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Adaptations of Cnossos from octave bands to 1/3 octave bands

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establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council

(Text with EEA relevance)

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ABSTRACT
CNOSSOS-EU is a new European calculation method for noise levels from road traffic, railway traffic and industry sources. The objective behind the EU directive that describes the method is to ensure that a uniform method is used throughout Europe to calculate noise levels for area planning and action plans for protecting the populations health from excessive noise levels. For computation of indoor noise levels according to current restrictions in Norway, the outdoor noise levels must be computed in 1/3 octave bands, which is not supported by CNOSSOS-EU in its current state. This report describes how 1/3 octave resolution can be introduced in CNOSSOS-EU to meet Norwegian requirements.

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2	2021-04-20	Final report
3	2021-07-02	Final report, revised coeffisients in appendix.

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APPENDICES

1 Introduction

CNOSSOS-EU is a new European calculation method for noise levels from road traffic, railway traffic and industry sources. The method is described in the EU Directive 2015/996 [1] and its objective is to ensure that a uniform method is used throughout Europe to calculate noise levels for area planning and action plans for protecting the populations health from excessive noise levels.

As of January 1st 2019, all EU member states are required to use this method when making noise maps in accordance with the European Environmental Noise Directive (END - EU Directive 2002/49/EC)[2]. Moreover, from January 1st, 2019, the so-called “equivalent” methods permitted by the original END shall no longer be allowed for strategic noise mapping in the END sense. Directive 2015/996/EC is in fact a revision of Annex II in the END. While the subsidiarity principle makes it possible to use another method than CNOSSOS-EU in the definition of the action plans required by the END, CNOSSOS-EU is likely to be used by several countries that implement the END, for the sake of continuity with strategic noise mapping.

CNOSSOS-EU will be prepared for adaption as the official noise assessment method in Norway. CNOSSOS-EU deviates from the current noise calculation methods in Norway and must therefore be amended to fit current Norwegian policies. For computation of indoor noise levels according to current restrictions, the outdoor noise levels must be computed in 1/3 octave bands, which is not supported by CNOSSOS-EU in its current state. This report describes how 1/3 octave resolution can be introduced in CNOSSOS-EU to meet the Norwegian requirements.

2 The CNOSSOS EU method

It is worth highlighting that as of May 2015 the reference document that specifies CNOSSOS-EU is Directive 2015/996/EC. Although entitled CNOSSOS-EU, and although still available online, the report published by JRC in 2012 [3] should be considered obsolete.

Directive 2015/996/EC counts more than 800 pages. Most of them, however, are tabulated data concerning aircraft noise. It is beyond the scope of this section to present CNOSSOS-EU in details. Only the general principles are provided here. For a more detailed account the reader can refer to Chapter 2 in [4].

The overall structure of the directive can be summarized as in Figure 1. As this figure indicates, CNOSSOS-EU is made up of two harmonized prediction methods: one for terrestrial noise sources and one for aircraft noise. The latter is very close to the well-established ECAC DOC 29 method [5]. It will not be described further here, and the following paragraphs will focus on the method for terrestrial sources. CNOSSOS-EU is defined in octave bands from 63 to 8000 Hz. Like in most engineering models for outdoor noise prediction, the general approach in CNOSSOS-EU is to separate the emission model from the propagation model. The emission model delivers a sound power level L_W as a function of various parameters like for instance vehicle speed and traffic flow in the case of rail or road emission. The propagation model calculates the attenuation A between the source and the receiver. While the emission model is specific to the type of sound source, since the physics of sound propagation is the same whatever the source, CNOSSOS-EU chooses to use a common set of attenuation formulas for the different types of terrestrial noise sources considered by the END.

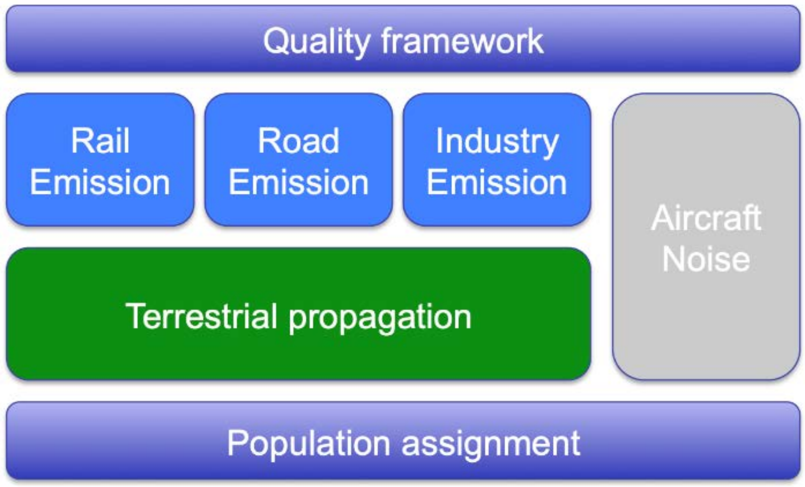

Figure 1: overall structure of Directive 2015/996/EC.

CNOSSOS-EU (1) breaks down the physical noise sources into equivalent point sources, to (2) identify the relevant propagation paths between one equivalent source and a receiver, before (3) computing the attenuation along the different paths. CNOSSOS-EU, however, does not specify the method for identifying paths. This aspect is left to software developers.

In CNOSSOS-EU's propagation model, the absorption from a ground surface is described by a frequency-independent ground factor *G*, while absorption factors in octave bands are used to describe the effect of obstacles like buildings. The real ground profile is not used directly in the computation of ground effect but replaced by one mean ground plane – when no diffraction occurs - or two mean ground planes when single or multiple diffraction on a horizontal edge occurs.

