Low frequency noise impact of road traffic in the Netherlands

Eric Schreurs, Tom Koeman and J. Jabben

RIVM, A. van Leeuwenhoeklaan 9, 3720 BA Bilthoven, Netherlands
jan.jabben@rivm.nl

Current traffic noise impact assessments are usually based on broadband A-weighted Noise indicators. A more complete picture and better correlation with annoyance and health effects may result from indicators that include temporal aspects and frequency character. These aspects are currently under investigation at RIVM. This paper gives an evaluation of low frequency noise impact from motor ways in the Netherlands. The results are based on low frequency noise maps covering the entire motorway network. The LF impact was estimated for indoor noise levels using a standard isolation spectrum. Two methods were studied: the LF-guideline according to the Dutch Association for Noise Annoyance (NSG) and the difference between C- en A- weighted noise levels. At approximately 5.6 million dwellings the NSG guideline for LF- indoor noise appeared to be exceeded This result indicates that for low frequency noise levels, propulsion noise and heavy vehicle traffic in general, are still of major importance for environmental noise quality - Eric Schreurs, Tom Koeman, Jan Jabben, National Institute of Public Health and Environment, The Netherlands.

1 Introduction

In the Netherlands, transport activities from roadways, airports and railways are major noise sources. The resulting noise levels have a severe impact on the environmental quality. Noise from roadway traffic causes the highest rate of annoyance: 29% of the Dutch population above the age of sixteen are severely annoyed by this source [1]. Due to further growth of traffic activity and population, the exposure to traffic noise will increase even more in the next decades. For this reason, noise monitoring studies on environmental noise quality are important for an effective policy aimed at preserving social well-being in the Netherlands.

In order to provide policymakers with the best information regarding noise exposure, a thorough knowledge of the various types of noise exposure and better understanding of the relation between exposure and effects is needed. In particular, the present knowledge of the influence of time and spectral characteristics of the noise on human perception should be improved. For this reason, RIVM has started a research program that aims at extending knowledge on noise exposure from the usual A-weighted noise exposure indicator (L_{den}) to other noise indicators such as background noise levels and low frequency (LF) noise. In a previous part of this research, a method has been developed to visualize the background noise levels due to road and railway traffic.

LF noise can cause more annoyance than predicted from A-weighted noise levels. Because complaints due to LF noise are often difficult to assess, these complaints take up a disproportionate amount of time. To gain a better understanding of this problem, better modelling of LF noise is needed. To address this, RIVM has mapped the LF noise from motorways. LF noise is usually attributed to local, industrial machinery, for example generators or cooling installations. The spatial extent of these sources is limited however, contrary to a possible contribution from motorways. Therefore the choice was made to model motorways. To gain some insight in the scope of the LF noise problem, two methods of evaluation of LF noise have been applied to these results.

2 Modeling of Low Frequency Noise from road traffic

RIVM predicts noise exposure using the Dutch National Standardized calculation method [2] and visualizes the exposure using noise maps covering the whole of the Netherlands. The noise maps indicate the noise caused by traffic for a certain region of observation in terms of L_{den}, which is a European standardised quantity that averages sound levels over a period of 24 hours, with penalties for noise produced in the evening and night periods. L_{den} itself can be treated as an initial noise emission term from the source L_E reduced by several attenuation factors and correction terms. This can be shown in a basic equation used for the of noise mapping:

$$L_{den,i} = L_{E,i} - A_{Geo,i} - A_{Air,i} - A_{Ground,i} - A_{Barrier,i} - C_M - 58{,}6 \qquad (1)$$

in which the A-terms denote attenuation due to geometric spreading (Geo), Air, Ground and Noise Barrier effects. C_M is a correction for the meteorology, and the constant of 58.6 dB is a correction for dimension changes. The i-terms denote the octave band center frequencies, which for the Dutch National Standard for road traffic noise range from 63 Hz up to 8 kHz. For this study however, information for a frequency as low as 31.5 Hz is preferred, therefore the current model was extended with this frequency. For the source term, a simplified source model from the Harmonoise project has been used [3].

