Determination of the acoustic characteristics of a gabion noise barrier

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ABSTRACT

In recent road construction projects in NL more and more stone gabions are used as noise reducing measure. First measurements on noise characteristics on gabions using EN 1793-5 showed peculiar results for sound absorption. This was thought to be an effect of the thickness of the gabion and due to scattering of the sound on the non-flat surface. A new investigation was done on stone gabion NRD's and on regular reflective and absorptive NRDs. Focus was on the applicability of EN 1793-5 for determination of the sound reflection characteristics of gabion NRD's. This paper shows the results of measurements on gabion and "regular" NRD's, and of model simulation of these measurements to understand the results, and give guidance on modeling a gabion NRD in a general TNM.

1. INTRODUCTION

In the period 2017 – 2021, several measurements were carried out on gabions to determine the acoustic properties (insulation and absorption) ([1], [2],[3]). The reason for this research was the application of gabions in projects, which led to discussion about the verification of the requirements regarding sound properties.

In planning studies, an absorption class A3 is assumed for sound-absorbing noise barriers. Verification of this requirement showed to be difficult for market parties because no representative measurement data appeared to be available. The risk for Road Authority Rijkswaterstaat is that the sound absorption of gabion noise barriers realized alongside the HWN not complies to the standard assumption (class A3) in a noise study. This leads to calculation of noise levels that are low, which subsequently turn out to be unfeasible in a realization project. The preliminary conclusion based on the available information was that the sound absorption of gabions is limited to a maximum of class A2. This currently controls the risk of conflicting requirements. However, this continues to lead to discussions in projects.

Validation of the sound absorption of gabions with the in-situ method EN 1793-5 appears not to provide sufficiently reliable results [3,4,6]. Uncertain aspect was how to deal with the acoustic "depth" of the construction. This depth is relevant when calculating the reflection index, that consists of a geometric correction for spherical wave propagation.

Sound absorption can also be determined using a sound intensity meter such as the Sonocat (Soundinsight). Comparison of results with EN 1793-5 will give information on the applicability of this type of instrument.

The following research questions were formulated:
- What is a realistic sound absorption that can be achieved with a gabion sound barrier or a “thick” barrier ?
- What acoustic “depth” should be assumed in accordance with EN 1793-5?
- Are Sonocat results comparable to EN 1793-5.
- How to model a gabion NRD in a general Traffic Noise Model.

This paper shows the results of measurements on gabion and “regular” NRD’s, and of model simulation of these measurements to understand the results, and give guidance on modeling a gabion NRD in a general TNM.

2. MEASUREMENTS ON NRD’s

In-situ measurements were carried out according to EN 1793-5 and with the Sonocat instrument. The measurements were also simulated using FEM calculations to understand the effect of scattering.
The measurements and FEM calculations are carried out on four different noise barriers;
- Two gabion noise barriers (Prinsenbeek and Oss);
- A regular thin sound absorbing noise barrier (Vught);
- A flat, reflective noise barrier (A2 exit 27 Best West).

The Gabion NRD Prinsenbeek is located between the railway and a residential area having a length of 500 m, is 3.5 m high and approximately 1 m thick. The closed insulation core is 20 cm thick. On the track side, the gabion is filled with basalt boulders. Clean rubble was used on the residential area side. The measurements were carried out on the resident side of the NRD. The height of the screen is 3.5 m. Therefore, it was measured at a height of 1.75 m from the ground.

Figure 1: Impression of the Gabion NRD in Prinsenbeek

The Gabion NRD in Oss is located between the railway, the N229 and a residential area. It consists of two parts, a part of 575 m long and 2 m high and a part of 340 m long and 5.80 m high. The core has a variable thickness and consists of sand-cement stabilization.
The gabion is filled with stacked Grauwacke stones (hard sedimentary rock), stone size 80/150 mm, and is approximately 30 to 40 cm thick. On the residents' side, the screen is slanted.

Figure 2: Impression of the gabion NRD in Oss

The sound absorbing NRD Vught is located along the A2, next to the Boxtelseweg. It is sound absorbing on both sides. The NRD is partly covered with vegetation, this was removed for the measurements. For safety reasons it was not possible to measure the screen on the A2 road side. The noise barrier has a height of 5 m.

The sound reflecting NRD is located along the A2 at exit 27 Best West. It has a height of 6 m. The surface consists of concrete with against this a metal net for the vegetation. The measurements were carried out on the resident side of the NRD.

Figure 3: Impression of the NRD's in Vught(left) and in Best (right).

Sound absorption measurements were carried out in accordance with EN 1793-5 and with the Sonocat instrument, in the period of November and December 2022.

