The Sound Insulation of Water

R.H.C. Wenmaekers[1], B.A. van der Aa[2], A.D.C. Pronk[2], A. Couthinho[3], L.C.J. van Luxemburg[1]

[1] *Level Acoustics, The Netherlands, Email: r.h.c.wenmaekers@tue.nl*

[2] *Eindhoven University of Technology, The Netherlands*

[3] *DHV, The Netherlands*

Introduction

New developments in architectural free form shaped buildings lead to the design of liquid filled multilayer membranes as a façade construction [1]. The water between the membranes can collect or radiate heat or cold from the façade and transfers it to and from the building services system. In the design competition "Create a Barrier of Silence" by Schiphol airport, the design-team "Silent Blue" has presented a noise barrier that implemented the multilayer membranes filled with water as a roof and wall structure [2]. In this design the water inside the membranes is also used as a sound insulating material. In the context of the barrier design competition, a sound reduction of 20 dB was required in the 31.5 Hz octave band for the attenuation of ground noise by airplanes.

A new laboratory test setup was created and sound insulation measurements of liquids have been performed by Rodrigues and Coutinho [3]. The presented results showed a promising use of water as a sound insulating material; however the absolute results may not be reliable due to limitations of the small measurement setup. To obtain the sound insulation values for a wider frequency range, a laboratory measurement has been performed on a 10 m^2 water layer with a average thickness of 26, 44 and 83 mm in accordance with ISO 140-3 [4]. The measurement setup and results from this measurement are presented in this paper.

Method

The airborne sound insulation of water was measured in accordance with standard ISO 140-3 "Laboratory measurements of airborne sound insulation of building elements" in the Laboratorium voor Akoestiek of Eindhoven University of Technology in the Netherlands. A water basin was created in the 10 m^2 floor opening between two highly sound insulated concrete test rooms. In the top 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 L_{eq} 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 [5]. The sound pressure level is averaged over two different loudspeaker positions.

Also, the reverberation time T has been measured by the impulse response method [6] 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).

$$A = 0.16\frac{V}{T} \qquad [\text{m}^2] \qquad (1)$$

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

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

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 m²;
A = the equivalent absorption area in the receiving room, in m².

Tested object

To be able to measure the sound insulation of the water layer only, a supporting structure was constructed in the 10 m^2 floor opening (3.16 x 3.16 m^2) with almost no sound insulation. For this a steel net with 10 x 10 mm^2 mesh was constructed on top of a wooden beam structure (see figure 1). Higher wooden beams were placed on the edge of the floor opening to create an edge for the water basin and to avoid sound leakage along the edges.

Figure 1: Water layer supporting structure

On top of the supporting structure, a watertight plastic foil (0.70 kg/m²) was tightly stretched and clamped to the edge beams by the use of wooden laths (figure 2).

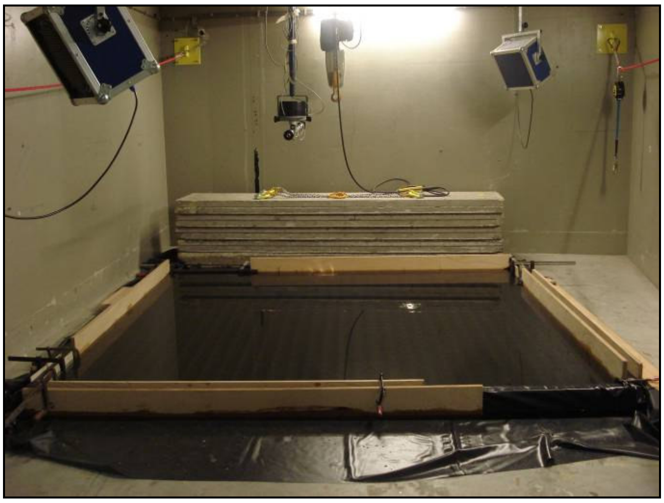

Figure 2: Water basin on plastic foil

After filling the basin with water, the structure was tested for leakage of sound by the use of a stethoscope (figure 3). Gaps were detected between the water layer and the edge beams, due to curving of the foil. Foam strips and putty were used to close the gaps and successfully stop the leakage of sound.

Figure 3: Testing of leakage of sound by stethoscope

The thickness of the water layer

The supporting structure was carefully levelled to achieve an equally thick water layer across the basin. Due to the levelling of the structure the deviation of water thickness along the basin was less than 3 mm. Despite the stretching and clamping of the foil, the foil bended slightly through the openings of the steel net due to the weight of the water layer (see figure 4). This resulted in a deviation of 3 to 4 mm from the average water layer thickness (6 to 8 mm between the deepest and most shallow point). The water layer thickness used in the presentation of results is the average thickness of the water layer as described in table 1.