For each propagation path, CNOSSOS-EU considers two standard atmospheres: a homogeneous atmosphere and a downward-refracting atmosphere (favourable conditions). This means that two sound levels (LH for homogeneous and LF for favourable) are computed for each propagation path. From the probability of occurrence of downward refraction conditions, one long-term sound level LLT can be computed form LH and LF for each propagation path.

For each propagation path, and for each octave band, it is first evaluated if diffraction should be calculated. If the answer is yes, then the attenuation due to diffraction A_{dif} – which includes the attenuation due to ground effects - is computed. If not, the attenuation due to ground effect A_{ground} is computed.

Since the CNOSSOS-EU calculation depends on a number of input parameters, the method includes a *quality framework* (Figure 1) to limit the uncertainty attached to individual input parameters within +/- 2 dB in terms of emission level. Since the reporting of noise exposure data in the EU includes numbers of people within 5 dB intervals, CNOSSOS-EU also specifies how to assign populations with respect to the different building façades (Figure 1).

The emission models included in CNOSSOS-EU draw from the deliverables of the Harmonoise/Imagine projects, but also from other references like the French emission model on the specific point of the road equivalent source height [6].

The CNOSSOS-EU model for terrestrial propagation is a simplified version of the standard French prediction model (NFS31-133), also known as NMPB2008 [6]. A key simplification especially worth mentioning here is that NMPB2008 is in 1/3rd octave bands from 100 to 5000 Hz while CNOSSOS-EU is in octave bands from 63 to 8000 Hz as already mentioned.

3 Necessary amendments

The following sections list necessary amendments to obtain 1/3-octave band resolution in CNOSSOS-EU. The text refers to the equations in the official EU directive [1] when relevant. Please note that this report is limited to road, railway and industry sources. The methodology for aircraft noise is not considered here, as this is not included in CNOSSOS-EU, but refers to [5].

3.1 Sound propagation

The sound propagation part of the method was originally is based on a 1/3-octave band method and can therefore be extended to 1/3-octave bands without much change. Some small adjustments are however necessary, and the affected sections in the EU directive are listed below. The relevant changes are marked in bold.

- Section 2.1.1 Indicators, frequency range and band definitions, page L 168/4 should now read:

  *"Noise calculations shall be defined in the frequency range from **50 Hz** to **10 kHz**. Frequency band results shall be provided at the corresponding frequency interval.*

  *Calculations are performed in **1/3 octave bands** for road traffic, railway traffic and industrial noise. For road traffic, railway traffic and industrial noise, based on these **1/3 octave band** results…"*

- Section 2.5.1 Scope and applicability of the method, page L168/26 should read:
  *"The method provides results per **1/3 octave band**, from **50 Hz** to **10 kHz**.*

3.2 Source description

The Source description part of CNOSSOS-EU separates between Road Traffic noise sources, Railway Traffic noise sources, industrial noise sources and aircraft noise sources. in the following paragraphs each source type is listed together with the necessary amendments. The only source type with significant changes, when transitioning from octave bands to 1/3 octave bands, are the road traffic sources. These will therefore be in focus.

3.2.1 Road traffic sources

3.2.1.1 Background

CNOSSOS-EU describes the sound power of a single vehicle as a function of the vehicle speed and the frequency in octave bands from 63 Hz to 8 kHz. The road traffic noise sources are grouped into five separate categories with different noise emission characteristics. These categories are:

Category 1: Light motor vehicles
Category 2: Medium heavy vehicles
Category 3: Heavy vehicles
Category 4: Powered two-wheelers
Category 5: Open category,

Category 4 is subdivided into 4a and 4b, where 4a is two-, three- and four- wheel mopeds and 4b is motorcycles with and without sidecars, tricycles, and quadricycles. Category 5 is currently not specified and is therefore not included in the following paragraphs.

The sound source power is calculated separately for the rolling noise generated by the tyre/road interaction, and the propulsion noise generated by exhaust, inlet, engine, gearbox etc. The two contributions are given by the equation (2.2.4) and (2.2.11) in the EU-directive and are rendered here:

$$L_{WR}(f) = A_R(f) + B_R(f) \cdot \log_{10}\left(v/v_{ref}\right), \quad (1)$$

and

$$L_{WP}(f) = A_p(f) + B_p(f) \cdot \frac{v-v_{ref}}{v_{ref}}, \quad (2)$$

In these equations subscript *R* denotes rolling noise and subscript *P* propulsion noise. The *v* denotes the vehicle speed and *f* the centre frequency of the octave or 1/3 octave band. The aerodynamic noise is incorporated in the rolling noise source. For two-wheelers (Category 4), only propulsion noise is considered for the source.

Equation (1) and (2) without any corrections are valid under certain reference conditions:

- Constant vehicle speed v, ($v_{ref} = 70$ km/h)
- Flat road
- 20 °C air temperature
- *"virtual reference"* road surface: a mixture of dense road surface types, between 2 and 7 years old, in a representative maintenance condition.

The various corrections to these reference conditions are described in chapters 2.2.3 - 2.2.6 in the relevant EU-directive. Most of these corrections can be implemented for 1/3-octave bands directly as described in [1], but with a frequency span of 50 Hz to 10 kHz and the centre frequencies of the 1/3 octave bands instead of the centre frequencies of the octave bands.