The standardized method EN 1793-5 [7] requires a proper sound source and a 3x3 microphone array with microphones placed at a distance of 40 centimeters in front of the noise barrier. The power spectra of the direct and reflected components forms the basis for calculating the sound reflection. By using a time window, unwanted reflections are excluded in the calculation of the reflection index. The measurement setup is shown in Figure 4.
An exponential sine sweep with a length of 2 sec. was used for the measurements, with emphasis on the frequency range between 100 and 5000 Hz. The sample rate was 48kHz. A second order IIR filter with a cut-off frequency of 10 kHz was used as anti-aliasing filter.

Measurements were done at distances of 0.25 cm and 0.50 cm from the front of the NRD, in order to check on the acoustic "depth". The averaged geometrical correction (Cgeo) for both distances is about 1.85 and 3.0. This difference has to compensate for attenuation due to spherical wave propagation.

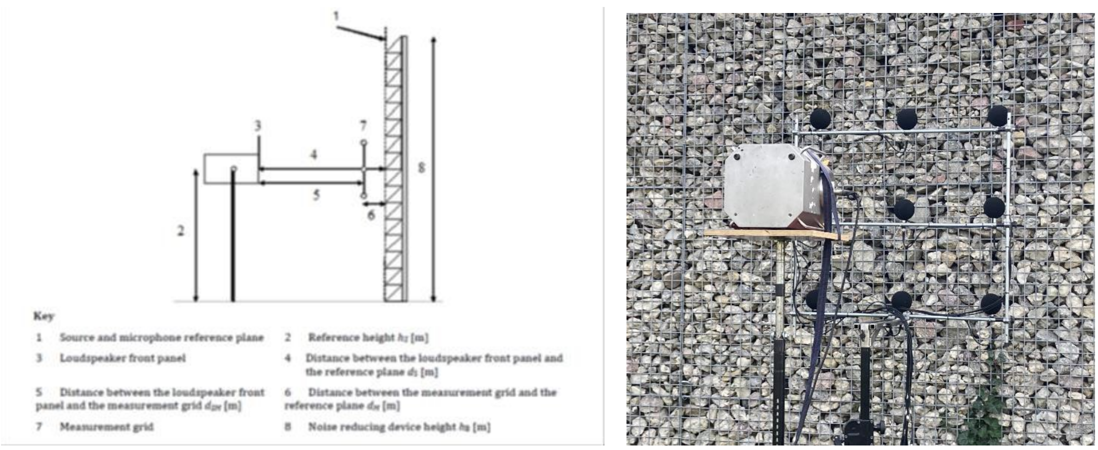

Figure 4: Left: Schematic representation of the measurement setup to determine the sound reflection in EN 1793-5. Right: measurement setup as used during the measurements.

Sonocat
The absorption coefficient of the NRD's were also measured with the Sonocat instrument. The Sonocat consists of a small sphere containing eight microphones, as shown in Figure 5.

Figure 5: The Sonocat (side and front view).

The red arrow shows the incident sound intensity, the green arrow the reflective intensity and the blue the (net) regular acoustic intensity. The orientation of the sensor should be such that the absorbing material to be measured is "under" the sensor. With a vertical wall, the sensor must therefore be kept in a vertical position (see also figure 6).

Using the so-called "local plane wave" method, the sound intensity of the incident and reflected sound (the red and green arrows) are measured simultaneously. A measurement is done close to the NRD surface (about 3-5 cm distance). This eliminates the need to work with a time window and a reference measurement, as necessary in the EN 1793-5 standard.

For the purpose of comparison with the measurement according to EN 1793-5 multiple measurements were performed with different types of sounds including "sweep sine", "white noise", as well as "pink noise". The sound source as described in the NEN-EN 1793-5 standard was used for both measurement methods.

Point measurements were done at the nine positions corresponding the microphone array as defined in the EN 1793-5 standard. The end result is derived by averaging (energy) over the 9 positions. The scanning measurements were performed over the same surface as the microphone array. For each measurement 300 time averages were used, resulting in a measurement time of 12.8 seconds. Figure 6 illustrates measurements with the Sonocat.

Figure 6: Performing scan or point measurements with the Sonocat instrument.

3. MEASUREMENT RESULTS

The results for the 4 different NRD's are shown in Figure 7. For each NRD location the following results are shown:

▪ Measurement according to EN 1793-5 with a distance of 25 cm from the NRD;
▪ Measurement according to EN 1793-5 with a distance of 50 cm from the NRD;
▪ The scan measurement with the Sonocat at a distance of 5 cm from the NRD, using a white noise sound signal.