Table 1: Overall water layer thickness

	Description		
	"26 mm"	"48 mm"	"83 mm"
Most shallow point (mm)	22	40	80
Deepest point (mm)	30	48	86
Average thickness (mm)	26	44	83
Deviation from average (mm)	4	4	3
Deviation from average (%)	15	9	4

Figure 4: Bending of foil through steel net

Results

In the graph in figure 5 the sound reduction index is plotted as a function of the frequency for one-third octave bands 50 to 5000 Hz for the 26, 44 and 85 mm water layer thickness.

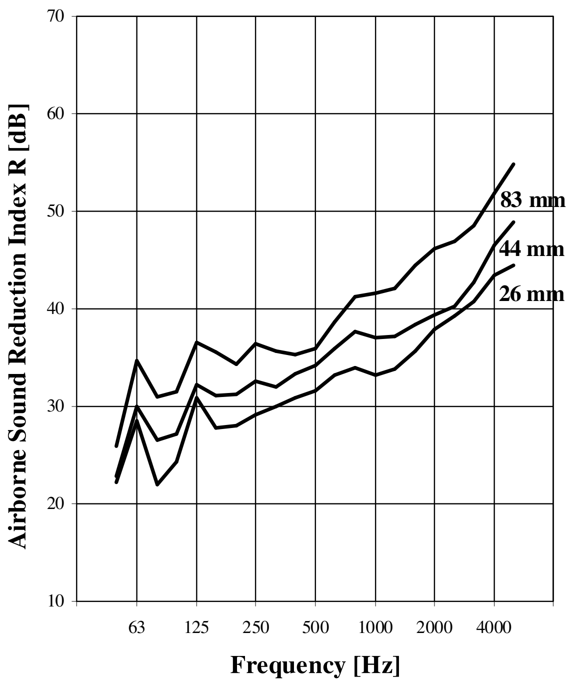

Figure 5: Airborne sound reduction index of a 26, 44 and 83 mm layer of water as a function of frequency

In table 2 values are given for the airborne sound reduction index for the 26, 44 and 83 mm water layer thickness. Also the single number ratings $R_w(C;C_{tr})$ are given in accordance with ISO 717-1 [7].

Table 2: Airborne sound reduction index of a 26, 44 and 83 mm layer of water for frequencies 50 to 5000 Hz

Frequency	Sound reduction index R for average water layer thickness		
	26 mm	**44 mm**	**83 mm**
50	22,2	22,8	25,9
63	28,5	29,9	34,7
80	22,0	26,5	30,9
100	24,3	27,1	31,5
125	30,8	32,2	36,5
160	27,8	31,1	35,6
200	28,0	31,2	34,3
250	29,1	32,5	36,4
315	30,0	31,9	35,6
400	30,8	33,3	35,3
500	31,6	34,1	35,9
630	33,2	36,0	38,7
800	34,0	37,7	41,3
1000	33,2	37,1	41,6
1250	33,8	37,2	42,1
1600	35,7	38,4	44,5
2000	37,9	39,4	46,2
2500	39,3	40,3	47,0
3150	40,8	42,7	48,5
4000	43,4	46,6	51,8
5000	44,5	48,9	54,8
$R_w(C;C_{tr})$	**35 (-1,-2)**	**38 (-1,-2)**	**41 (-1,-3)**

measured value uncertain

--- ISO 717-1 range

Influence of the construction

To investigate the influence of the sound insulation of the supporting structure, the sound insulation of the mesh and foil structure without water has been tested. Compared to the sound insulation of the construction with the thinnest layer of water (26 mm) the sound insulation difference of the supporting structure itself was more than 10 dB for all frequencies. From this, it can be assumed that the influence of the supporting structure is negligible and that the measured sound insulation is mainly caused by the actual water layer.

Conclusion / discussion

It is shown that water is a useful material in terms of sound insulation properties. The single number ratings for the airborne sound insulation $R_w(C;C_{tr})$ for an average water layer thickness of 26, 44 and 83 mm are 35(-1;-2), 38(-1;-2) and 41(-1;-3) dB respectively.

The single number ratings show that by approximately doubling the water layer thickness the weighted sound insulation index R_w increases 3 dB. Also the graph of the sound insulation shows that the increase per (logarithmic) frequency is more or less linear and smoothly, although the curve becomes more steep above 1000 Hz.

The average increase per frequency is about 3 dB/octave, calculated from linear regression lines of the three measurements. From this, the sound insulation of a 26, 44 and 83 mm water layer thickness was estimated to be respectively 20, 23 and 26 dB for the octave frequency band 31.5 Hz.

References

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[7] ISO 717-1:1996 “Rating of sound insulation in buildings and of building elements -- Part 1: Airborne sound insulation”