The two exceptions are the corrections for studded tyres, and the corrections for other road surfaces which are both frequency dependent. The correction term for studded tires is given as:

$$\Delta_{stud,i}(v) = \begin{cases} a_i + b_i \cdot \log_{10}(50/70) & for\ v < 50\ km/h \\ a_i + b_i \cdot \log_{10}(v/70) & for\ 50 \leq v \leq 90\ km/h \\ a_i + b_i \cdot \log_{10}(90/70) & for\ v > 90\ km/h. \end{cases} \quad (3)$$

The correction term for non-reference road surface is given by the following equation:

$$\Delta L_{W,P,road,i,m} = \alpha_{i,m} + \beta_m \cdot \log_{10}\left(\frac{v_m}{v_{ref}}\right). \quad (4)$$

3.2.1.2 Amendments – A_R, B_R, A_P, B_P

The coefficients A_R, B_R, A_p, B_p in equation (1) and (2) are tabulated values given in octave bands from 63 Hz to 8 kHz and are different for the different road traffic noise source categories. The original values for all these coefficients were first derived in the EU 6th Framework project IMAGINE [7]. The distinction between the rolling noise and propulsion noise components is based on measurement campaigns using various datasets. The total overall noise levels have been calibrated using roadside pass-by noise measurements in several EU countries [8]. The resulting coefficients are therefore representative for the *average* European vehicle fleet under the given reference conditions. A revision of the current EU directive is in progress and the revised version must be implemented by all member states before December 31st, 2021 [9] . The revised version presents new values for the mentioned coefficients, however still only in octave bands.

Third octave band values are presented in the following tables. The A_R and A_p coefficients have been estimated from the revised octave band values using linear interpolation, and adjustments in order to maintain original octave band levels at reference speed. The spectral curves have been visually compared to the original IMAGINE curves. The B_R, and B_p octave band coefficients have been replicated within each 1/3-octave band to maintain the best possible consistency between the source power levels in 1/3-octave bands and the original octave band levels, across varying speed. The sound energy in the octave bands are therefore the same for the suggested 1/3 octave band coefficients as for the new official coefficients [9]. The new 1/3 octave band coefficients are presented in Appendix A.

3.2.1.3 Amendments – studded tyres corrections a_i and b_i

The coefficients a_i, b_i in equation (3) are only presented in octave bands both in the current and the planned revised version of the EU-directive. The octave bands presented in [10] have not been revised and are therefore used as reference. A similar interpolation approach as that described in section 3.2.1.2 has been used. The resulting coefficients are shown in Appendix B.

3.2.1.4 Amendments road surface corrections $\alpha_{i,m}$ and β_m

The coefficients deciding the correction term for non-reference road surface, $\alpha_{i,m}$ and β_m in equation (4), are given in octave bands in both the original EU directive [1] and the revised version. Third octave bands have been established as described in paragraph 3.2.1.2. The results are presented in Appendix C.

3.2.2 Railway traffic noise sources

The relevant noise sources contributing to the generation of noise from railways and trams consists of various components of the track-train system. Both engine noise, noise from compressors, fans, wheels, and rails are included. The various contributing factors with corrections are all thoroughly described in the EU directive. Computation of noise from railway traffic is already preformed in 1/3 octave bands and do not need to be amended.

3.2.3 Industrial noise source emission

The industrial sources are of varying size and complexity. CNOSSOS-EU does not present a generalized methodology for industry noise estimation, but rather refers to relevant ISO/EN standards and encourage measurements of the source. No specific amendments are therefore necessary in order to allow for computation in 1/3-octave bands.

3.2.4 Aircraft noise prediction

The method for calculation for aircraft noise [5, 11, 12] does not support basic spectral resolution for sound propagation and resulting noise on the ground. Aircraft noise is therefore not considered in this report.

4 Illustrative examples

Two illustrative examples have been used to explore whether the introduction of 1/3 octave bands effect the predicted sound levels: one case with acoustic hard ground and one case with soft ground.

The 1/3 octave band computations are done using the coefficients in Appendix A. The octave band computations are done using the coefficients in the CNOSSOS-EU amendment [9]. The results from these to computations are consistently compared in octave bands in order to control the amendments in this report.

A line source consisting of 20 000 cars of category 1 per 24 hours has been used as noise source, and the parameter L_{den} has been computed. All traffic is set during the day, hence L_{den} should give the same noise level as the $L_{eq,24h}$ metric for these examples.

The examples use flat terrain and a vehicle speed of 50 km/h. The distance from the noise source to the edge of the road is 2 m as illustrated in Figure 2. The distance from the edge of the road to the receiver d is varied in 10 m intervals from 10 m to 150 m. The source height is set to 0.05 m as specified in CNOSSOS-EU and the receiver height to 4 m for all computations.

The sound power from equation (1) and (2) are used to produce the noise source level at the source position. When computing the attenuation from the source to the microphone position, geometrical divergence, atmospheric absorption and the attenuation due to the boundary of the propagation medium is included for both cases. Both cases use 50 % favourable and 50 % homogenous conditions. Atmospheric absorption is computed for a temperature of 15°C, and a relative humidity of 70 %.

The total level at the receiver is thereafter found from integrating over the contributions from source points on the road within an angle from - 80° to + 80°, including scaling due to traffic volume to get the correct noise metric L_{den}.