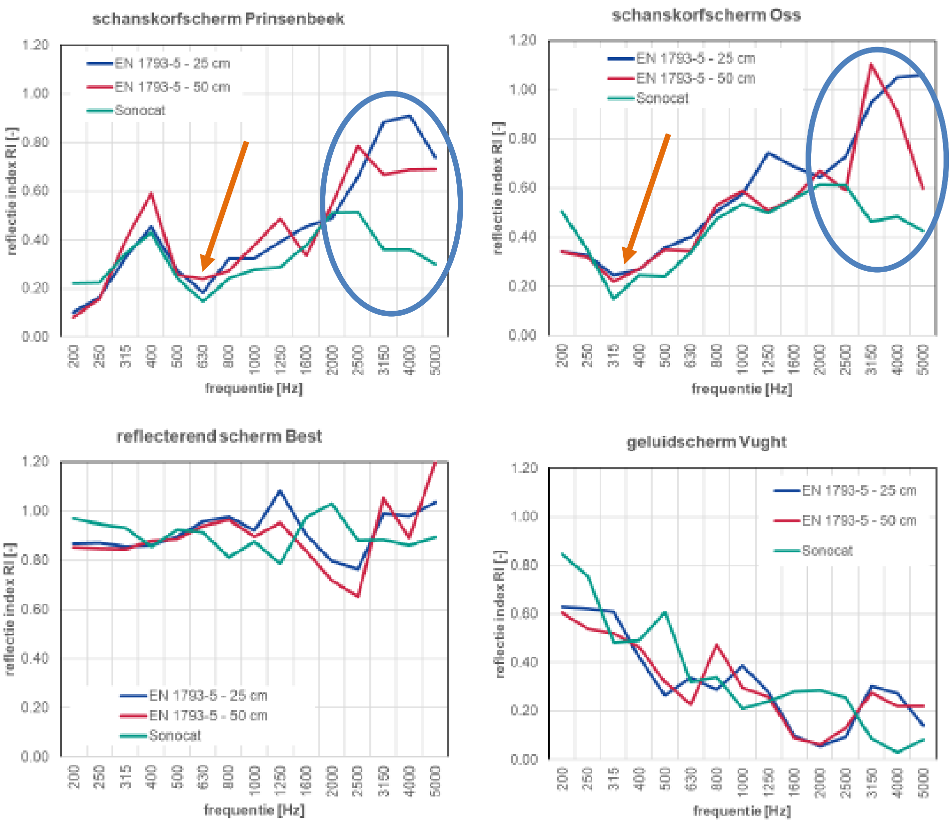

Figure 7: Reflection Index results measured at the 4 locations.

In general the results correspond well for the different settings. The gabion NRD's (above) have low reflection values at low frequency that corresponds with the layer thickness of the open stone layer (arrows in fig. 7), and higher values at high frequency what can be explained by reflection on the "hard" stones in the gabion NRD. The reflecting NRD (low left) shows a high value as to be expected. The sound absorbing NRD (low right) shows a familiar result with a lower reflection index in the high frequency range.

The results for both measurement distances (25 and 50 cm) show just small differences. This confirms that the geometrical correction in EN 1793-5 compensates well for the spherical wave propagation.

For the gabion NRD's (above in fig. 7) large differences between EN 1793-5 and Sonocat are found in the frequency range above 2 kHz (ovals in fig. 7). Further analysis of the measurement data showed a large variance between results of individual microphones/positions in the EN 1793-5 method. Results for individual microphone positions showed reflection index values higher than 1, what is not realistic. An explanation for these high values can be the effect of scattering of sound waves on the hard stones in the gabion NRD's.

4. MODELLING EN 1793-5

Initially a frequency domain simulation was chosen for the model calculations. The reflection index of a gabion NRD was determined using the local plane wave method.
Secondly, a time dependent analysis was needed for an investigation of the effect of acoustic "depth" on the reflection index measurements on gabions according to EN 1793-5. First calculations with a direct time-dependent numerical model showed that this approach would take too much calculation time, so, an analytical/numerical combination model was used.

Using the LPW ("Local Plane Wave") model, as also used in the Sonocat measurements, the reflection index of a noise barrier can be determined directly with the sound pressure P and (normal) particle velocity Un in the scanning surface just in front of the gabion. In the simulation using a FEM analysis these quantities are available. Thus the amplitudes of the incoming and reflective sound wave at each point of the scanning surface can be calculated. With these the sound power of the incoming and reflective sound waves can be determined with an integration over the surface. The reflection index is defined as $RI = Wrefl/Win$.

In the FEM model, the "stones" have been removed from the calculation domain, so that only the air "around" the stones is modelled. Various models have been calculated with randomized dimensions for a "Monte-Carlo" analysis: by averaging multiple models the reflection index of the NRD is estimated, without knowing the exact dimensions of the stones. The stones are assumed not to be absorbent, so the stone-air interface is therefore assumed to be acoustically hard. Some damping has been included due to viscous and thermal effects in the air layer between the stones.

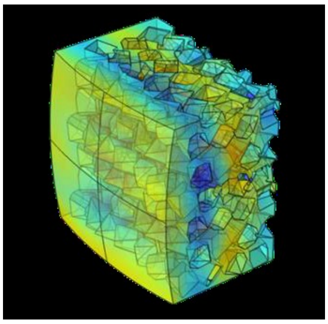

Figure 8: sound pressure at 1 kHz in the model for a gabion NRD

Figure 9 shows the reflection index (RI) of seven models with randomized dimensions. The average RI has a value around 0.1 at low frequency and increases to 0.4 at higher frequency. The variance due to randomization increases above 1kHz. This is to be expected because the wavelength for high frequencies is in the order of the stone size. The results show somewhat lower values than the measurements of the gabion NRD's in Prinsenbeek and Oss. The spectral behavior with a low value at around 600 Hz and higher values at high frequency corresponds reasonably well to the measured results.

