panel was filled with air and the surface mass for each panel was 1,95 kg/m^2. In the second test, the panel was filled with water and the surface mass of the whole element was 200 kg/m^2.


Figure 19 a-b


Figure 20

3.1 Experimental results

Figure 21 shows the sound reduction index as a function of frequency for one-third octave bands 50 to 5000 Hz for the 2 two tests.

In Table 1 values are given for the airborne sound reduction index for the air and water panel. Also the single number ratings R_w are given in accordance with ISO 717-1 [3].

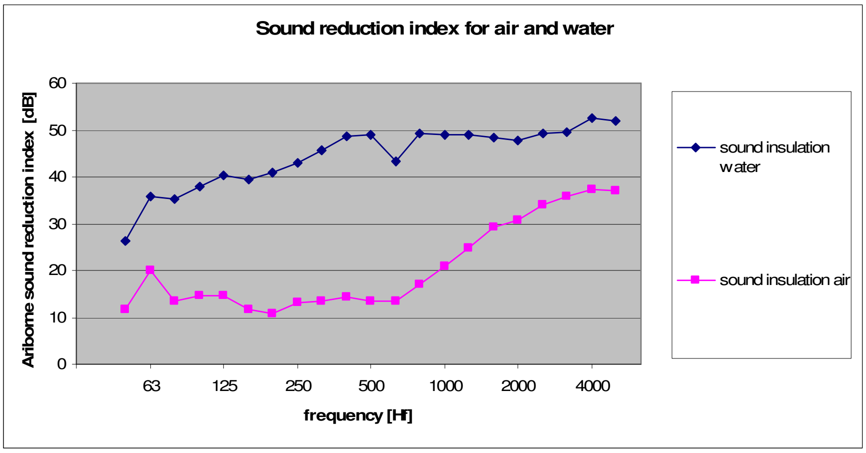

Figure 21

Frequency [Hz]	**Sound reduction index R [dB]**	
	Air	**Water**
50	11,7	26,2
63	19.9	35,9
80	13,5	35,1
100	14,6	38
125	14,5	40,2
160	11,7	39,5
200	10,8	41
250	13	42,9
315	13,5	45,7
400	14,3	48,5
500	13,3	48,9
630	13,3	43,3
800	17,2	49,1
1000	21	48,9
1250	24,8	48,8
1600	29,1	48,4
2000	39,8	47,8

2500	33,9	49,4
3150	35,9	49,5
4000	37,3	52,6
5000	37,1	52
R_w	**20**	**48**

Table 1

3.2 Discussion

The sound insulation of a double membrane panel distant fabric of with a cavity of 200 mm thick (surface mass of 1,95 kg/m^2) filled with air is comparable to the one provided by two medium-density wooden panels of 3 mm thick (surface density of 2,1 kg/m^2), with an air chamber of 200 mm in-between (Figure 24). To compare the sound insulation of these panels to those of other materials, the software INSUL (Marshal Day acoustics) was used. The connections between the two membranes in the distant fabric were considered as point-connections at a distance of 30 mm. (Figure 22)

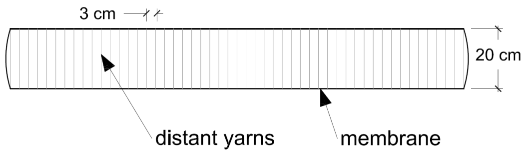

Figure 22

The sound insulation of water is much higher then that of air, as expected. The sound insulation curve of the water panel shown in the chart in Figure 21 shows a low sound insulation at high frequencies, probably because the water panel, above the valve level, was not completely filled in. To assure the maximum filling and have an homogeneous panel, the membrane was pierced with a needle in top part of the panel (Figure 23). Also there must have been sound leaks at the perimeter because the panel was moving in the test opening during the (continuous) filling.

The single number rating measured in this test is higher than the one expected from extrapolation of the result of the previous tests (Wenmaekers *et al* [9]). A R_w value of 45 dB was expected and 48 dB is the measurement result. The increase of 3 dB could be a consequence of the presence of two layers of membrane (distant fabric) instead of the single layer of the previous test. This value of sound insulation for a 200 mm thick water panel (surface density of 200 kg/m^2) is comparable to the sound insulation of a 100 mm thick concrete wall (surface mass of 230 kg/m^2) or a 150 mm thick brick wall (surface mass of 250 kg/m^2) (Figure 24). However, in practice, a thinner layer of water (around 80-100 mm) should be used otherwise problems of stability would become relevant.