In the European Harmonoise project, traffic noise sources are modelled using a combination of tyre/road surface noise and propulsion noise, in addition to a distinction with regard to the spectral properties between light (LV), medium heavy (MV) and heavy vehicles (HV). The source spectra for LV and HV used in the Harmonoise model are shown in Figure 1.

For the LV as well as the HV, the sound power level rapidly decreases for frequencies below 63 Hz. This is mainly due to the fact that the propulsion noise peaks at around 80 Hz for all the vehicle types, and the tyre/road surface noise has a high frequency characteristic. Subsequently for the RIVM model, with the knowledge that the 31.5 Hz will not be decisive for the amount of low frequency noise caused by road traffic, an extrapolation towards the 31.5 Hz octave band could be made using roughly the same coefficients for the source model as the Harmonoise model. The results of this extrapolation can also be seen in Figure 1, in comparison with the source spectrum used by Harmonoise.

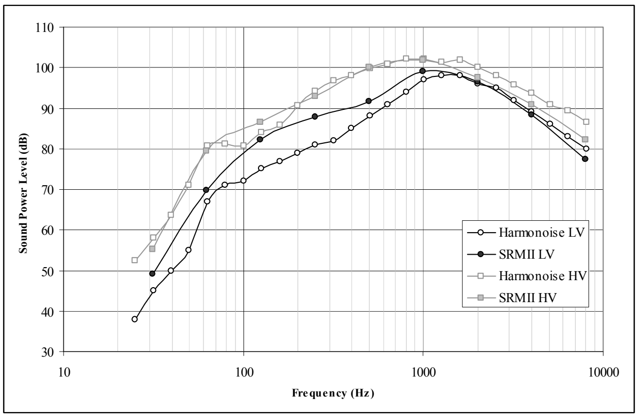

Fig. 1 Source spectra for Light (LV) and Heavy vehicles (HV), used for the Harmonoise[3] and the Dutch National Standard (SRMII)[2].

3 Low Frequency Noise Assessment

After modelling LF noise, RIVM used two methods to try and evaluate the scope of the LF noise exposure, namely the guidelines proposed by the Dutch Association for Noise Annoyance (NSG) and a method based on the difference between C-weighted and A-weighted noise levels.

NSG guideline – If a person complains about LF noise, it is often the case that only the complainant can actually hear the noise, while others living in the same dwelling or environmental health officers may not hear it. Because of this, the guidelines proposed by NSG focus on objectifying the complaint, with the assumption that whenever low frequency noise is audible, annoyance may occur. This is due to the loudness which increases more rapidly for LF-sound than for 'normal' sound. Because of this, the reference values are based on the hearing threshold for a common group of 50 to 60 year old people, of which 10% is able to just hear the sound [4].

The LF-region is defined as ranging from 20 Hz up to 100 Hz, as for frequencies higher than 100 Hz the extent of annoyance can be assessed with the usual A-weighting. In order to objectify the complaint, the sound levels of the frequencies in the defined region are compared to reference values. If these reference values are exceeded, it is assumed that the complaint is objectively attributable to a LF source. The reference values of the guideline are shown in Table 1.

Frequency (Hz)	20	25	31.5	40	50	63	80	100
Reference (dB)	74	62	55	46	39	33	27	22
Assumed Isolation (dB)	8	9	10	11	12	13	14	16

Table 1 Reference values as given by the Dutch Association for Noise Annoyance (NSG) for low frequency noise assessment and assumed isolation.

C-A method - In order to apply the NSG method, the Sound Pressure Levels in dB have to be assessed for each of the 1/3 octave bands. Since measuring noise for specific frequencies requires specialized equipment, it has been proposed to assess the LF content in the total spectrum of the noise by assessing the difference between average C-weighted and A-weighted values [5,6]. Figure 2 shows the curves used to perform the A- and C-weighting.

