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Nord 2000. New Nordic Prediction Method for Road Traffic Noise

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Abstract

A new Nordic method to predict road traffic noise is proposed. It is based on a complete separation of source emission and sound propagation. Each vehicle is modelled as a number of point sources each with a certain sound power with or without directivity. The source model is connected to point source sound propagation theory to yield the sound pressure level in an arbitrary receiver position. The propagation model is based on accurate analytical models and it is capable of predicting propagation effects both with and without the influence of meteorological parameters.

Key words: Prediction, road traffic, noise, sound, propagation

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Preface

This prediction method has been developed within the frame of a Nordic project, Nord 2000. It would not have been possible without the generous support from authorities and research councils throughout the Nordic countries. The main financial support has come from the Nordic Council of Ministers but additional support, both to the main project and to related projects, has come from the following organizations:

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Norwegian State Pollution Authority
The Swedish Rail Administration
The Swedish Road Administration
The National Board of Health and Welfare, Sweden
The Swedish Transport & Communications Research Board
The Swedish Environmental Protection Agency
Nordtest

The prediction method was developed by a joint Nordic project group consisting of Jørgen Kragh and Birger Plovsing, DELTA Danish Electronics, Light & Acoustics, Denmark, Svein Storeheier and Gunnar Taraldsen, Sintef Telecom and Informatics, Norway, and Hans Jonasson, Mikael Ögren and Xuetao Zhang, SP Swedish National Testing and Research Institute. Juhani Parmanen, VTT Building Technology, Finland has been an observer.

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Conclusions

The new Nord 2000 prediction method for road traffic noise makes it possible to calculate 1/3-octave band sound pressure levels with good accuracy in most situations. It is possible to mix different ground impedances, to have more than one barrier and to vary the meteorological conditions. Provided that the source strength data are the same the method will, in simple terrain situations, give similar results as the old 1996 model if a soft ground impedance of 500 kNsm^{-4} and a downwind component of 3 m/s along the horizontal normal to the road are used as input parameters.

1 Introduction

1.1 Background

In 1996 the revision of the current Nordic prediction methods for environmental noise started. Thus this new prediction method for road traffic noise is the result of 5 years of joint Nordic work. The aim has been ambitious, to develop methods physically correct to the largest possible extent and with a complete separation between source emission and sound propagation. The latter requirement was essential to make it possible to use the same propagation method both for road and rail traffic noise and for industrial noise. In addition there was a requirement to be able to deal also with varying weather conditions.

Another aim has been to obtain a method suitable for large-scale engineering applications. In order to comply with this aim the propagation model used is based on analytical solutions. Thus the most advanced numerical methods have been used for verification purposes only as these methods still require unacceptably long computing times.

When making the new method we have tried to compromise as little as possible and make the method as accurate as possible. It may turn out afterwards that some parameters were not significant enough and that simplifications can be made without affecting the result too much. Examples of such simplifications could be a more limited frequency range, octave bands instead of one-third octave bands or fewer source positions to represent the vehicle as sound source. However, such simplifications can easily be made afterwards, once there is an accurate reference method.

Comparatively little effort has been devoted to collecting new source emission data although some new measurements have been carried out in all Nordic countries.

1.2 Principle

Each vehicle is treated as a moving source consisting of a number of sub sources emitting noise within a wide frequency range. The strengths of the sources depend on vehicle category, speed, road surface and driving conditions. The sub sources are located at different heights above the road surface. The strengths of the sources are expressed as sound power levels. The sources are either omni directional or assigned a specified directivity. All calculations are carried out in one-third octave bands.

When the noise propagates from a source to a receiver it will be affected by spherical spreading, air attenuation, ground reflection, screening, scattering, etc. In some cases it will be amplified due to reflections in vertical surfaces. The propagation will also depend on vertical wind and temperature gradients. The attenuation during propagation is calculated for each point source. The propagation model is identical to the one for industrial noise and rail traffic noise.

The noise contributions of each source are summed up by adding the sound exposure levels during pass-by. The road is divided into a number of road segments. First the sound exposure level of each sub source is calculated for each road segment. Then all sources and all segments are added and the L_{eq}-level is calculated. L_{eq} can be calculated for any combination of vehicle categories, traffic flows and weather conditions. The only limitation is the availability of relevant input data.

The maximum sound pressure level (time weighting *F*) is calculated from the sound power level as described in clause 5.

1.3 What can and what cannot be calculated?

The prediction method can calculate L_{eq}, A-weighted or in frequency bands, for any combination of road vehicles provided that suitable input data are available. The default calculation is the sound pressure level of the incident sound field, that is, in receiver positions near a façade, the last reflection from the façade is not included. It is also possible to calculate maximum sound pressure levels corresponding to time-weighting F. The maximum levels can be calculated from individual vehicles or combinations of vehicles with selected positions. However, the prediction method does not give statistical methods to calculate maximum levels of vehicle combinations.

The prediction method can also handle different uncomplicated weather conditions. However, very strong or varying wind gradients and layered atmospheric conditions have been excluded. By combining results from different weather conditions it is possible to calculate yearly averages such as the L_{den} proposed by the European Union, [3].

The prediction method can handle any number of and any combination of varying ground conditions with and without screens. In principle any number of screens could be dealt with but for practical reasons the algorithms have been limited to two screens. The screens can be thin or thick or wedge shaped. At present more complicated or sophisticated screen tops cannot be dealt with by the model itself and data on extra attenuation by such devices must be provided elsewhere.

The prediction method does not specifically deal with indoor noise. No special guidelines or data on the sound insulation of windows or facades are given.

1.4 Relation to the old prediction method

The old Nordic prediction method, [2], was last revised in 1996. This method has now been in official use for about 20 years. It is based on research carried out in the 1970-ies. Although it was revised twice the major structure remained unchanged.

The new prediction method described in this report is a completely new method. In principle there are no links to the old method. Both source data and propagation model are completely new. For simple geometries, like the type cases of the old model, it is expected that, with few exceptions, the difference between the new and the old model will not exceed 2 dB . These 2 dB refer to A-weighted sound pressure levels, calibration to the same sound exposure values at 10 m, a soft ground impedance of 500 kNsm^{-4} and a downwind component of 2-3 m/s along the horizontal normal to the road, see clause 7.

1.5 Notation

a = sound absorption parameter used for tunnel calculations
C = correction to obtain sound power level from SEL-measurement;
$C_{e,\text{tunnel}}$ = correction to obtain sound energy level in a tunnel opening from the sound power level of a passing vehicle, in dB;
$C(v)$ = speed dependent correction = L_{W} - L_{E}, in dB;
C_w^2 = strength of wind turbulence;
C_t^2 = strength of temperature turbulence;
d = measurement distance (distance to vehicle centre line), in m;
E_{Ta} = sound energy radiated from the opening of a tunnel with specific acoustic treatment, in joules;
E_{Tr} = sound energy radiated from the opening of a tunnel without any specific acoustic treatment, in joules;
h = height of tunnel, in m;
h_r = height of the microphone/receiver;
i = index for the position of a source/sub source;
j = index for a sub source;
L = general notation for calculated levels with index f for favourable, index h for homogeneous and index u for unfavourable propagation conditions;
L_{den} = day evening night weighted L_{eq}, in dB;
L_{eq} = equivalent continuous sound pressure level, in dB;
L_E = the sound exposure level, in dB;
$L_{\text{E,v}}$; = sound exposure level due to an individual vehicle;
L_{Fmax} = maximum sound pressure level using time weighting F, in dB;
L_{J} = sound energy level, in dB;
L_{p} = sound pressure level, in dB;
L_{t} = length of tunnel, in m
L_{W} = sound power level, in dB;
L_{Wref} = reference sound power level determined from a pass-by measurement, in dB
L_{yav} = L_{den} averaged over a typical year;
m = number of road segments or sub source positions used to approximate integration by summation;
n_{j} = number of sub sources of a specified vehicle category;
N_{j} = number of sources of category j during a specified time interval;
N_{vc} = number of vehicles of a specified category;
N_{cat} = number of vehicle categories;
p = probability (1=100%) for favourable (index f), homogeneous (index h) and unfavourable (index u) propagation conditions;
r_{i}= the shortest distance (from the nearest wheel) between point i and the receiver;
r = radius of tunnel, in m
R = radius of curvature of a sound ray;
t = time, in s;
T = temperature, in Kelvins, or time, in s;
u = wind velocity, in m/s;
v = speed of vehicle, in m/s;
x = distance from tunnel opening to vehicle position
w = the axle width of the vehicle (= 1,5 m for cars and 2,5 m for trucks unless other information is available)
w_T = half the width of tunnels ;
W = notation for sound power, in watts
W_{T} = sound power in tunnel openings;
z = coordinate in the vertical direction;
α = sound absorption coefficient or angle;