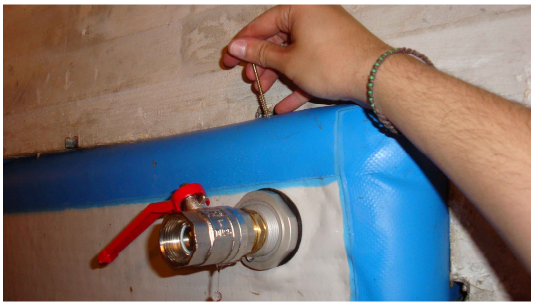

Figure 23

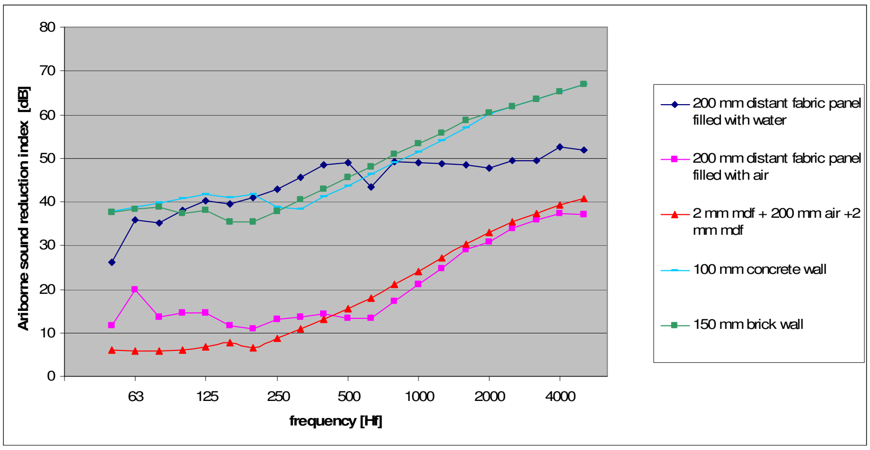

Figure 24

4. Conclusions

The research proved that water can be used as structural (please have a look at the other paper) and sound insulating material for architectural application.

Sound insulation tests demonstrate that water can work as a noise barrier for architectural applications. A 200 mm thick water panel could insulate as much as a 100 mm concrete wall. However, due to stability problems, thinner layers are preferable in practice.

As a conclusion, we can sum up the advantages of using water in architectural applications: firstly, the large (heat) accumulating capacity; secondly, the capability to resist at compression; thirdly, sound insulation capacity. In addition we should mention the low price and the availability. These last two points are of great importance because they assure that this kinds of application could be used almost everywhere, as long as water is available in the surroundings.

Systems described before could be used for temporarily structures, such as pavilions, tents, and for exhibitions but also for free-form architecture. In addition, due to the availability of the material, applications in case of emergency are also possible. These kinds of solutions can be built rapidly, easily disassembled and re-used. Furthermore, only small storage accommodation is needed to store the whole elements.

Acknowledgement

Buitink Technology and Acoustics Laboratory of Eindhoven University played a key role in the success of this research.

References

[1] DIRAC 4.1 software, B&K / Acoustics Engineering.

[2] ISO 140-3:1996 *Laboratory measurements of airborne sound insulation of building elements.*

[3] ISO 717-1:1996 *Rating of sound insulation in buildings and of building elements, part 1: Airborne sound insulation.*

[4] ISO 18233:2006 *Application of new measurement methods in building and room acoustics.*

[5] Mehra, Schew-Ram, Aufblasbarer Schallschutz mit Bauteilen aus Folien und Membranen, in *Bautechnik 79,* H.11, S 794-797, 2002.

[6] Pronk A.D.C., de Haas T., Cox M., Heat-Transmitting Membrane, in *International conference on Textile Composites and Inflatable Structures*, Barcelona, 2007.

[7] Rodrigues and Coutinho, Master of Science Thesis *Evaluation of the Sound Insulation of Liquid-Filled Panels*, International conference paper for Internoise, Shanghai, China, 2008.

[8] Schiphol Group *Create a Barrier of Silence,* book with presented designs, 2009.

[9] Wenmaekers R:H:C, van der Aa B.A., A.D.C. Pronk, A. Couthinho, L.C.J. van Luxemberg, The sound insulation of Water, *Proceedings of the NAG-DAGA Conference*, Rotterdam, 2009.