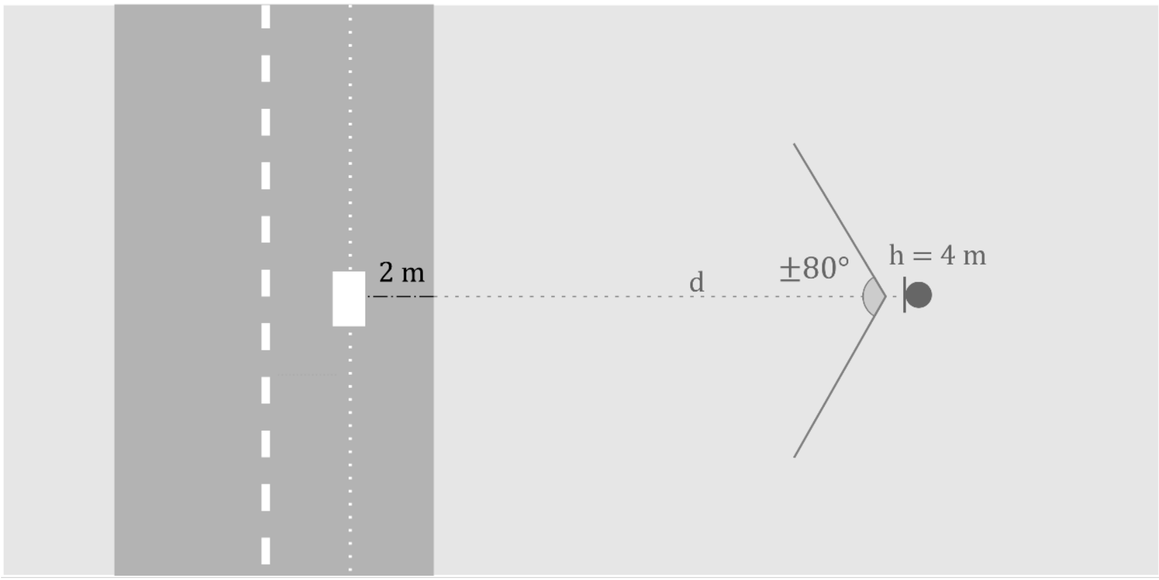

Figure 2: Geometry for the example cases as seen from above.

4.1 Comparison of L_{den} as a function of distance d

Figure 3 illustrates the difference: L_{den} (octave bands) - L_{den} (1/3-octave bands) as a function of distance from the road. The upper part of the figure illustrates the situation with acoustic hard ground and the lower part the situation with soft ground. The difference between the results from the octave band calculations and the 1/3-octave band calculations are all within approximately 0.1 dBA.

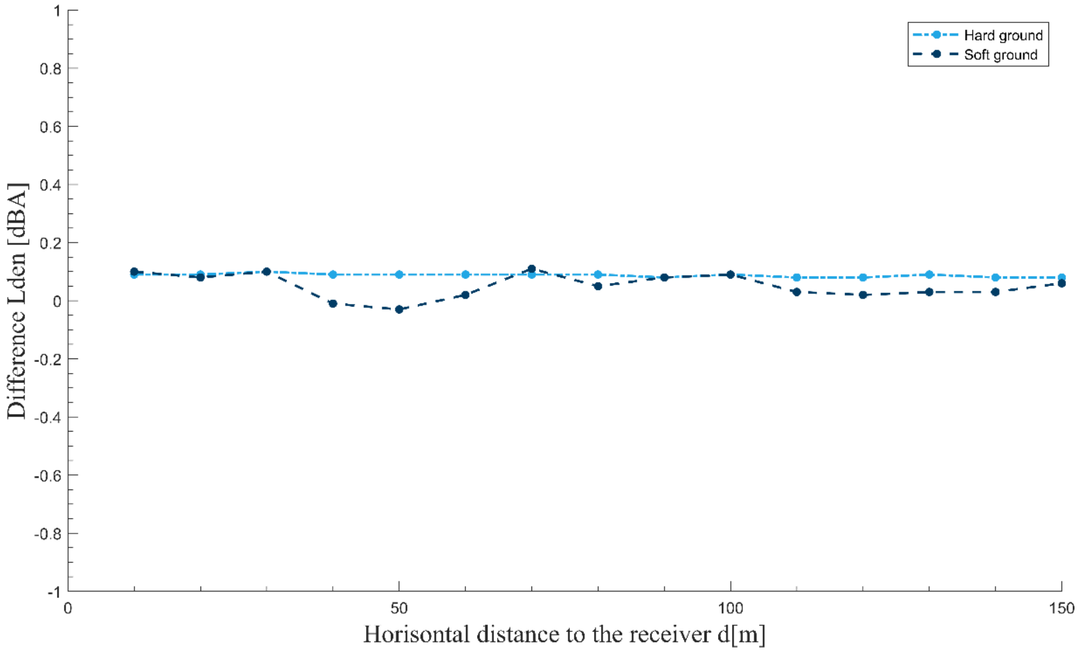

Figure 3: Illustrates the difference in L_{den} for octave band calculations and 1/3 octave band calculations as a function of horizontal distance d.

4.2 Comparison of L_{den} as a function of frequency at d=50m

Figure 4 illustrates the frequency distribution at d = 50 m for the case of hard acoustic ground. Figure 5 illustrates the same for the case with soft ground. In both figures the dark blue bars are the sum of the third octave band values illustrated by the light blue bars. The red crosses are the results from the original octave band computations.

When comparing the summed third octave bands (dark blue bars) and the original octave bands (red crosses) these are slightly more different than in Figure 3 which showed the difference in L_{den}. Especially for the highest frequencies the difference is more pronounced. In the 8kHz octave band the difference in level (octave bands) - (1/3-octave bands) is -1.2 dB for the hard ground case and -0.87 dB for the soft ground case. These differences are because the damping in the octave bands in the original CNOSSOS assumes even damping throughout each octave. This matters when the slope of the spectrum curve is steep. With the higher frequency resolution given here, more realistic results are presented.