ΔL_J = difference in sound energy level radiated through a tunnel opening between a tunnel without and with sound absorbing treatment respectively, in dB;
$\Delta L(\varphi)$ = correction for horizontal directivity, in dB;
$\Delta L(\psi)$ = correction for vertical directivity, in dB;
$\Delta \mathrm{L}(\phi)$ = correction for directivity of tunnel openings;
ΔL_{ij}= -10 lg($4\pi r_i^2$) + corrections due to ground influence, etc.;
Δx_i = length of road segment *i*;
$\Delta\alpha_i$ = angle of circular sector covering road segment *i*;

2 The source

2.1 General

The road vehicle is a complex noise source. The main sources are the engine, the exhaust, the transmission, the tyres and the car body.

Engine noise depends mainly on the type of engine and the revolutions per second (rps) of the engine. The speed dependence of the sound power level is in general about 30 lg(rps). The frequency range is rather wide up to about 2000 Hz. The engine is located in a screened compartment with the main openings in the bottom of the car. This means that most of the noise will come from under the car. As the engine is screened the sound pressure level will decrease when the height of the receiver increases.
Exhaust noise is dominated by very low frequencies. For heavy diesel engines the 3rd or 6th harmonic will dominate. Typically, for heavy lorries, the highest rps= 30 that is the dominating frequencies will be below 180 Hz. For all passenger cars and about 90% of all heavy vehicles in Europe the exhaust will be located at the bottom of the vehicle, that is 30 cm or less above the road surface. For heavy vehicles it will be on the right or the left side and for passenger cars it will be located in the rear. In the Nordic countries most heavy vehicles will have the exhaust on the left side, that is it will be partially screened on the right side. About 10% of the heavy vehicles will have a vertical exhaust at about 3,2 m above the road surface.

Transmission noise is important for heavy vehicles. The noise is often tonal and it depends to a large extent on the load of the vehicle. The frequency range is about 500-1500 Hz. The variations may be about 20 dB between minimum and maximum load.

Aerodynamic noise has a speed dependence of about 60 lg(speed). It is not important at low speeds but at higher speeds it may become important at low frequencies. The main sources will be along the perimeter of the car body.

Tyre/road interaction will be the dominating noise source under most conditions above about 800 Hz. The mechanical part will have a speed dependence of about 30 lg(v) and the aerodynamic part of about 60 lg(v). The noise will be directional. Due to the horn effect between tyre and road surface high frequencies will radiate more in the forward direction. Tyre/road noise varies with the temperature of the road surface. Typically it increases with about 0,05 dB per 1° decrease.

The road surface will affect both the noise generation and the noise propagation above the surface.

2.2 Source model

In order to be able to calculate the excess attenuation due to screening and ground reflections the heights of the sources are important. For L_{eq}-calculations and moving vehicles the location along the vehicle is not important. For L_{max}-calculations the horizontal locations should be of interest at distances less than about the length of the vehicle, which, for heavy lorries with trailers may be 24 m. However, as comparisons between calculations and measurements, see 7.2, indicate rather good results with one horizontal location only the length of the vehicle will not be considered, not even for long vehicles.

The source is located flush with the nearest wheel side and not at the centre line as this has been shown to be more accurate, see [8].

The horizontal directivity is not very important for L_{eq}-calculations. However, for L_{max}-calculations it should be considered. Otherwise the horn effect will cause an overestimate of the maximum level. The directivity, if different from 0, is given in table 2.2.

In principle each vehicle should be divided into the sources shown in table 2.1 and the sound power should be distributed between them in an appropriate way. The three low sources are based on findings in [8]. It should be observed that the source distribution is more critical for high than for low frequencies. At high frequencies single centimetres may be important whereas it has to be tens of centimetres to affect the propagation of low frequencies.

Table 2.1 Road vehicles. Principle source locations.

	Height above the road surface (m)
Source 1 Tyre/road Engine, low exhaust Low aerodynamic sources	0,01
Source 2 Tyre/road Engine, low exhaust Low aerodynamic sources	0,15
Source 3 Tyre/road Engine, low exhaust Low aerodynamic sources	0,30
Source 4 Front of engine	Actual height
Source 5 High exhaust	Actual height of exhaust
Source 6 High aerodynamic sources	To be determined in each case

As there is limited access to data accurate enough to make it possible to include all sources only the sources 1-3 and 5 will be included in this first version of the prediction method. Thus the source model to be used will be as follows:

Table 2.2 Passenger cars. Source locations.

	Height	**Frequency range**
Source 1	0,01 m	25-10000 Hz
Source 2	0,15 m	25-10000 Hz
Source 3	0,30 m	25-10000 Hz

[1)] Often frequencies below 50 Hz and above 5000 Hz can be neglected.

All sources will be assigned equal strength, that is the total sound power is distributed equally between them. The horizontal directivity of passenger cars is given in table 2.3. The angle φ is shown in figure 2.1.

Table 2.3 Passenger cars. Horizontal directivity, see figure 2.1.

	Height	Frequency range	Directivity
Source 1	0,01 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 2	0,15 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 3	0,30 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))

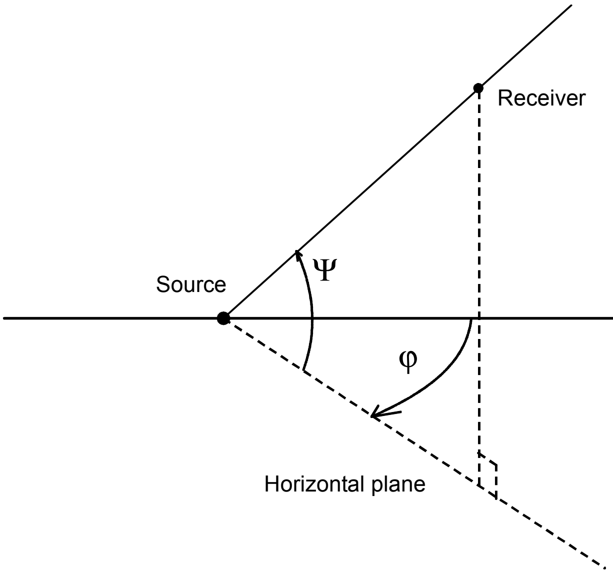

Figure 2.1 Sketch of angles of directivity

There is some vertical directivity for cars. The car body will screen some sources like the image engine. At low frequencies aerodynamic sources may also be important. The directivity is, however, rather small for moderate angles and we have not had access to enough data to include it in this first version of the prediction method. Nevertheless we recommend that computer programmes are made to make it easy to include a directivity function later on.

Table 2.4 Heavy vehicles. Source location.

	Height	Frequency range
Source 1	0,01 m	2 000-10000 Hz
Source 2	0,15 m	25(250)-10000 Hz
Source 3	0,30 m	25(250)-10000 Hz
Source 4 Vertical exhaust only	3,2 m	50-200 Hz

Table 2.5 Heavy vehicles. Horizontal directivity, see figure 2.1..

	Height	Frequency range	Directivity
Source 1	0,01 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 2	0,15 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))
Source 3	0,30 m	1600 - 10000 Hz	-5 + 7 abs(cos(φ))

The sound power is distributed equally between all sources indicated within the frequency range specified.

According to table 2.2 and 2.5 at least three vertically distributed source positions are required. For some applications it may not be necessary to use all these positions.