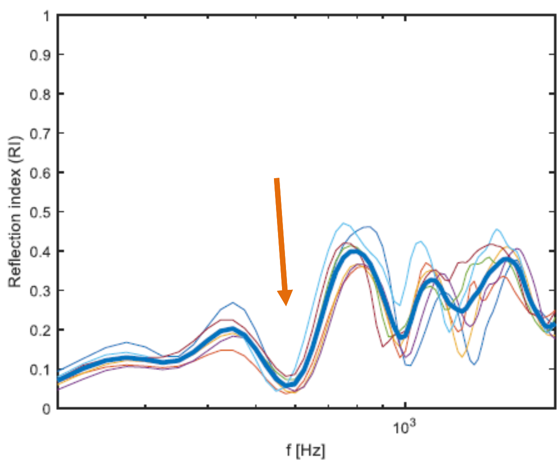

Figure 9: The reflection index (RI, based on the LPW method) as a function of the frequency for 7 randomized gabions. The thick solid line is the average value.

Time-domain analysis - An analytical/numerical combination model was used for simulation of the measuring method EN-1793-5. This combination model is constructed as in fig. 10:

1. Fourier decomposition of the "Gaussian pulse".
2. Evaluation of the "Gaussian pulse" at the microphone position.
3. Scattering analysis of the "Gaussian pulse" spectrum on the gabion/reflecting wall using a finite element analysis in the vicinity of the wall. This is possible a calculation domain consisting only of the reflective objects will suffice.
4. Kirchhoff-Helmholtz integral radiance analysis from the envelope surface of the finite element model to the microphone position. This means there is no additional calculation domain necessary between the reflective objects and the microphone position.

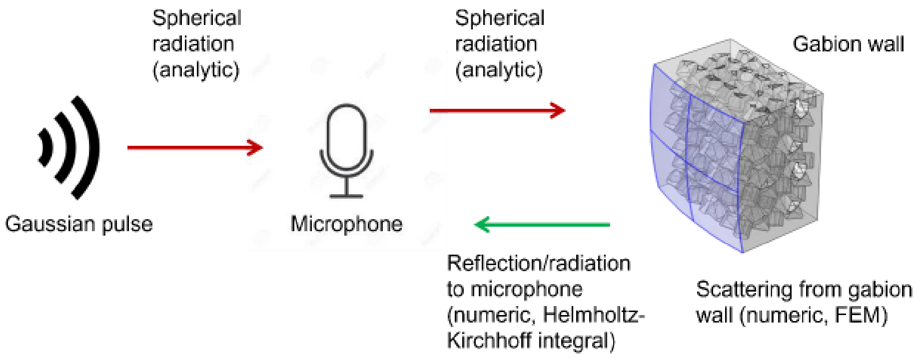

Figure 10: steps in the analytical/numerical combination model

Results of time domain analysis confirm the geometrical correction in the EN 1793-5 method. As expected, for a larger microphone-array-screen distance, the time delays are also larger. Time domain results (figure 11) show that the reflection of a gabion NRD is more spread out over time, and that the amplitude of the reflection is much lower than for a reflective surface. For the gabion NRD (right figure) it is noticeable that a small amount of energy falls outside the time-window (arrow). This was also found in measurements previously carried out on a gabion NRD [3]. We expect this to be a result of scattering of sound waves on the irregular stones in the NRD's surface.

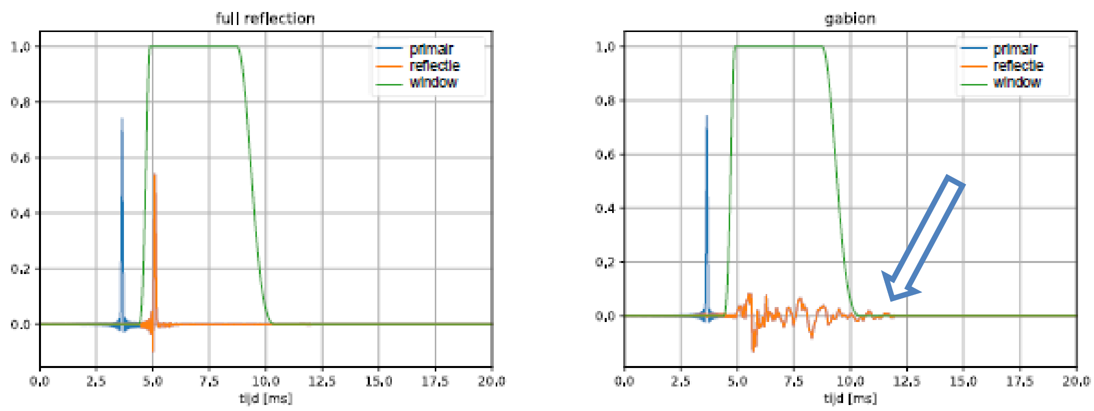

Figure 11: The simulated measurement signal for the central microphone of the microphone array cf EN-1793-5 for a reflective noise barrier (left) and a gabion barrier (right).