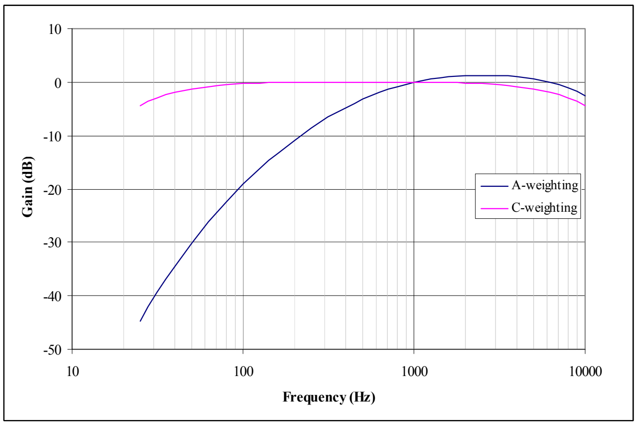

Fig. 2 A-weighting and C-weighting filters.

Based on the 40 phon equal-loudness contour, A-weighting reduces the contribution of low frequency noise when determining average sound levels, and now is commonly used for the measurement of environmental noise. C-weighting however was based on the 100 phon equal-loudness contour, as with higher sound power levels (SPL) the ear behaves as a 'flat' filter. Figure 2 shows that the main difference between A-weighting and C-weighting is the amount of reduction applied in the LF-region, with differences of 20 dB at 100 Hz and almost 40 dB at 30 Hz. As the two filters behave approximately the same in the >1kHz region, combined with a high value of the SPL, this method could able to predict whether noise has a strong LF characteristic.

4 Noise Maps

Using traffic data of the Dutch motorways, LF noise maps for the major motorways were set up according to the two methods outlined in the previous chapters. All calculated outdoor levels were converted to indoor levels before testing, using the isolation from Table 1. This is based on a sound isolation characteristic of 4mm glass [7]. All indoor levels were calculated for average nighttime exposure from 23:00-7:00 hour. In order to apply the NSG assessment, the RIVM model was used to calculate the noise exposure for single octave band frequencies. For the low frequency region, this means that calculations for the 31.5 Hz, 63 Hz and 125 Hz octave bands were made. The noise exposure levels subsequently were weighted with the values from Table 1, taking into account that the 125 Hz octave band is weighted with the corresponding A-weighting value of 16 dB. Taking the maximum of the three weighted levels resulted in a measure of low frequency noise exposure caused by road traffic. For the C-A weighting method, the RIVM model was applied to calculate C-weighted and A-weighted noise exposure for the entire frequency range. The subtraction of the two exposure levels revealed the low frequency characteristic of the noise exposure.

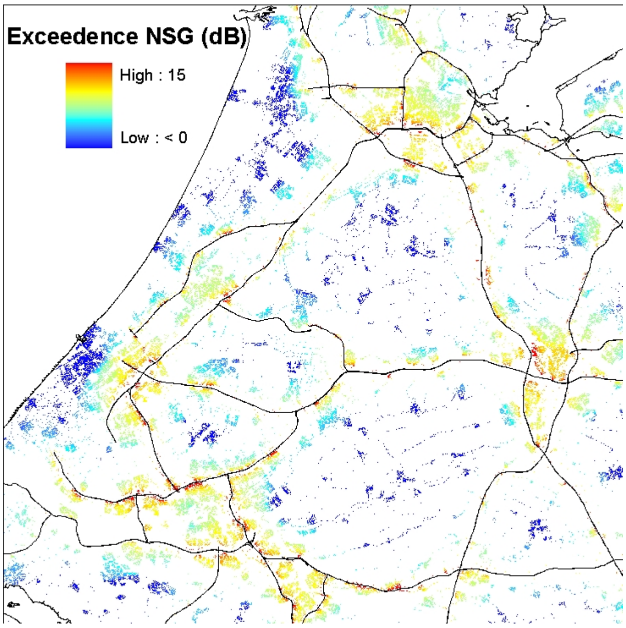

Fig. 3 NSG exceedence on dwellings in the ‘Randstad’.

Figure 3 shows the noise map of the ‘Randstad’ region in the Netherlands for the dwellings where the NSG guideline is exceeded. The Randstad is a region in the western part of the Netherlands, which consists of the four largest Dutch cities (Amsterdam, Rotterdam, The Hague and Utrecht. Including the surrounding areas, almost half of the population of the Netherlands live and work in this region. Consequently the motorways cope with major congestions on a daily basis.