Examples of such cases are calculations of A-weighted sound pressure levels only at low speeds where the error will become only about 0,5 dB when reducing the number of source positions from three to one.

2.3 Source strength

2.3.1 General

Ideally the source strength of each sub source should be known. However, at present there is not enough data available. Thus the starting point is still pass-by measurements including all noise sources. The basic data is the sound exposure level from which the sound power level is determined. The total sound power is then distributed to the different sub sources according to the source model. The maximum sound pressure level is calculated from the sound power level using the source model.

The sound power level is determined from pass-by measurements according to the Nordtest method [9]. SEL is measured at a distance *d* between 7,5 m and 15 m. Two microphone heights, h_r, are used: 0,2 m and 4,0 m. The low height is used to guarantee that the direct and the reflected sound has the same phase at low frequencies whatever the height of the source and the high height is used to minimize excess attenuation at high frequencies. The measurement result is normalized to 10 m and an angle of integration of 2,75 radians (157,4 degrees) using the formula:

$$L_{E,10m} = L_E + 10\lg\left[\frac{\sqrt{\left(d - \frac{w}{2}\right)^2 + h_r^2}}{10}\right] - 10\lg\left[\frac{\Delta\alpha}{2\arctan(5)}\right] \tag{2.1}$$

where

L_E = the sound exposure level measured, in dB
d = measurement distance (distance to vehicle centre line), in m
w = the axle width of the vehicle (= 1,5 m for cars and 2,5 m for trucks unless other information is available)
h_r = height of the microphone)
$\Delta\alpha$ = angle of circular sector covering the line of integration, in radians

Note The normalization takes place in order to simplify the calculation of the sound power level. It has been shown to be accurate, se [8]. For practical reasons the integration is restricted to $\pm$ 79° which will cause an error of less than 0,5 dB compared to $\pm$ 90°.

As the measurements have taken place on two heights one of the values has to be selected to calculate the sound power level. In order not to underestimate the sound power level due to unexpected sound attenuation or screening the $L_{\mathrm{E,10m}}$ yielding the highest sound power level should be selected. However, due to wind and other background noise problems at low frequencies and high receiver heights it has been decided always to use the lowest microphone height only below 100 Hz.

The sound power level is then given by

$$L_{\mathrm{W}} = L_{\mathrm{E,10m}} + C(v) \tag{2.3}$$

where $C(v)$ is determined for each geometry using the prediction method as described in 4.1 by calculating

$$C(v) = L_W - L_{E,10m} \tag{2.4}$$

As C(v) is constant apart from a distance dependence it is more practical to write (2.3) as

$$L_W = L_{E,10m} + C(50) + 10\lg\left(\frac{v}{50}\right) \tag{2.5}$$

$C(50)$ has been calculated for the two geometries d-$w/2/h_r$ = 10 m/0,2 m and 9,2 m/4 m respectively assuming a road surface with the specific flow resistivity of 20000 kRayls. These values are given in figure 2.2 and table 2.6. The values are valid for the three lowest sources given in table 2.1 and 2.4. The precalculated values can be used for normal asphalt only. Other corrections have to be used for drain asphalt or other highly absorbing surfaces. It should be observed that the corrections for the low microphone at high frequencies are sensitive to impedance variations. Thus, unless the exact road impedance is known, it is generally safer always to use the values of the high microphone position, which is much less sensitive to impedance variations. The calculated values refer to omnidirectional sources. Introducing corrections for the horizontal directivity as given in table 2.3 and 2.5 may change these corrections up to 1 dB. For practical reasons it has been decided to ignore these differences. By doing so it is possible to improve the directivity functions later without having to change $C(50)$.

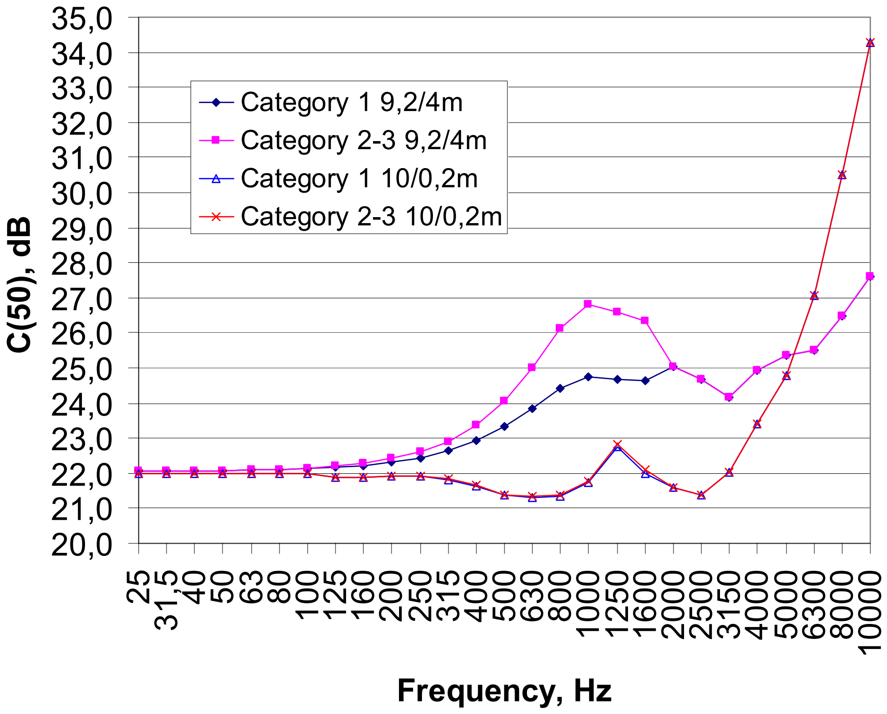

Figure 2.2 $C(50)$ of eq. (2.5)

Table 2.6 C(50) of eq. (2.5) and figure 2.2.

Frequency Hz	**Category 1 9,2/4m**	**Category 2-3 9,2/4 m**	**Category 1 10/0,2m**	**Category 2-3 10/0,2m**
25	22,1	22,1	22,0	22,0
31,5	22,1	22,1	22,0	22,0
40	22,1	22,1	22,0	22,0
50	22,1	22,1	22,0	22,0
63	22,1	22,1	22,0	22,0
80	22,1	22,1	22,0	22,0
100	22,1	22,2	22,0	22,0
125	22,2	22,2	21,9	21,9
160	22,2	22,3	21,9	21,9
200	22,3	22,4	21,9	21,9
250	22,4	22,6	21,9	21,9
315	22,6	22,9	21,8	21,8
400	22,9	23,4	21,6	21,7
500	23,3	24,0	21,4	21,4
630	23,9	25,0	21,3	21,3
800	24,4	26,1	21,4	21,4
1000	24,7	26,8	21,7	21,8
1250	24,7	26,6	22,7	22,8
1600	24,6	26,3	22,0	22,1
2000	25,0	25,0	21,6	21,6
2500	24,7	24,7	21,4	21,4
3150	24,2	24,2	22,0	22,0
4000	24,9	24,9	23,4	23,4
000	25,3	25,3	24,8	24,8
6300	25,5	25,5	27,1	27,1
8000	26,5	26,5	30,5	30,5
10000	27,6	27,6	34,3	34,3

The above means that the formal definition of the reference sound power level used as input is the following:

> The sound power level, which, after distribution among the sub sources given by the source model, when integrated omni directionally during a vehicle pass-by, gives the sound exposure level measured according to the emission measurement method. In the following this sound power level will be denoted reference sound power level, L_{Wref}.