5. MODELLING OF SCATTERING

Large gabion NRD's are chosen to be part of the building design in one of the Dutch road construction projects. Legal noise constraints were determined in advance, with regular noise absorbing NRD's in the planning phase. The final road construction design including gabion NRD's is supposed to comply to the legal noise immission levels.
Discussion was on modelling the gabion NRD's in the TNM, knowing that scattering will affect the reflecting properties of the NRD at the higher frequencies. Primary step was to add a sound absorbing back-wall in the gabion design in order to have some sound absorption.

Investigation was done with a multi stage approach consisting of;
1. Measurements of sound absorption in a reverberation room according EN 1793-1.
Figure 12 (right) shows the sound absorption peak at lower frequency (250 Hz) that is typical for a gabion NRD.

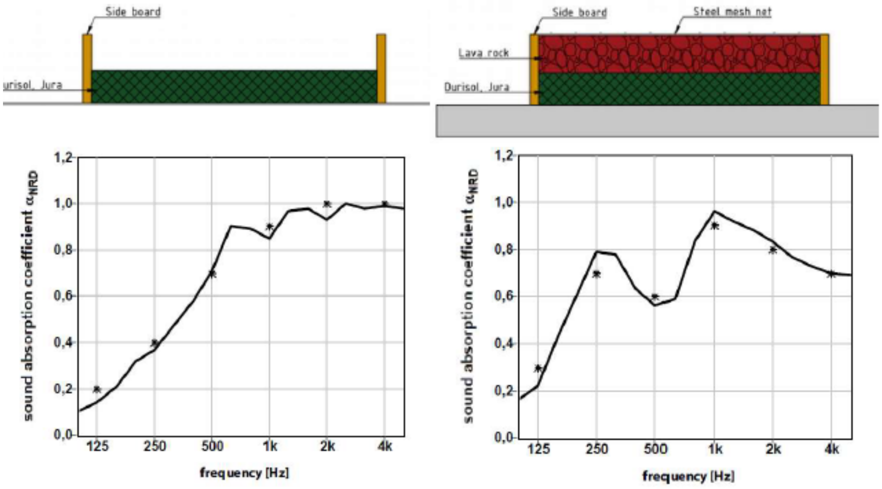

Figure 12: measured sound absorption in reverberation room (EN 1793-1) for just the backing-wall (left), and for the total construction with added the layer of stones (right).

2. Numerical simulation of the gabion NRD to get information on absorption characteristics and on the spatial distribution of the reflected sound due to scattering.
A two-dimensional FEM model (Comsol) was used to determine the sound absorption characteristics at various angles of incidence (0 to 80 degrees). In this way the diffuse sound field in the reverberation room was simulated. First step was to model just the absorbing backing-wall fitting a value for the flow resistance, using the Delayney-Bazley-Miki model.
The numerical model was completed adding randomly distributed layers of stones. In this way three layers were generated for calculations. Figure 13 shows an impression of the acoustic pressure distribution for sound fields with various angles of incidence.

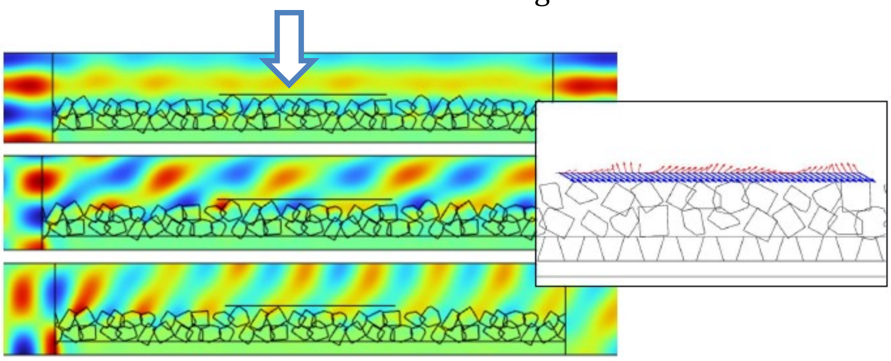

Figure 13: Impression of the acoustic pressure distribution for sound fields with various angles of incidence (0, 30 and 60 degrees, left figure). The sound intensity of incoming and reflected sound is determined directly above the modelled stone layer (arrow and right).