Noise maps of the normal A-weighted L_{den} levels indicate that the urban areas in the Randstad cope with high noise exposure, yet the range of the exposure from the motorway noise is less then for LF noise. This is because the L_{den} is largely influenced by the higher frequencies, which are strongly attenuated due to sound barriers and ground and air attenuation. Figure 3 however shows that the lower frequencies are attenuated less and that the exposure extends much further. For the four largest cities the NSG guideline is exceeded in virtually the entire region, although in some parts the guideline is barely exceeded.

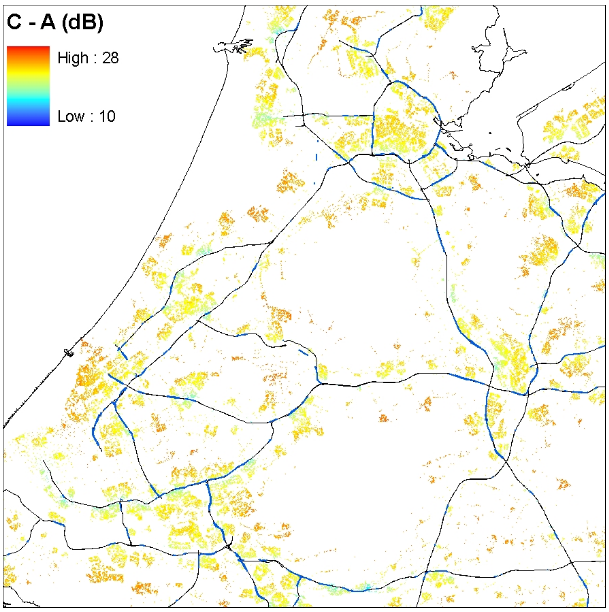

Fig. 4 C-A level difference on dwellings in the ‘Randstad’

Figure 4 shows the noise map using the C-A method. As with Figure 3, the exposure has a wide range. The high C-A levels further away from the motorways indicate that the LF noise levels are still relevant due to the lack of air attenuation for low frequency noise. LF noise also has less ground attenuation compared to the higher frequencies. At the urban areas close to the motorways, where ground attenuation is not present, the C-A levels minimize, indicating that high frequencies dominate the noise exposure.

When observing the entire noise map for both methods, two problem areas emerge where the noise exposure contains unusually high levels in the lower frequencies. These turned out to be areas behind noise barriers, and motorways with a large amount of heavy vehicle traffic.

5 Noise Barriers

Figure 5 shows a detailed view of Figure 4, with the red lines indicating noise barriers.

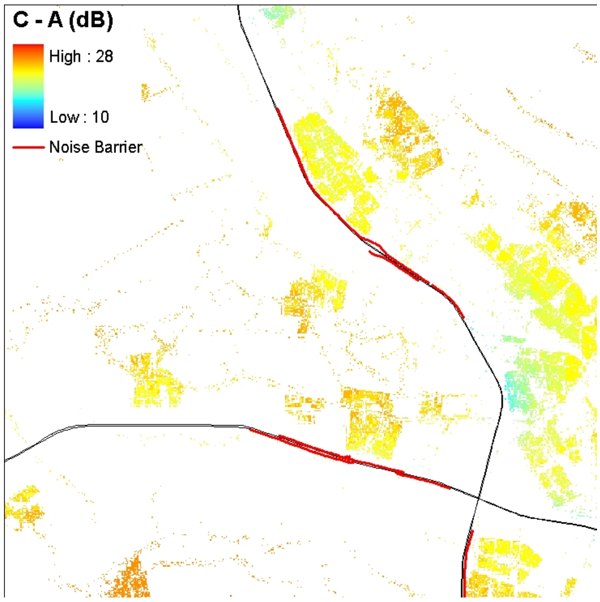

Fig. 5 Noise Map of motorways with sound barriers

The motorways shown here are the A2 running from north to south, and the A12 from east to west in the vicinity of Utrecht. The noise barriers are largely located near urban areas. At the locations just behind the sound barriers, which are the locations that should benefit the most from those barriers, the C-A levels are higher than at locations where there is no barrier present. This means that the A-weighted noise levels are lower at the sound barrier regions than at the regions with no barrier, yet the C-weighted levels are not affected as much by the sound barriers. This is because the higher frequencies of sound are more effectively attenuated by sound barriers than the lower frequencies. Consequently sound barriers affect the ‘colour’ of the noise; instead of a broad frequency noise, the regions behind the barriers perceive a noise without a masking effect by the high frequencies.