L_{Wref} will normally be distributed between a number of sub sources. The reference sound power level of sub source *j* will be denoted $L_{\mathrm{Wref,j}}$. To summarize:

$L_{\mathrm{Wref}} = \{L_{\mathrm{W}}$ calculated from eq (2.5) for the low measurement height$\}$, $f < 100$ Hz
$L_{\mathrm{Wref}} = \mathrm{MAX}\{L_{\mathrm{W}}$ calculated from eq (2.5) for the two measurement heights$\}$, $f \geq 100$ Hz
(2.6)

2.3.2 Classification of vehicles, surfaces and driving conditions

Because the new prediction method will work in frequency bands it is expected that many more categories of vehicles, road surfaces and driving conditions will be required. The categorization proposed is probably over ambitious but it is much easier to combine old classes afterwards than it is to introduce new ones. The vehicles are divided into the following classes:

Table 2.7 Vehicle categories

Main category	Sub category	Category name	Objective description
1		**Cars**	
	1a	Passenger cars excluding other light vehicles	4 wheels, two axles
	1b	Other light vehicles: cars with trailers or caravans, light utility vehicles, minibuses, vans, motor homes, recreational and utility vehicles	4 wheels, two axles or 6 wheels, 3 axles
2		**Dual-axle heavy vehicles.**	6 wheels, two axles
	2a	City buses	6 wheels, two axles
	2b	Light and medium trucks	4-6 wheels, two axles
3		**Multi-axle heavy vehicles**[1)]	
	3a	Large city buses	8-10 wheels, 3 axles
	3b	Medium trucks	8-10 wheels, 3 axles
	3c	Heavy trucks	4-5 axles
	3d	Very heavy trucks	$\geq$ 6 axles
4		**Motor cycles**	
5		**Mopeds**	

1) Trailers, if any, included

All new emission measurements should be classified according to table 2.7. However, it may turn out that it is not necessary to use all the subclasses. Until sufficient data have been obtained and analysed it is recommended to use the main categories only. A problem in this context is that traffic counts so far have not included the different categories. Normally only the percentage heavy vehicles, that is vehicles with a mass exceeding 3,5 tons, is known.

The road surfaces are divided into the following 8 main categories:

Table 2.8 Road categories

Main category	Sub category	Name
1	1a	Asph. concr., dense, smooth (≤12-16 mm)
	1b	Asph. concr., dense, smooth (≤ 8-10 mm)
2	2a	Mastic asphalt (SMA) (max 12-16 mm)
	2b	Mastic asphalt (SMA) (max 8-10 mm)
3	3a	Chipped asphalt (BCS) ("hot rolled asph.")
	3b	Chip seal, single (Y1), max 16-20 mm
	3c	Chip seal, single (Y1), max 10-12 mm
	3d	Chip seal, single (Y1), max 6-9 mm
4	4a	Chip seal, double (Y2), max 16-20 mm
	4b	Chip seal, double (Y2), max 10-12 mm
5	5a	Porous asph., max 14-16mm ($\geq$20%voids)
	5b	Porous asph., max 8-12 mm ($\geq$20% voids)
6	6a	Cem. concr., dense, smooth max 20-80 mm
	6b	Cem. concr., dense, smooth, max 12-18 mm
	6c	Cem. concr., ground (grinding not worn)
7		Paving stones, cobble stones (older type)
8		Cement block pavement (interlocking)

The following driving conditions are used:

Table 2.9 *Driving and other conditions*

Category	Name	Objective description
1	Cruising	Constant speed and gear
2	Acceleration	Continuous acceleration[1)]
3	Deceleration	Continuous deceleration[2)]
4	Uneven	Both acceleration and deceleration
5	Uphill	Lower gear required to keep speed constant
6 6a 6b	Winter	The car is equipped with winter tyres Tyres with studs Tyres without studs

[1)] E.g. after crossings, traffic lights or speed limit signs
[2)] E.g. before crossings, traffic lights or speed limit signs

2.3.3 Input data

Preparations have been made to include the following input data to describe the source:

- vehicle category as given by table 2.7;
- road surface as given by table 2.8;
- driving condition as given by table 2.9;
- road temperature, t;
- speed

For each of the above conditions there has to be a reference sound power level as defined in 2.3.1. In addition two additional corrections are possible:

- horizontal directivity, $\Delta L(\varphi)$;
- vertical directivity, $\Delta L(\psi)$;

These corrections may vary between different sub sources. For sub source j the corrections will be denoted $\Delta L_j(\varphi)$ and $\Delta L_j(\psi)$ respectively.

Although preparations have been made to collect detailed data according to the requirements above it is foreseen that it will take several years before all parameters will be used for calculations. The number of data is likely to be insufficient to use all possible parameters. Experience may also show that some parameters or categories are redundant.

Traditionally input data has been based on regression analysis of measurement data. However, as the new prediction model is based on frequency band data and not on A-weighted values it is not as simple as it used to be. A car, which slows down, may change gear and thus increase engine speed and low frequency noise although the dominating high-frequency noise decreases. Thus the input data in this prediction method will be taken from a data bank of measurements. The measurements have been divided into speed ranges with the width 5 km/h. Within each range the energy average of each vehicle category is used. This range represents the centre speed of the range, e.g. 90 km/h for the range 90±2,5 km/h. For speeds between the centre speeds of two adjacent ranges interpolation is used. However, it is recommended to round all speeds to the nearest 5 km/h.

As to road temperature there are strong indications that tyre/road noise is affected by as much as 0,1 dB/°C. The warmer the asphalt the lower the noise level.

At the beginning it is recommended to use the following parameters only as input:

- vehicle categories 1, 2 and 3
- only the main road categories
- driving condition 1 (cruising)
- speed rounded to the nearest 5 km/h

2.3.4 Sound power levels

The sound power levels will be given in a Nordic data base. Some examples are given in annex A and figure 2.3.

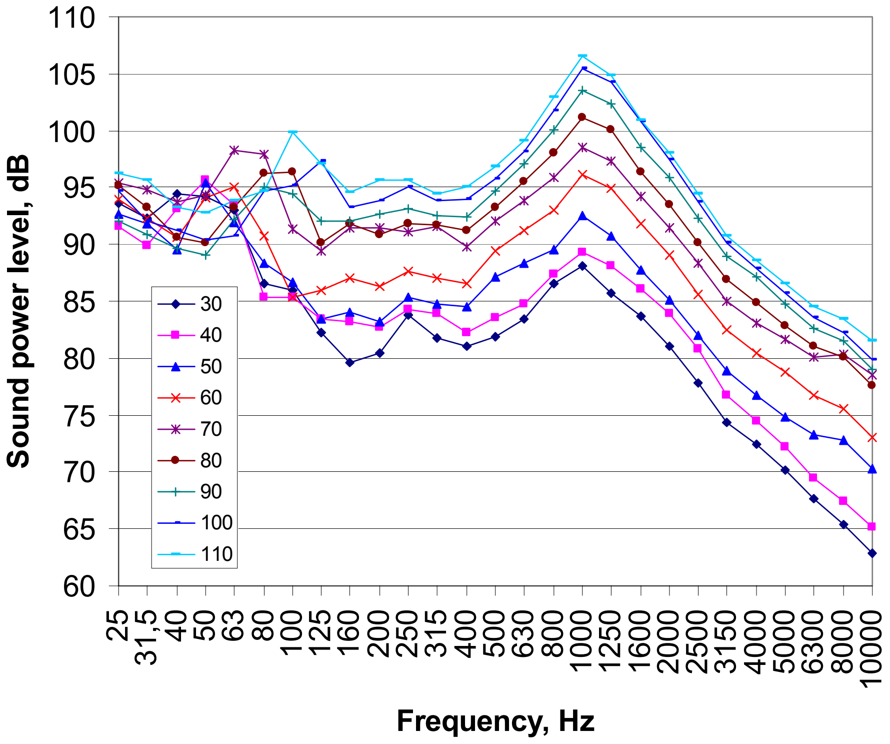

Figure 2.3 Examples of sound power levels of vehicles of type 1a on a road surface of type 2a. The parameter is speed in km/h.

2.4 Tunnel openings

2.4.1 General

Tunnel openings are regarded as special sound sources. Each vehicle passing through a tunnel yields a certain sound energy level, L_J, through the tunnel opening. This energy depends on the total sound power level of the vehicle and its speed, but will also depend on the sound propagation properties inside the tunnel.