The sound intensity of incoming and reflected sound is determined directly above the modelled stone layer (the horizontal line). The sound reflection is calculated from the ratio of the sound intensities.
The sound absorption of the gabion NRD was determined for 3 types of stones with different acoustic absorption (high, middle and low). The sound absorption was modelled using 3 values of the flow resistance (80 , 500 and 5000 Pa.s/m2) representing the characteristics of pumice stones (high absorbing), sandy ground (medium abs.) and hard rock.

Calculation results show absorption values that are more or less constant with frequency and with angle of incidence. Resulting in values around 0.8 to 1.0 for sound absorbing stones, to ~0.5 for "hard" stones.

The distribution of the direction of scattering was determined from the direction of the reflected sound intensity (the red arrows in fig. 13, right), using 5 degrees intervals and summing the intensity in octave bands. An example of a result is shown in figure 14. The values are normalized to the total reflected sound intensity. In a setting with a flat surface all energy would be reflected opposite the angle of incidence (here -60 degrees).

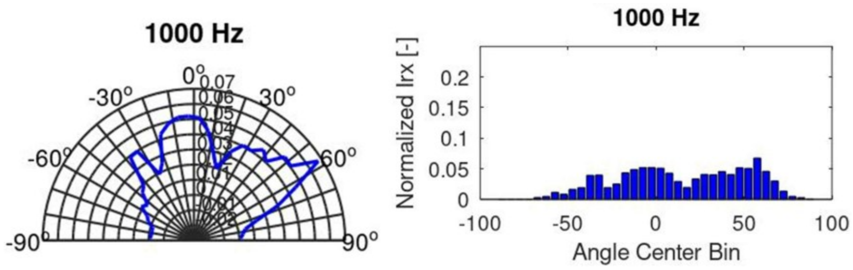

Figure 14: the calculated distribution of the angle of reflected sound intensity, the angle of incidence is -60 degrees.

Histogram results were derived for 6 angles of incidence (0, 15, 30, 45 , 60 and 75 degrees). A typical result is shown in figure 15, giving the distribution for an angle of incidence of 15 degrees, for the situation with acoustic hard stones. In general for frequencies above 250/500 Hz, the reflected energy is distributed over a wide angle.

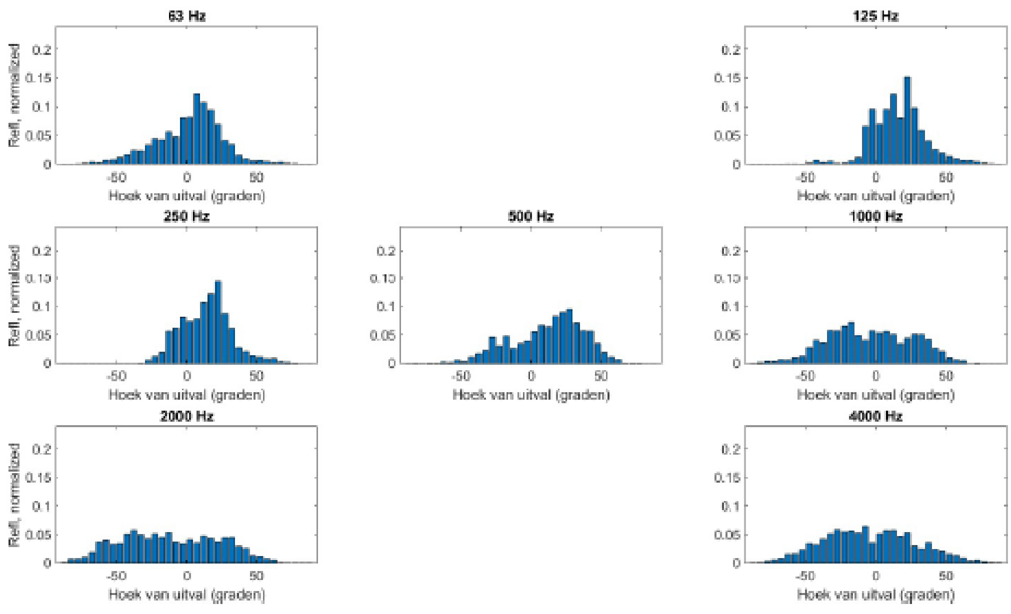

Figure 15: scattering distribution, angle of incidence 15 degrees (hard stones)

- Simulation of sound absorption and scattering in an TNM

A situation similar to that in the project was modelled as depicted in figure 16, with 9 meter high NRD's on both sides of the road. The sound level of a source positioned at 0 was calculated at 2 receiver positions at 30 meter distance.