It should be noted however that the C-A levels shown in the noise map do not indicate absolute sound levels. In other words, they do not indicate whether the high differences correspond to high levels of the dB(A) and dB(C) noise. Noise barriers in general perform better for higher frequencies than for lower frequencies, yet the absolute attenuation may still be enough to solve the noise problems in the affected region. Future research should be able to combine these C-A noise maps with regular noise maps, in order to indicate at what regions low frequency noise problems may occur.

6 Propulsion noise vs. Tyre/Road surface noise

The second problem area where noise can have large low frequency characteristic turned up when the 63 Hz NSG noise map was expanded to the whole of the Netherlands. Outside the Randstad region, the amount of traffic is not as large, yet Figure 6 shows two motorways outside the Randstad where the model indicates high 63Hz levels.

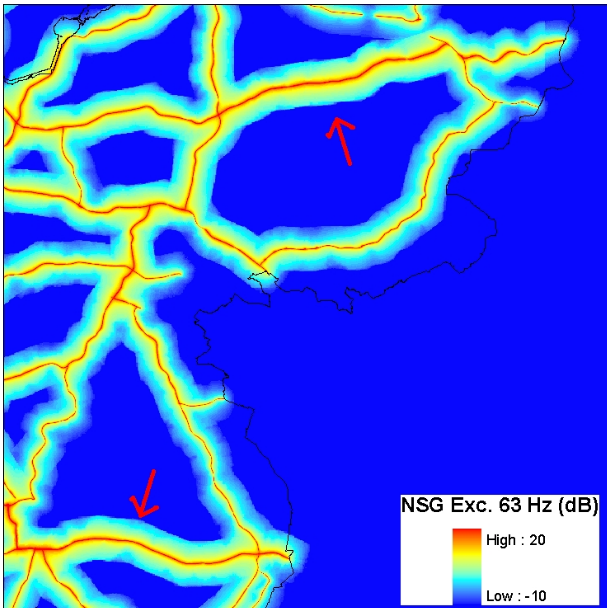

Fig. 6 Noise Map of roads with large amounts of Heavy Vehicles.

The motorway indicated by the upper arrow in Figure 6 is the A1, running from Amsterdam to Enschede. At the German border it transfers to the Bundesautobahn 30, from where major German cities such as Hamburg and Berlin can be reached. The motorway indicated by the lower arrow is the A67, which connects the Belgian port of Antwerp with the German industrial zone the Ruhr Area. Both these motorways are used by significantly more heavy weight traffic (HV) than other motorways in the vicinity. Since the noise caused by heavy weight traffic has a stronger low frequency characteristic than light vehicles (LV), these motorways can be exposed to an unusual amount of low frequency noise.

For motorways with a high amount of HV traffic, a different approach to noise attenuation should be considered. Recent research in the field of noise reduction concentrates largely on tyre/road noise, resulting in projects for silent roads [8] and quiet tyres [9]. Figures 7(a) and (b) show that according to the Harmonoise source modelling [3] the source model for LV in the high frequency region consists largely of tyre/road noise. For HV traffic however, propulsion noise has the largest contribution to the source modelling, especially in the low frequency region where it peaks at 63 Hz. Therefore, noise attenuation projects should take into account the low frequency component of heavy traffic caused by propulsion noise in certain areas.