2.4.2 Model of sound energy radiation

At a certain moment a single vehicle is positioned inside the tunnel at the distance x from the tunnel mouth. For a stationary vehicle, consider its sound power radiating through the tunnel opening to be $W_{T.}$ In a short time interval Δt the corresponding energy ΔE through the opening will be $W_T \cdot \Delta t$. The time interval can be estimated by $\Delta x/v$, Δx and v being the driving distance and the speed respectively during the time Δt. Positioning it at subsequent equidistant positions can simulate the pass through of the car through the tunnel and thus the total radiated energy through the tunnel opening can be calculated.

It is shown [6] that the sound power W_T radiating through the tunnel opening due to a stationary sound source in the tunnel, is:

$$W_T(a,x) = \frac{W}{2}\left(1 - \frac{ax}{\sqrt{r^2 + (ax)^2}}\right) \tag{2.7}$$

W is the total sound power, in watts, of the vehicle, corresponding to the sound power level defined in 2.3.1. x is the distance (m), from the tunnel mouth to the source position, r is the radius (m), of the tunnel (in case of a semi-circular cross section), a is a parameter regarding the sound absorption inside the tunnel ($0 \le a \le 1$). For convenience the value of a is assumed to be constant throughout the tunnel.

For a tunnel with a rectangular cross section, the sound power is [6] :

$$W_T(a,x) = \frac{W}{\pi} \tan^{-1}\left[\frac{w_T h}{\sqrt{x^4 + (w_T{}^2 + h^2)(ax)^2}}\right] \tag{2.8}$$

w_T is half the width, in m, of the tunnel mouth, h is the height, in m.

For a tunnel with a semi-circular cross section, the total energy radiating through the tunnel opening during a vehicle passage through the tunnel is:

$$E_T = \frac{W}{2}\frac{\Delta x}{v}\left[\sum_{i=1}^{i\max}(1 - \frac{ax_i}{\sqrt{r^2 + (ax_i)^2}}\right] \tag{2.9}$$

$x_i = \Delta x \cdot i$, *imax* = INTEGER($L_t/\Delta x$) (after rounding), L_t = tunnel length, in m, v is the driving speed, in m/s.

For a tunnel with rectangular cross section, the corresponding total energy radiating through the tunnel opening is :

$$E_T = \frac{W}{\pi}\frac{\Delta x}{v}\left\{\sum_{i=1}^{i\max} \tan^{-1}\left[\frac{w_T h}{\sqrt{x_i{}^4 + (w_T{}^2 + h^2)(ax_i)^2}}\right]\right\} \tag{2.10}$$

2.4.3 Sound absorption

For a tunnel with a specified average sound absorption coefficient, α, the value of a is estimated by, [6]:

$$a \approx 1-\sqrt{(1-\alpha)} \tag{2.11}$$

Table 2.10 gives some guidance to the value of α in case no other information is available. The sound energy radiated in case 1 is denoted E_{Tr}. This case is the reference case to determine the directivity of the sound emission from the tunnel mouth, see clause 2.4.3. The sound energy radiated in the other cases is denoted E_T.

Table 2.10 Sound absorption coefficient, α

Frequency range, Hz	f < 160	160-400	500-1250	f≥1600
1. Reference, E_{Tr} Smooth concrete surfaces	0,08	0,08	0,08	0,08
2. Rough concrete surfaces	0,08	0,11	0,14	0,14
3. Typical sound absorbing treatment	0,15	0,5	0,8	0,65

The effective value of a in case of several tunnel sections with different a-values, is approximated by eq. (2.12) :

$$a = \frac{1}{L_t'} \sum_{j=1}^{j\max} a_j \cdot l_j \tag{2.12}$$

where a_{j} and l_{j} are the a-value and length of the various sections respectively L'_{t} is the smaller of the total tunnel length L_{t} and 300 m. The sum includes the sections, as seen from the tunnel mouth, limited to the greater of the tunnel length L_{t} and 300 m (corresponding to *jmax*), whichever is applicable.

In the special case comprising two tunnel sections with different sound absorption (as will be the case with an absorption section near the tunnel mouth), a more detailed procedure is proposed, see the comments under *Note 2* at the end of this chapter.

2.4.4 Calculation procedure

The calculation of the sound energy level caused by a single vehicle's passage through the tunnel, is carried out according to the following steps :

1 Choose a value of Δx.
10 m is an appropriate default choice.

2 Determine sub-source distribution.
The sound energy level is distributed between 4 different sub-sources located according to Table 2.11 and figure 2.4, for a semi-circular- and rectangular cross section respectively. The positions are expressed in terms of the cross section radius r, or the height h and half width w_T. The source positions are associated with approximately equal sub- areas of the tunnel opening. The positions are given relative to the road centre line, on the road surface.

Table 2.11 Point source distribution in the tunnel opening.

Source	**Semi-circular**		**Rectangular**	
	Horizontal	Vertical	Horizontal	Vertical
Source 1	0,5r	0,21r	0,5w	0,24h
Source 2	0,5r	0,68r	0,5w	0,75h
Source 3	-0,5r	0,21r	-0,5w	0,24h
Source 4	-0,5r	0,68r	-0,5w	0,75h

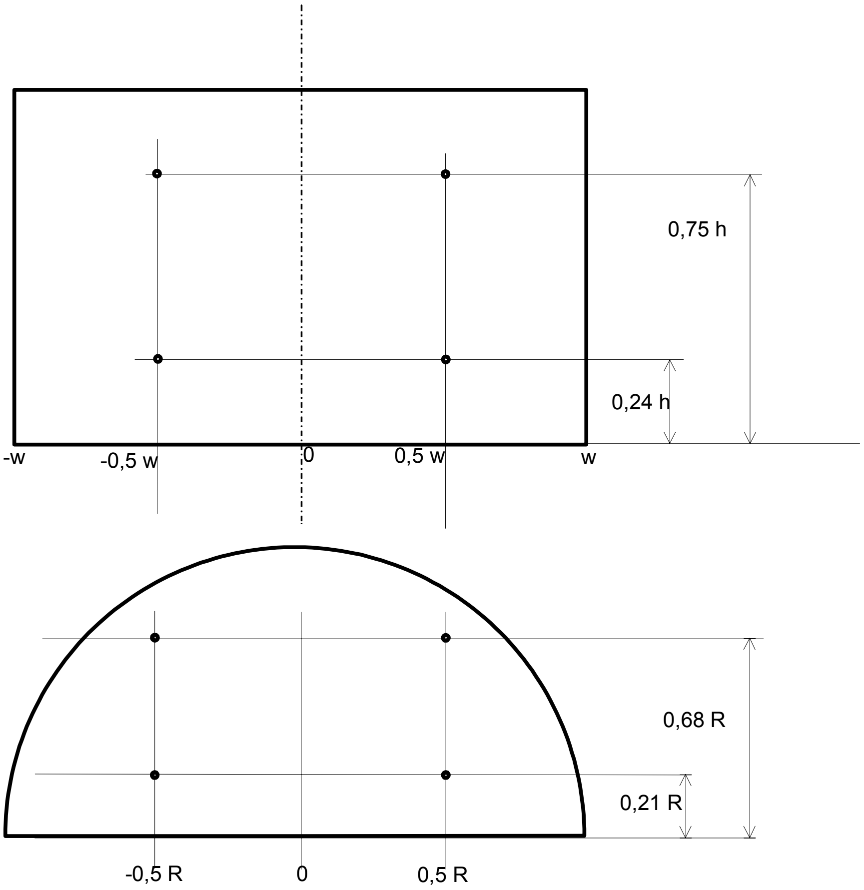

Figure 2.4 Point source distribution in tunnel openings

3 Determine sub-source strength

Assuming that the tunnel opening and the sub-sources radiate like point sources, the energy level radiating from the tunnel opening sub-source *j*, due to the passage of one vehicle (at tunnel opening *i*), is given by:

$$L_{J,ij} = 10\ \log\left(\frac{E_T}{10^{-12}}\right) + \Delta L(\phi) - 10\ \log(n) \qquad (2.13)$$

n is the number of sub-sources (= 4), ϕ is the angle between a line parallel to the tunnel axis through the sub-source midpoint and pointing outwards, and a line from this midpoint towards the receiver. E_T is calculated using Eq.(2.9) or Eq.(2.10), applying the appropriate value of a. $\Delta L(\phi)$ (in dB) is the directivity correction, see item 4.