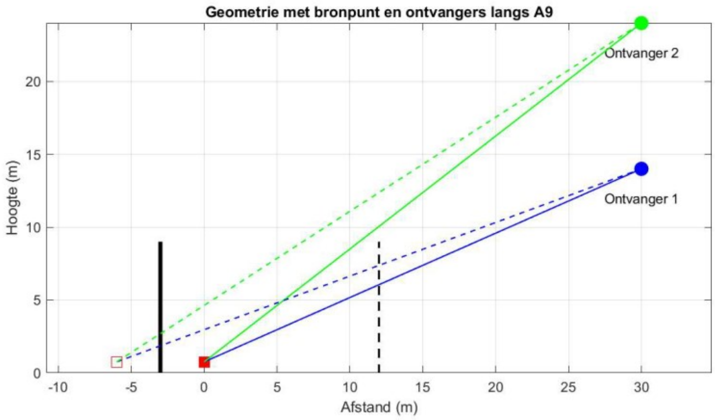

Figure 16: simplified geometry with direct sound path's from source to receiver positions, and added the mirror sound source on the left side.

In this simplified model sound propagation in 2D is assumed for calculation of the sound pressure levels for the primary sound source (direct contribution) and for the mirror sound source (reflected contribution).

The direct SPL is defined as: $Lp = Lw - 10\log(2\pi Rdirect) - Dbarrier$ (1)

The reflected SPL is defined as: $Lp = Lw - -10\log(1-\alpha) - 10\log(2\pi Rrefl) - Dbarrier'$ (2)

Including the noise barrier (dashed line) the SPL is lower due to shielding, represented here by Dbarrier. The Dutch TNM (SRM) will calculate the insertion loss in octave bands. Here calculation results are presented at 250 Hz.

Contribution from scattering from the gabion NRD is calculated by adding sound sources on the high barrier wall. The barrier wall is assumed to act as an extra line source that radiates sound in all directions (uniform distribution for scattering). The source strength Lwi is defined by the distance to the primary sound source(Ri) and the individual height (dZ) on the wall.

$$Lwi = Lw - 10\log(2\pi\, Ri) + 10\log(dZ) \quad (3)$$

The sound levels for the extra sound sources (Lpi) at the receiver positions with distance (Rpi) are defined as; $Lpi = Lwi - -10\log(1-\alpha) - 10\log(2\pi\, Rpi) - Di$ (4)

Here the sound absorption of the barrier wall and shielding (Di) are taken into account.

The total contribution of scattering is an (energy) summation of the individual sound levels (Lpi). The calculations were done in Matlab.

The sound levels (direct, reflected and scattering) for a situation with a sound reflecting wall (α=0) and no shielding from the second barrier are shown in figure 17. The SPL due to scattering is 71.7 dB, what is 5.2 dB lower than the direct level of 76.9 dB. This shows that scattering is not negligible in the total SPL at the receiver position.

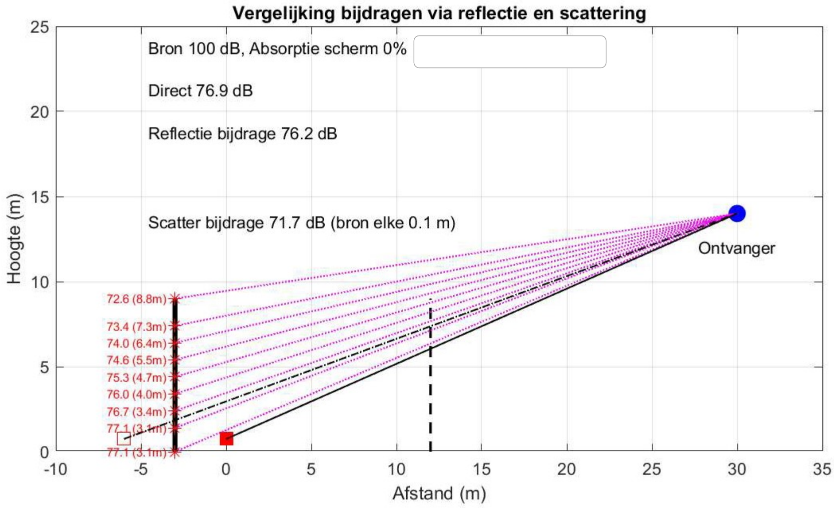

Figure 17: The sound levels (direct, reflected and scattering) for a situation with a sound reflecting wall (α=0) and no shielding from the second barrier. The labels (in red) indicate the added sound sources on the wall that simulate scattering.

The situation with shielding from the second barrier is shown in figure 18. The effect of shielding is determined for each individual sound source. The direct SPL is 66.7 dB, being 10.2 dB lower as result of shielding. The reflected SPL is 68.4 dB (shielding effect 7.8 dB). The SPL due to scattering is 66.5 dB, what is 0.2 dB lower than the direct SPL and 2.9 dB lower than the reflected SPL.