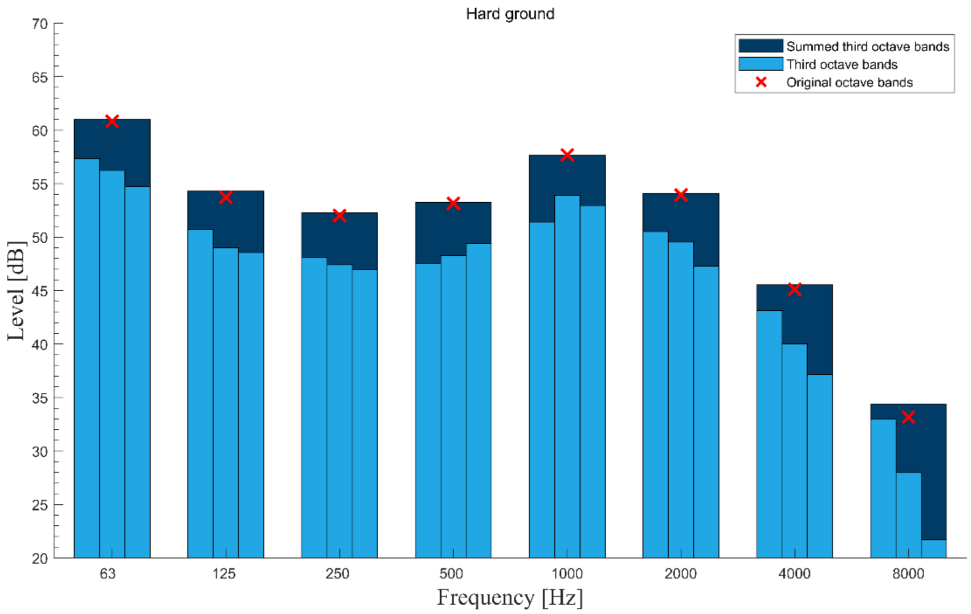

Figure 4: Spectral results at 50 m distance from the source in the case of hard ground.

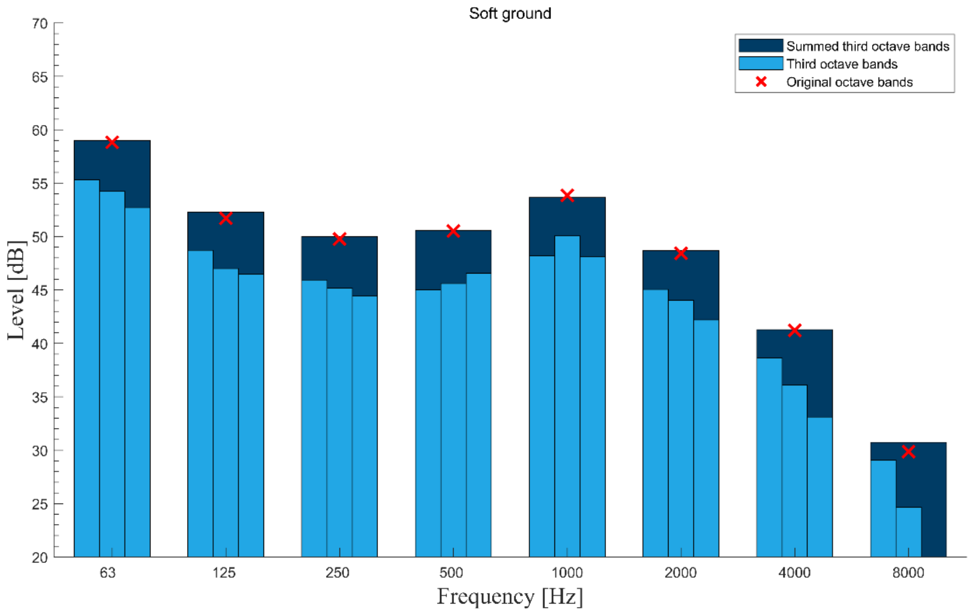

Figure 5: Spectral results at 50 m distance from the source in the case of soft ground.

5 Suggested further work

The original and revised EU-Directive provides the formulas for calculating the noise propagation as well as tabulated values for the default sound power coefficients for noise emissions at 70 km/h and speed coefficients to calculate the levels for other vehicle speeds. In this report 1/3 octave band values have been suggested based on these coefficients. However, as stated in the introduction. These coefficients are based on measurements performed to capture the *European* average fleet. In reality these coefficients will differ from country to country and in order to produce as correct noise predictions as possible, the end goal should be that these are adapted for Norwegian conditions. Due to the high proportion of electric cars in Norway, it would make sense to define dedicated emission values that would fit in CNOSSOS-EU cat. 5. Some of the coefficients are also based on fairly old measurements, as the work in the IMAGINE project was carried out in the early 2000s [7]. Iinitial studies of the modern vehicle fleet in Norway indicates that the propulsion noise contribution is lower now than when the original measurement campaign was conducted.
The tabulated values for road surface corrections given in Appendix C is interpolated from [9] is also likely to be different for Norwegian conditions than for the general European case. Computation of maximum noise levels is also currently not supported by CNOSSOS-EU.

6 References

[1] "Commission Directive (EU) 2015/996 of 19 may 2015 establishing common noise assessment methods according to directive 2002/49/ec of the European Parliament and of the Council," *Official Journal of the European Union*, vol. 168, p. 58, 2015.

[2] "Directive 2002/49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise," *Official Journal of the European Communities*, vol. 189, no. 18.07, p. 2002, 2002.

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[10] E. N. J. O. J. E. U. L. Directive, "Commission Directive (EU) 2015/996 of 19 may 2015 establishing common noise assessment methods according to directive 2002/49/ec of the European Parliament and of the Council," vol. 168, p. 58, 2015.