4 Determine the directivity correction $\Delta L(\phi)$.

The correction given in Table 2.13 is mainly valid for tunnels with smooth and reflective (or almost reflective) walls, estimated from results in [7].

Table 2.13 *Directivity correction $\Delta L_r(\phi)$, in dB.*

Angle ϕ (°)	**Frequency range, 1/3 octave band centre frequencies**			
	f<160 Hz (dB)	160 - 400 Hz (dB)	500 - 1250 Hz (dB)	f≥1600 Hz (dB)
0	3	5	6	7
15	3	5	5	5
30	3	4	4	4
45	3	3	2	1
60	3	2	0	-2
75	2	-3	-6	-7
90	-2	-10	-17	-19
$105 \leq \phi \leq 180$	-6	-24	-26	-27

Values of $\Delta L_r(\phi)$ for intermediate angles are found by linear interpolation.

Note 1 :

If the tunnel walls have significant absorption, the directivity correction may change, as indicated by the results shown in [10]. The practical experience with this change is limited. A preliminary estimate to the directivity correction $\Delta L_a(\phi)$, is given by the figures in Table 2.14.

Table 2.14 *Directivity correction $\Delta L_a(\phi)$, in dB.*

Angle ϕ (°)	**Frequency range, 1/3 octave band centre frequencies**			
	f<160 Hz (dB)	160 - 400 Hz (dB)	500 - 1250 Hz (dB)	f≥1600 Hz (dB)
0	3	$5 + 0.15\Delta L_J$	$6 + 0.15\Delta L_J$	$7 + 0.15\Delta L_J$
15	3	$5 + 0.15\Delta L_J$	$5 + 0.15\Delta L_J$	$5 + 0.15\Delta L_J$
30	3	$4 - 0.15\Delta L_J$	$4 - 0.35\Delta L_J$	$4 - 0.4\Delta L_J$
45	3	$3 - 0.15\Delta L_J$	$2 - 0.35\Delta L_J$	$1 - 0.4\Delta L_J$
60	3	$2 - 0.15\Delta L_J$	$0 - 0.35\Delta L_J$	$-2 - 0.4\Delta L_J$
75	2	$-3 - 0.15\Delta L_J$	$-6 - 0.35\Delta L_J$	$-7 - 0.4\Delta L_J$
90	-2	$-10 - 0.15\Delta L_J$	$-17 - 0.35\Delta L_J$	$-19 - 0.4\Delta L_J$
$105 \leq \phi \leq 180$	-6	$-24 - 0.15\Delta L_J$	$-26 - 0.35\Delta L_J$	$-27 - 0.4\Delta L_J$

Calculate the energy E_{Tr} (the reference case), E_T (with absorption), and the energy level difference ΔL_J given by :

$$\Delta L_J = 10 \cdot \log(\frac{E_{Tr}}{E_T}) \qquad (2.14)$$

using eqs (2.9-2.10) and the appropriate values of input data : W, Δx, r (or w and h), a-values, tunnel length L_t and tunnel section lengths if applicable.

Note 2 :

If the tunnel is divided into two sections with a-values that differ significantly (as will be the case with an absorption section near the tunnel mouth), modifications to eq.(2.9) and eq.(2.10) are proposed. The approach is preliminary.

For a tunnel with semi-circular cross section, the energy radiating through the tunnel opening due to the passage of one vehicle, is calculated approximately by :

$$E_T = \frac{W}{2}\frac{\Delta x}{v}\left(\left[\sum_{i=i1}^{i\max}\left(1-\frac{a2(x_i - x1)}{\sqrt{r^2+(a2(x_i-x1))^2}}\right)\right]\cdot\left(1-\frac{a1\cdot x_1}{\sqrt{r^2+(a1\cdot x1)^2}}\right)+\sum_{i=1}^{i=i1-1}\left(1-\frac{a1\cdot x_i}{\sqrt{r^2+(a1\cdot x_i)^2}}\right)\right) \tag{2.15}$$

For a tunnel with rectangular cross section, the energy radiating through the tunnel opening due to the passage of one vehicle, is calculated approximately by :

$$E'_T = \frac{W}{\pi}\frac{\Delta x}{v}\left\{\sum_{i=i1}^{i\max}\tan^{-1}\left[\frac{w_T h}{\sqrt{(x_i-x1)^4+(w_T{}^2+h^2)(a2\cdot(x_i-x1))^2}}\right]\left(1-\frac{w_T h}{\sqrt{(x1)^4+(w_T{}^2+h^2)(a1x1)^2}}\right)\right\}$$

$$E_T = E'_T + \frac{W}{\pi}\frac{\Delta x}{v}\left\{\sum_{i=1}^{i1-1}\tan^{-1}\left[\frac{w_T h}{\sqrt{x_i{}^4+(w_T{}^2+h^2)(a1\cdot x_i)^2}}\right]\right\} \tag{2.16}$$

Here is :

a1 = a-value for tunnel section no. 1,
a2 = a-value for tunnel section no. 2,
x1 = distance (m) from the tunnel mouth to the transition between section 1 and 2,
i1 = index corresponding to the transition between section 1 and section 2.

3 Propagation

3.1 General

Sound propagation from a point source is explained and described in [1]. Using the methods therein it is possible to calculate the sound attenuation during propagation from the source to the receiver. A point source, sub source number *j*, being in position *i* and having the sound power level L_{Wij} in the direction from position *i* to the receiver will yield the following sound pressure level at the receiver

$$L_{\mathrm{p,ij}} = L_{\mathrm{W,ij}} + \Delta L_{ij} \qquad (3.1)$$

where

$$L_{\mathrm{W,ij}} = L_{\mathrm{Wref,j}} + \Delta L(\varphi_{\mathrm{i}}) + \Delta L(\psi_{\mathrm{j}}) \qquad (3.2)$$

$$\Delta L_{ij} = -10\lg(4\pi r_{\mathrm{ij}}^{2}) + \text{corrections due to ground influence, etc.} \qquad (3.3)$$

r_{ij}= the distance between point *ij* and the receiver

ΔL_{ij} can be calculated for different weather situations.

All distances refer to the nearest side of the vehicle (the nearest wheel) and NOT to the vehicle centre line.

3.2 Necessary input data - nonrefracting atmosphere

In order to carry out the calculations the following input parameters are required:

- the geometry of each propagation path, including intersection points between different ground surfaces and vertical coordinates describing screens and height variations;
- the flow resistivity of each ground and screen surface under the propagation path;
- the roughness of each ground surface;
- the air temperature;
- the relative humidity;
- the strength of atmospheric turbulence

The flow resistivity is used to calculate the acoustic impedance of the ground. The basis for measurement and calculation is the Nordtest method NT ACOU 104, [4]. To simplify the use of the prediction method the ground surfaces are divided into 7 different flow resistivity classes:

Table 3.1 Impedance classes of ground surfaces

Impedance class	**Representative flow resistivity σ(kNsm^{-4}, kRayls)**	**Range of Nordtest flow resistivity classes**	**Description**
A	12,5	10, 16	Very soft (snow or moss-like)
B	31,5	25, 40	Soft forest floor (short, dense, heather-like or thick moss)
C	80	63, 100	Uncompacted, loose ground (turf, grass, loose soil)
D	200	160, 250	Normal uncompacted ground (forest floors, pasture field)
E	500	400, 630	Compacted field and gravel (compacted lawns, park area)
F	2000	2000	Compacted dense ground (gravel road, parking lot)
G	20000	20000	Hard surface (dense asphalt, concrete, water)

The soft ground of the old Nordic prediction method resembles class E above.

The large scale roughness of the ground is divided into three different roughness classes:

Table 3.2 Roughness classes

Roughness class	**Roughness parameter**	**Range of surface height variation**
N: Nil	0	$\leq$ 0,25 m
S: Small	0,25	$\pm$ 0,5 m
M: Medium	0,5	$\pm$ 1 m
L: Large	1	$\pm$ 2 m

The air temperature and the relative humidity is needed to determine the air attenuation. It is most important at high frequencies and long distances.