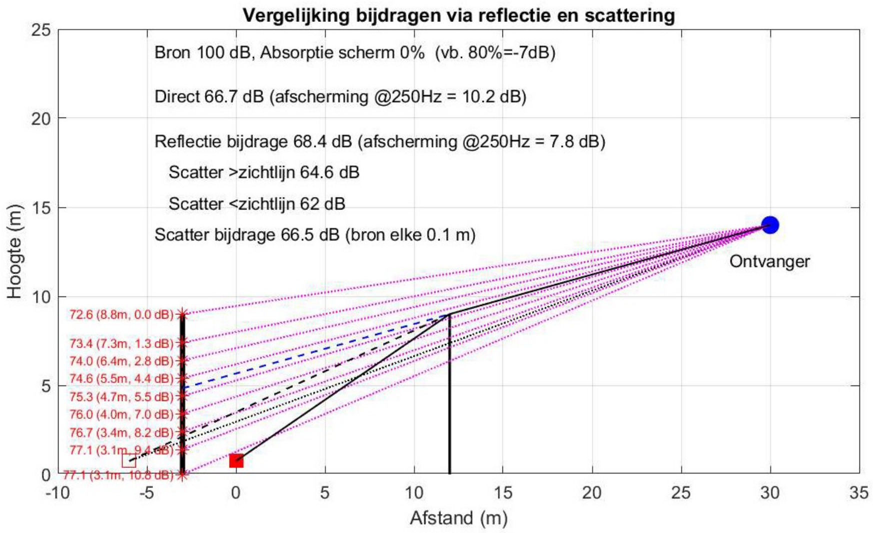

Figure 18: The sound levels (direct, reflected and scattering) for a situation with a sound reflecting wall (α=0) and with shielding effect from the second barrier. The labels (in red) indicate the added sound sources on the wall that simulate scattering.

In case of a sound absorbing gabion wall the SPL for reflection and scattering are lowered by $10\log(1-\alpha)$. In a situation with 80% absorption the SPL will be 7 dB lower, resulting in a more negligible contribution to the total SPL (5.2+7= 12.2 dB lower than direct SPL). In case of shielding with the second barrier the difference is 0.2+7= 7.2 dB, what is not negligible.

The 2D simulations of TNM calculations show that scattering cannot be neglected in a situation with high gabion sound barriers. The effect of scattering/reflection is even more dominant in a situation with shielding of the direct sound path. The scattering/reflection contribution can be reduced with sound absorbing stones.

In all situations the calculated reflected sound from the image sound source showed to be higher than the contribution of scattered sound. Thus it was concluded that regular modelling of sound barriers in a TNM was acceptable since this would not give an under estimation of the effect of scattering.

5. CONCLUSIONS

Measurements and modelling results have shown that the sound absorption of gabion NRD's can well be determined by measurements according to EN1793 series, and also with the Sonocat instrument. All methods show the high absorption at low frequencies that corresponds with the thickness of the open stone layer. At high frequency above 2 kHz the in-situ method EN 1793-5 shows high reflection values over 1.0 what is not realistic for a surface with acoustic reflecting stones. At these high frequencies a value of around 0.5 seems to be more appropriate for the situation with acoustic hard stones.

The in-situ results for two measurement distances (25 and 50 cm) show just small differences. This confirms that the geometrical correction in EN 1793-5 compensates well for the spherical wave propagation.

Evaluation of scattering at a stone layer surface with numerical models shows that the reflected energy is distributed over a wide angle, for frequencies above 500 Hz. At lower frequency the physical laws of reflection are more dominant. 2D simulations of TNM calculations show that scattering cannot be neglected in a situation with high gabion sound barriers.

Question was how to model a gabion NRD in the Dutch TNM (SRM) knowing that scattering is relevant, and that it is not possible to add sound sources with a distance dependent source strength in the TNM. Since the simulations showed that the calculated SPL for reflection has a higher value than the contribution due to scattering, it was decided that the regular way of modelling of NRD's is appropriate also for gabion NRD's.

REFERENCES

1. W. Schwanen, "Bepalen akoestische eigenschappen geluidscherm", M+P.RGPO.18.10.2, 17, december 2018;
2. C. Tollenaar & W. Schwanen, "Eerste inzicht in de akoestische absorptie van schanskorfschermen", M+P.RWSWNZ.19.02.2, november 2019;
3. W. Schwanen, E. van Gils (M+P); EN 1793-5 reflection measurements of gabion walls, M+P.RGPO.21.06.2, December 2021
4. W. Schwanen & W.J. van Vliet, "Application of sound absorption measurements according to EN 1793-5 on gabion walls", proceedings Internoise 2022, Glasgow, 2022;
5. W. Schwanen (M+P), Y. Wijnant (4Silence); Onderzoek absorberende eigenschappen geluidschermen, M+P.RGPO.22.02.2, oktober 2023
6. F. van der Eerden (TNO); "Reflectie en/of scattering van geluid aan een wand bekleed met (lava)stenen.", TNO 2023 M11925, octobar 2023.
7. EN 1793-5:2021 - Road traffic noise reducing devices - Test method for determining the acoustic performance – Part 5: Intrinsic characteristics – Sound absorption under direct sound field conditions.