[11] R. T. Randeberg, H. Olsen, and I. L. N. Granøien, "NORTIM version 3.3. User Interface Documentation," 2007.

[12] Eurocontrol, "ANP database," 2020.

A Revised coefficients A_R, B_R, A_P, B_P for the different vehicle categories in 1/3 octave bands.

Table 1: Category 1.

Coefficient	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
AR	76.7	78	79.7	82.8	85.3	84.8	82.8	82.2	83.6	86	88.1	90	93.6	96.4	95.5	93.4	92	89.6	84.8	80.6	77.9	74.6	70.1	64.8
BR	30	30	30	41.5	41.5	41.5	38.9	38.9	38.9	25.7	25.7	25.7	32.5	32.5	32.5	37.2	37.2	37.2	39	39	39	40	40	40
AP	94.2	93.1	91.6	89.2	87	86.5	86.7	85.9	85	83.5	82.1	81.4	80.3	79.3	80.1	82.6	83.9	83	81	79.5	77.7	74.8	71.7	68
BP	-1.3	-1.3	-1.3	7.2	7.2	7.2	7.7	7.7	7.7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Table 2: Category 2.

Coefficient	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
AR	82.8	83.7	85	86.9	88.7	89.4	89.7	90.7	92.1	94.6	96.6	96.8	97.2	97.5	95.9	92.3	89.7	87.8	85.1	82	80.9	80.4	78.7	76.6
BR	30	30	30	35.8	35.8	35.8	32.6	32.6	32.6	23.8	23.8	23.8	30.1	30.1	30.1	36.2	36.2	36.2	38.3	38.3	38.3	40.1	40.1	40.1
AP	101.8	100.7	99.3	96.7	94.6	94.7	95.8	95.9	95.5	94.2	93.5	94.1	95.9	96.8	96	94.3	93	91.3	88.4	85.6	84.1	82.4	79.8	76.7
BP	-1.9	-1.9	-1.9	4.7	4.7	4.7	6.4	6.4	6.4	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5

Table 3: Category 3.

Coefficient	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
AR	85.8	86.7	88	89.9	91.7	92.3	92.2	93	94.7	98.2	100.8	100.9	100.8	100.8	99.2	95.7	93.1	91.2	88.5	85.3	83.9	82.8	80.5	77.7
BR	30	30	30	33.5	33.5	33.5	31.3	31.3	31.3	25.4	25.4	25.4	31.8	31.8	31.8	37.1	37.1	37.1	38.6	38.6	38.6	40.6	40.6	40.6
AP	105	104	102.8	100.6	98.8	98.6	99	98.7	98.5	98.3	98.1	98	98.2	98.1	97.1	95.1	93.4	92.2	90.6	88.6	87.1	84.9	82.3	79.1
BP	0	0	0	3	3	3	4.6	4.6	4.6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Table 4: Category 4a. (Rolling noise should not be computed for Category 4)

Coefficient	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
AR																								
BR																								
AP	88.2	88.2	88.2	88.2	88.2	88.3	88.4	88.6	89.1	89.9	90.6	91.1	91.6	92.4	93.2	95.1	96.4	95.2	92.5	90.6	89.4	88	85.9	83.4
BP	4.2	4.2	4.2	7.4	7.4	7.4	9.8	9.8	9.8	11.6	11.6	11.6	15.7	15.7	15.7	18.9	18.9	18.9	20.3	20.3	20.3	20.6	20.6	20.6

Table 5: Category 4b. (Rolling noise should not be computed for Category 4)

Coefficient	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
AR																								
BR																								
AP	94.6	95.1	95.6	97	97.8	96.4	93.4	91.3	90.7	90.2	89.2	89.4	90.3	90.6	90.5	90.3	90.1	89.4	88.3	87.2	86.3	85.2	83.7	82
BP	3.2	3.2	3.2	5.9	5.9	5.9	11.9	11.9	11.9	11.6	11.6	11.6	11.5	11.5	11.5	12.6	12.6	12.6	11.1	11.1	11.1	12	12	12

B Revised coefficients a_i and b_i in 1/3 octave bands.

Table 6: Category 1. (No correction should be applied for the lower frequencies)

Coefficient	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
a_i										1.9	2.9	3	2.9	3.1	2.7	1.8	1.2	1.4	1.4	1.7	3.5	5.3	8.3	11.7
b_i										-3.1	-3.1	-3.1	-6.4	-6.4	-6.4	-14	-14	-14	-22.4	-22.4	-22.4	-11.4	-11.4	-11.4

C Revised coefficients $\alpha_{i,m}$ and β_m in 1/3 octave bands

Table 7: Reference road surface. Valid speed interval: all km/h. (No correction should be applied for the reference road surface)

	$\alpha_{i,m}$																								β_m
Category	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1																									
2																									
3																									
4a																									
4b																									

Table 8: 1-layer ZOAB. Valid speed interval: 50-130 km/h. (No correction should be applied to Category 4.)