Suitable default values for general calculations are given in table 3.3.

Table 3.3 Suitable default values for general calculations

Property	**Default value**
Ground impedance Soft ground Road	 Class E (500 kNsm^{-4}, kRayls) Class G (20000 kNsm^{-4}, kRayls)
Roughness class	Class N (0)
Air temperature	15°C
Relative humidity	70%

3.3 Different weather conditions

Depending on the purpose of the calculations different weather conditions can be used as input data in the propagation model. One of the following three procedures should be used:

Table 3.4 Weather classes

Weather parameters	**Comment**
1. Neutral	Here it stands for zero wind and temperature gradients. In the 1996 Nordic prediction method *neutral* is not explicitly defined. Some results indicate that neutral in this method corresponds to light downwind conditions (About 2 m/s at 10 m)
2. Actual condition	To be used for specific cases only
3. Yearly average Carry out three calculations: 1. Neutral (=homogeneous) 2. Downwind (= favourable) 3. Upwind (=unfavourable)	To be used to calculate long time average based on meteorological statistics

For calculations of yearly average downwind conditions are defined as conditions corresponding to a wind speed component of 3 m/s at 10 m above the ground. Actual weather statistics are required to determine the percentage of the time during which favourable (=downwind) conditions exist, see clause 4.5. Unfavourable(=upwind) conditions can usually be ignored as they contribute very little to the yearly average.

For actual propagation conditions the curvature of the sound rays is calculated using a logarithmic wind profile wind speed at specified height and roughness length of the ground as input parameters.

The following input data are required to carry out calculations:

- roughness length, normally 0,02-0,05 m
- temperature at ground level
- temperature gradient
- standard deviation of temperature gradients
- height for wind speed data
- wind speed, *u*, at specified height
- standard deviation, *su*, of wind fluctuations at specified height
- strength of wind and temperature turbulence, C_w^2 and Ct^2 respectively

If u> 3 m/s the following relationships can often be used:

su = 0,15 *u* for flat ground
su = 0,3 *u* for rough ground

For calculations under standard conditions the following default values are recommended:

Table 3.5 Suitable default values for standard conditions

Property	**Default value**
Roughness length	0,05 m
Temperature on ground level	15°
Temperature gradient	0 °C/m
Standard deviation of temperature gradient	0 °C/m
Height for wind speed indication	10 m
Wind speed at 10 m	
Favourable propagation	3 m/s
Homogeneous propagation	0 m/s
Unfavourable propagation	-3 m/s
Standard deviation of wind speed	
Favourable propagation	0,5 m/s
Homogeneous propagation	0,5 m/s
Unfavourable propagation	0,5 m/s

3.4 Multiple reflections

3.4.1 Basic situations

Vertical sound reflecting surfaces on both sides of the road can cause multiple reflections. The main basic situations of this kind are:

1. City streets with adjoining or partly adjoining building facades on both sides,
2. City side streets exposed to traffic noise generated in the main street,
3. Depressed roads or parallel road barriers.

3.4.2 Main principles

The propagation module, [1], describes how to handle single reflections assuming single sound sources. Multiple reflections regarding L_{eq} are dealt with accordingly by adding up the sound levels from the real and mirror sources incoherently. Normally the number of subsequent reflections can be limited to 2 or 3. In the following the basic principles are described using the first- and second order reflections in addition to the direct sound. This is thought to cover most practical situations, although the description can be extended to higher orders of reflection. A sound reflection in a vertical surface (building façade, noise screen, retaining wall, etc.) is associated with a loss in sound energy according to the energy absorption coefficient α of the surface. The energy reflection coefficient ρ may be given or estimated. The relation between α and ρ is given in Eq.(3.4):

$$\alpha = 1 - \rho \qquad (3.4)$$

ρ is given for some practical situations in [1]. Also see Section 3.5.
For all distributed point sources S_i, mirror sources and points of reflection shall be constructed with respect to the reflecting surface and the receiver position. The details are outlined in Annex B for the matter of convenience. In the case of city streets it is assumed that the adjoining facades form rather large surfaces. In addition the sound sources are distributed along the road line causing many sound level contributions to add up at the receiver positions. The Fresnel-zone considerations used when dealing with single source/single reflections in [1] are therefore omitted.

3.4.2.1 City streets with adjoining building facades

The basic situations are outlined in Figure 3.1. In situation a) the building facades are adjoining, and the two facades may, or may not, have the same sound absorption coefficient. A sub-source position S_{ij} is indicated, it belongs to one of the distributed sound sources of one road traffic line. The position of S_{ij} and the associated road segment length Δx_i are determined according to section 4.3.

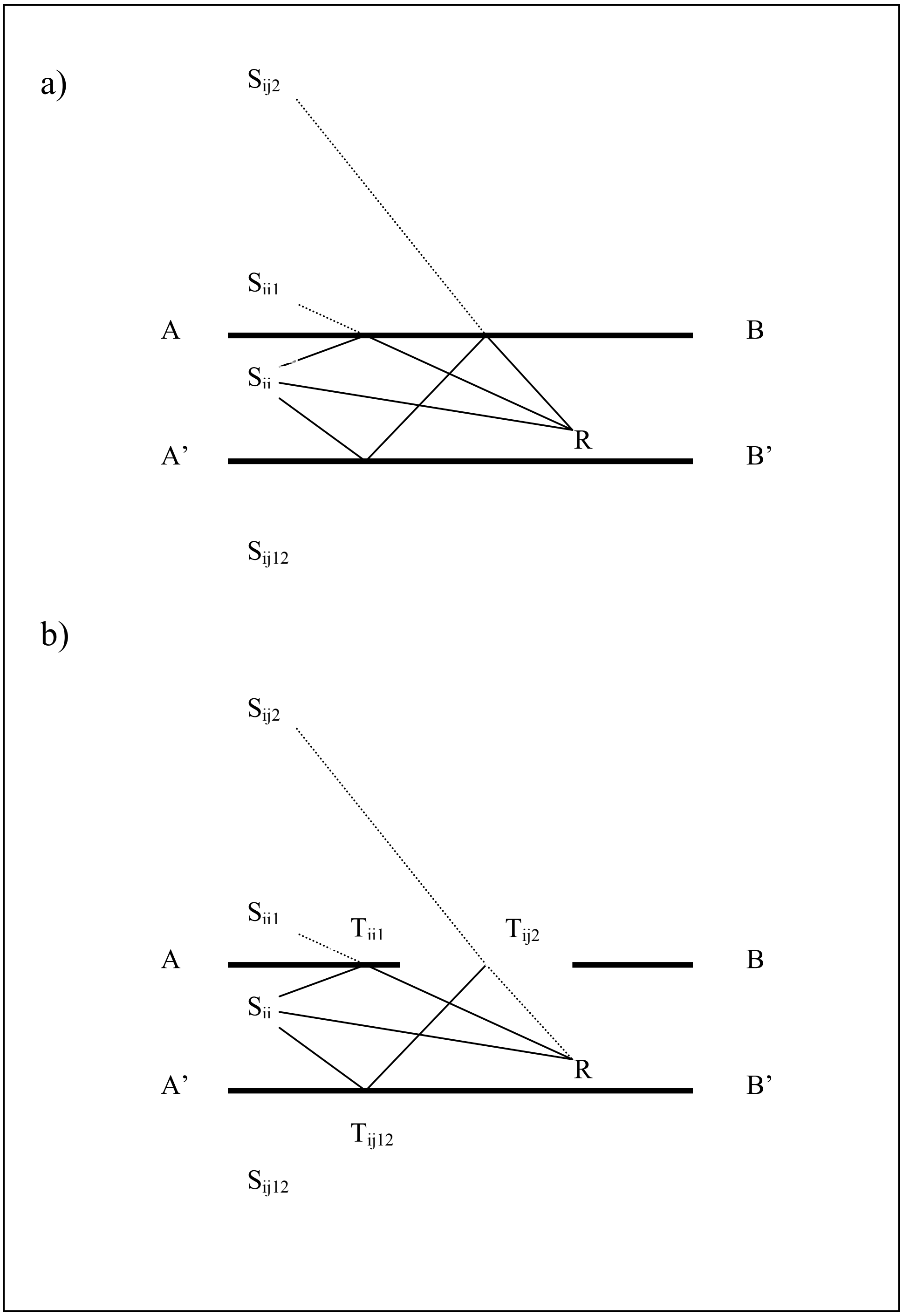

Figure 3.1 The principles of direct-, first- and second order reflection sound propagation in a city street. a) Adjoining facades, b) not adjoining facades.