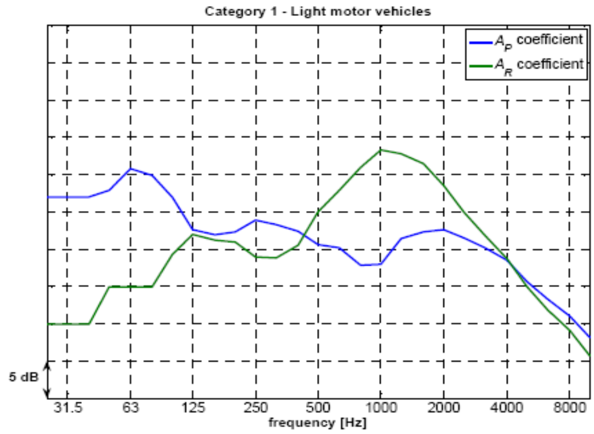

Fig. 7(a)

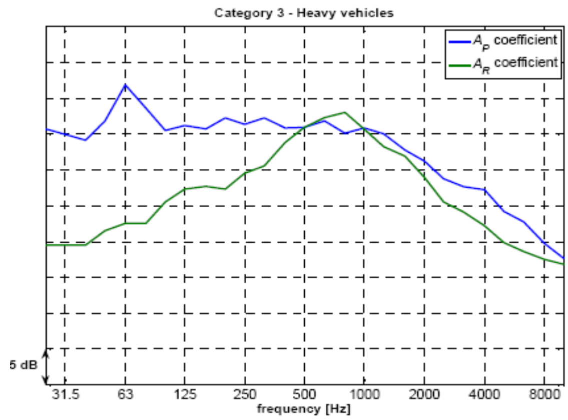

Fig. 7(b) Harmonoise coefficients for the source modelling of light vehicles (a) and heavy vehicles (b), A_P denoting propulsion noise, A_R denoting tyre/road noise.

7 Impact on population

Table 1 shows the number of households situated in areas where the limits proposed by the NSG are exceeded, or where C-A weighted noise levels exceed 15 or 20 dB. As can be seen, the number of households where these limits are exceeded can be substantial.

Guideline	Number of households (mln)	Percentage of total (%)
NSG guideline 63 Hz	3.0	43
NSG guideline 125 Hz	5.6	79
NSG guideline 63 or 125 Hz	5.6	79
C-A ≥ 15 dB	4.2	59
C-A ≥ 20 dB	0.64	9

Table 2 Number and percentage of households exceeding various guidelines for LF noise

For the frequency of 63 Hz, the NSG guideline would be exceeded at 43% of households in the Netherlands. For the frequency of 125 Hz, this number is 79%. The number of households where either the limit of 125 Hz or 63 Hz is exceeded also amounts to about 79% of the total. This shows that the frequency of 125 Hz is important when looking at the number of exposed households.

When looking at C-A as a measure of the content of LF noise in the total noise spectrum, 59% of households are exposed to noise with a C-A equal to or exceeding 15 dB. However, it appears that the number of exposed households quickly decreases if C-A is equal to or exceeds 20. In this case around 9% of households are exposed to this level of low frequency noise.

8 Discussion

Almost 80% of households in the Netherlands showed a LF noise exposure exceeding the NSG guideline. In the Randstad this guideline was exceeded almost everywhere. From the results it seems that the frequency of 125 Hz is the determining factor in the amount of exposure. However, in more than half of those households the limit for 63 Hz was also exceeded. We did not assess whether the 63 Hz frequency might be dominant in cases where the guideline is exceeded for both frequencies. Future modelling can take this into account to better characterize the exposure. It should be noted that the NSG guideline is based on the 10% hearing threshold of the elderly population [4]. This guideline therefore does not give a good indication whether the noise is heard by people. Therefore it also does not give an indication of the number of people who are annoyed.

Modelling the noise levels using the C-A method indicated that areas behind noise barriers and motorways with a large amount of heavy vehicle traffic show high C-A levels. This may indicate that these areas are exposed to noise with a strong low frequency characteristic. Modelling the C-A levels further indicated that the number of households exposed to a strong low frequency characteristic depends strongly on the threshold value of C-A level chosen. Further research is necessary to assess whether this higher low frequency component can present a problem by causing higher amounts of annoyance.

As this tentative study shows, the low frequency noise emission should not be underrated. The range of LF exposure is relatively large and measures like barriers and silent roads/tyres are less effective. The contribution of propulsion noise in the dB(A) noise levels is therefore still important for environmental noise quality.

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