	$\alpha_{i,m}$																								β_m
Category	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	-1.4	-0.2	1.2	4	6.1	5.8	4.6	4.2	4.1	4.6	4.6	3.2	0.4	-1.7	-2.2	-2.7	-3.6	-3.4	-3.1	-2.8	-2	-0.9	0.5	2.2	-6.5
2	8.7	7.9	6.9	5.1	3.7	4	5.5	5.9	4.4	1.3	-1	-2.2	-4.1	-6	-5.8	-4.9	-4.7	-4.3	-3.6	-2.9	-2.5	-2.2	-1.5	-0.7	0.2
3	10.2	9.3	8.1	6	4.3	4.4	5.8	6	4.5	1.3	-1	-2.3	-4.1	-6	-5.8	-4.9	-4.7	-4.3	-3.6	-2.9	-2.5	-2.2	-1.5	-0.7	0.2
4a																									
4b																									

Table 9: 2-layer ZOAB. Valid speed interval: 50-130 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	All frequencies
1	1	1.5	2.2	3.7	4.6	3.6	1.5	0	-0.9	-2.1	-3.4	-3.7	-3.6	-4	-4.5	-5.7	-6.6	-6.3	-5.5	-4.9	-4.2	-3.4	-2.2	-0.8	-3.0
2	8.4	7.3	5.8	3.5	1.3	0.7	0.6	-0.3	-1.5	-3.9	-5.9	-6.1	-5.9	-6.2	-6.2	-6.2	-6.1	-5.7	-4.9	-4.3	-4	-3.9	-3.5	-3.1	4.7
3	9.5	8.3	6.6	3.9	1.4	0.7	0.6	-0.4	-1.7	-3.9	-5.9	-6.1	-5.9	-6.3	-6.3	-6.3	-6.2	-5.8	-5.1	-4.4	-4.1	-4	-3.5	-3	4.7
4a																									
4b																									

Table 10: 2-layer ZOAB (fine). Valid speed interval: 80-130 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	All frequencies
1	-2	-1.2	-0.1	2.3	3.9	2.6	-0.1	-1.9	-2.9	-4.3	-5.8	-6.1	-5.9	-6.3	-6.8	-8.2	-9.1	-8.3	-6.5	-5.2	-4.4	-3.8	-2.6	-1.2	-0.1
2	9.4	7.8	5.7	2.1	-1.1	-1.6	-1.1	-1.9	-2.9	-4.9	-6.5	-6.5	-6	-6.1	-6.2	-6.8	-7.1	-6.6	-5.6	-4.7	-4.5	-4.3	-3.8	-3.3	-0.8
3	11.2	9.2	6.7	2.4	-1.3	-1.9	-1.1	-1.9	-2.9	-4.9	-6.5	-6.5	-6	-6.1	-6.2	-6.7	-6.9	-6.5	-5.4	-4.6	-4.4	-4.3	-3.8	-3.3	-0.9
4a																									
4b																									

Table 11: SMA-NL5. Valid speed interval: 40-80 km/h. (No correction should be applied to Category 2-4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	12.4	10	6.9	1.4	-3.1	-2.6	0.3	1	1.3	1.9	2.2	1.3	-0.8	-2.3	-2.5	-2.5	-2.9	-2.7	-2.3	-2	-1.8	-1.6	-1.3	-1	-1.6
2																									
3																									
4a																									
4b																									

Table 12: SMA-NL8. Valid speed interval: 40-80 km/h. (No correction should be applied to Category 2-4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	7.2	6	4.4	1.7	-0.6	-0.6	0.3	0.3	0.2	0.1	0	-0.1	-0.4	-0.6	-0.8	-1.1	-1.3	-1.2	-0.8	-0.6	-0.6	-0.7	-0.7	-0.7	-1.4
2																									
3																									
4a																									
4b																									

Table 13: Burshed down concrete. Valid speed interval: 70-120 km/h. (No correction should be applied to Category 4.

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	9.9	8.1	5.7	1.4	-2.1	-1.2	1.9	3.2	3.2	2.7	2.7	2.7	2.7	2.6	2.2	1.3	0.6	0.4	0	-0.5	-0.4	-0.2	-0.1	0	1.4
2	-0.8	0.1	1.3	3.5	5.2	4.6	3.2	2.4	1.7	0.5	-0.6	-0.6	-0.1	-0.1	-0.2	-0.4	-0.5	-0.6	-0.8	-1	-0.9	-0.8	-0.8	-0.8	5.0
3	-1.1	0	1.4	4.1	6.2	5.4	3.4	2.3	1.6	0.5	-0.6	-0.6	-0.1	0	-0.2	-0.4	-0.6	-0.7	-0.9	-1.1	-1	-0.9	-0.9	-0.9	5.5
4a																									
4b																									

Table 14: Optimised brushed down concrete. Valid speed interval: 70-80 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	-0.1	-0.2	-0.3	-0.8	-1	-0.4	0.8	1.7	1.6	1.3	1.2	1.2	1.3	1.3	0.6	-0.9	-2	-2.1	-1.9	-2.1	-2	-1.9	-1.8	-1.7	1.0
2	-1.6	-0.8	0.2	2.4	3.9	2.5	-0.8	-2.8	-2.7	-1.5	-1.3	-1.4	-1.6	-1.8	-2	-2.5	-2.9	-2.7	-2.2	-1.9	-1.9	-1.9	-1.9	-1.9	-6.6
3	-1.7	-0.7	0.6	3.4	5.3	3.6	-0.5	-2.9	-2.8	-1.4	-1.2	-1.3	-1.5	-1.7	-1.9	-2.3	-2.7	-2.5	-2	-1.7	-1.7	-1.8	-1.8	-1.8	-6.6
4a																									
4b																									

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Table 15: Fine broomed concrete. Valid speed interval: 70-120 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	9.7	7.9	5.5	0.9	-2.6	-1.1	3.5	5.7	5	2.9	1.9	1.6	1.3	0.9	1.3	2.3	2.9	2.6	2	1.5	1	0.3	-0.6	-1.7	7.6
2	-2.1	-0.3	2	6.2	9.6	9.2	7.8	7.2	6.2	4.1	2.6	2.7	3.5	3.7	3.6	3.4	3.2	2.6	1.4	0.4	0.2	0.4	0.1	-0.2	3.2
3	-2.6	-0.5	2.1	7.1	11	10.4	8.3	7.4	6.3	4.3	2.6	2.5	3.2	3.1	3	2.7	2.5	2	1	0.1	0	0.2	0	-0.2	2.0
4a																									
4b																									

Table 16: Worked surface. Valid speed interval: 50-130 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	9.5	8.3	6.6	3.5	1.1	1.9	4.4	5.5	5.4	4.9	4.8	4.6	4.6	4.3	3.3	1.2	-0.4	-0.7	-0.7	-1.2	-1.1	-0.9	-0.8	-0.7	-0.3
2	-1.5	-0.2	1.5	4.5	7	6.9	6.2	6	5	3	1.4	0.7	0.1	-0.8	-1.2	-1.7	-2.2	-2.2	-1.9	-1.8	-1.7	-1.7	-1.6	-1.5	1.7
3	-2	-0.4	1.6	5.3	8.3	8	6.8	6.4	5.2	3.1	1.3	0.7	0	-1	-1.3	-1.8	-2.3	-2.3	-2	-1.9	-1.8	-1.8	-1.7	-1.6	1.4
4a																									
4b																									

Table 17: Hard elements in herringbone. Valid speed interval: 30-60 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	29	26.7	23.8	18.7	14.3	13.9	15.7	15.1	12.8	8.2	4.8	4	4.1	2.8	1.8	-0.2	-1.8	-1.2	0.2	1.2	2	2.8	4.2	5.9	2.5
2	31.3	29.3	26.7	22.3	18.5	17.8	18.8	17.9	15.4	10.3	6.4	5.9	7.2	6.4	4.6	0.4	-2.5	-1.4	1.7	3.4	3.9	4.2	5.1	6.1	2.5
3	31	29.3	27	23.3	20	19.1	19.6	18.4	15.8	10.7	6.8	6.1	6.8	5.6	4	0.3	-2.4	-1.4	1.5	3.2	3.9	4.4	5.6	7	2.5
4a																									
4b																									

Table 18: Hard elements not in herringbone. Valid speed interval: 30-60 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	33.5	31.1	27.9	22.4	17.7	16.9	18.1	16.9	14.7	10.4	7	6.7	7.8	7.3	6.3	3.9	2.4	3.5	6.3	8.2	8.5	8.5	9	9.7	2.9
2	35.9	33.8	30.9	26.1	21.9	20.9	21.3	19.8	17.4	12.5	8.8	9.1	11.7	12.1	11.3	8.8	7.4	8.4	11.2	12.9	12.3	10.9	10	8.9	2.9
3	35.5	33.6	31.1	27	23.4	22.2	22	20.3	17.9	13	9.2	9.2	11.2	11.2	10.2	7.4	5.8	7.1	10.5	12.7	12.4	11.3	10.8	10.2	2.9
4a																									
4b																									

Table 19: Quiet hard elements. Valid speed interval: 30-60 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	29.1	26.4	22.8	16.5	11.3	10.8	12.9	12.2	10.1	6.1	2.9	1.4	-0.2	-2.5	-3.5	-5	-6.6	-5.9	-3.9	-2.6	-1.9	-1.2	0	1.4	-1.7
2	10	9.2	8.3	6.7	5.2	5	5.2	4.9	4.2	2.8	1.8	2.3	3.8	4.6	4.8	4.9	5.2	5.2	5.7	5.8	4.7	2.6	0.7	-1.6	0.0
3	9.6	9.1	8.4	7.4	6.4	6	5.8	5.2	4.5	3.2	2.1	2.5	3.5	4.1	4.1	3.8	3.8	4.1	5.2	5.7	4.7	2.7	0.9	-1.1	0.0
4a																									
4b																									

Table 20: Thin layer A. Valid speed interval: 40-130 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	12.2	10.2	7.5	3	-0.9	-1.3	-0.2	-0.7	-0.9	-0.9	-1.1	-1.6	-2.4	-3.1	-3.6	-4.4	-5.2	-4.8	-4	-3.4	-2.9	-2.4	-1.5	-0.5	-2.9
2	15.4	13.7	11.4	7.4	4.1	3.6	4.6	4	2.9	0.8	-1	-1.3	-1.4	-2	-2	-2.1	-2.3	-1.9	-1.1	-0.6	-0.4	-0.4	-0.2	0	0.5
3	15.7	14	11.8	8.1	4.9	4.3	4.9	4.1	3	0.8	-1	-1.3	-1.4	-2	-2	-2.1	-2.3	-1.9	-1.1	-0.6	-0.4	-0.4	-0.2	0	0.3
4a																									
4b																									

Table 21: Thin layer B. Valid speed interval: 40-130 km/h. (No correction should be applied to Category 4.)

Category	$\alpha_{i,m}$																								β_m
	50	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	**All frequencies**
1	8.4	6.7	4.5	0.7	-2.6	-2.6	-1.3	-1.3	-1	-0.2	0.2	-1	-3.6	-5.5	-6	-6.6	-7.5	-6.9	-5.6	-4.7	-4.3	-4	-3.3	-2.5	-1.8
2	15.4	13.7	11.4	7.4	4.1	3.6	4.6	4	2.9	0.8	-1	-1.3	-1.4	-2	-2	-2.1	-2.3	-1.9	-1.1	-0.6	-0.4	-0.4	-0.2	0	0.5
3	15.7	14	11.8	8.1	4.9	4.3	4.9	4.1	3	0.8	-1	-1.3	-1.4	-2	-2	-2.1	-2.3	-1.9	-1.1	-0.6	-0.4	-0.4	-0.2	0	0.3
4a																									
4b																									

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