It is assumed that the sound pressure level to be predicted represents *the incoming sound pressure level in front of the façade under study*. This means that it is sufficient to calculate the level contributions coming from the source along the direct path, the path including one reflection in the opposite façade, and the path including one reflection in the near façade followed by one reflection in the opposite façade. The associated mirror source positions S_{ij1}, S_{ij12} and S_{ij2} are indicated. The subscripts i and j refer to the position (road segment) i and the sub-source j. For the j^{th} sub-source position S_{ij} the mirror source positions have to be calculated. The details are outlined in Annex B.

S_{ij1} is calculated using the coordinates of the source S_{ij} and the reflection plane A – B. S_{ij12} is calculated using the coordinates of the source S_{ij} and the reflection plane A' – B'. S_{ij2} is calculated using the coordinates of the mirror source S_{ij12} and the reflection plane A – B. The coordinates of A, B (and A', B') are not critical provided they represent the surface of the respective facades.

An additional subscript k (= 0, 1, 2) is introduced to indicate the contribution from the sub-source by the direct path, and the paths of the first- and second order reflection. When considering the source levels, it is assumed that the source directivity is relevant only for the direct path, not for the reflected paths. The source strengths $L_{W,ijk}$ to be used are therefore:

The direct path:	$L_{W,ij0} = L_{Wref,j} + \Delta L_j(\varphi) + \Delta L_j(\psi)$
Path of first reflection:	$L_{W,ij1} = L_{Wref,j} + 10\lg(1-\alpha_1)$
Path of second reflection:	$L_{W,ij2} = L_{Wref,j} + 10\lg(1-\alpha_1) + 10\lg(1-\alpha_2)$

(3.5)

$L_{Wref,j}$ is the sub-source strength according to section 2.3.1. α_1 and α_2 are the sound absorption coefficients of facades A – B and A' – B' respectively.
It is further assumed that the propagation effect given by ΔL_{ij} in eq.(3.3) in these cases are limited to spherical divergence, air absorption and ground effects above the street (ground impedance of the street), all depending on the geometrical distance between source and receiver, r_{ij}. The relevant distances are given by:

The direct path:	$r_{ij0} = \mid S_{ij} R \mid$
Path of first reflection:	$r_{ij1} = \mid S_{ij1} R \mid$
Path of second reflection:	$r_{ij2} = \mid S_{ij2} R \mid$

(3.6)

R is the receiver position.
The sound exposure level for the sub-source j in position i within the road segment Δx_i, is then given by:

$$L_{E,ij} = 10\lg\left[\frac{\Delta x_i}{v_i}\sum_{k=0}^{2}10^{(L_{W,ijk}+\Delta L_{ijk})/10}\right] \qquad (3.7)$$

where $L_{W,ijk}$ and ΔL_{ijk} correspond to the source strengths and propagation effects given above. eq.(3.7) is equivalent to eq.(4.3) in Section 4.1. The L_{eq} from a vehicle flow is then obtained by inserting into eqs.(4.4 – 4.7) in Section 4.1 and 4.2. $L_{F\max}$ is calculated according to eq.(5.1) based on the direct sound contributions.

3.4.2.2 City streets with partly adjoining building facades

In situation b) in Figure 3.1 the building facades are partly adjoining, leaving gaps in the façade surfaces. In this case the reflection points should be tracked. The reflection contribution corresponding to a reflection point in a gap should be excluded from the summation in eq.(3.7). This is obtained by specifying the gap absorption coefficient equal to 1 (e.g. 0.99 for practical reasons). The formalism of eq.(3.7) can then be used, and the calculation of L_{eq} from a vehicle flow is carried out as explained above. The positions of the reflection points (T) in the façade surfaces are needed. They can be calculated as shown in Annex B.

The use of eq(3.7) which in principle covers gaps and varying absorption coefficients, makes this approach a rather general approach for city streets.
$L_{\mathrm{F\,max}}$ is calculated according to eq.(5.1) based on the direct sound contributions.

3.4.2.3 Side streets

In side streets which are exposed to sound generated by traffic in the adjoining main street, the concept of contributions from the sources by direct paths and paths including one and two reflections in the facades, can still be applied. These cases are slightly complicated by the fact that only a portion of the traffic line “is seen” from the receiver R. The rest is considered not to contribute due to the shielding effect by the corner buildings towards the main street.

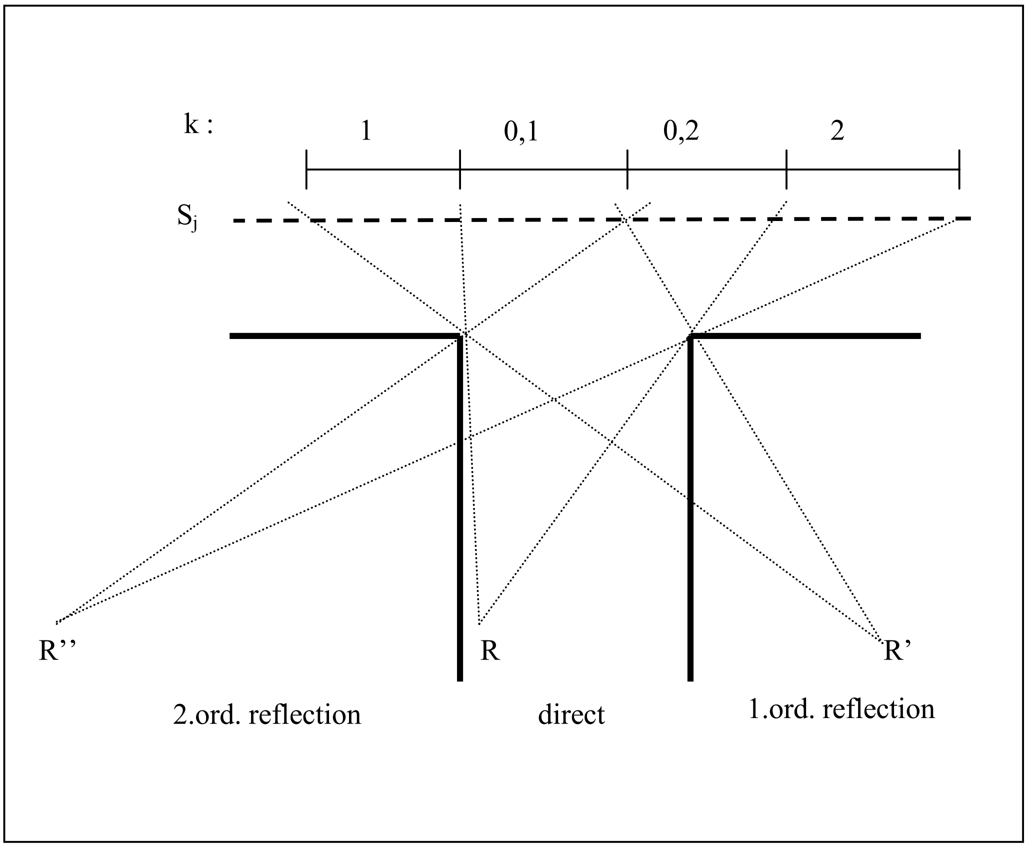

Figure 3.2 The principle of “visible sound sources” is shown for the side street situation. The sound source line is indicated by S_j.

Using the principle of "visible" sources, the contributing sources for the direct sound and sound that is reflected once and twice are indicated in Figure 3.2. R is the receiver in front of the façade A' – B'. R' is the mirror receiver regarding the reflecting surface of façade A – B. R'' is the mirror image of R' regarding the reflecting surface of façade A' – B'. For a certain source S_{ij} (positioned according to Section 4.3) it must be determined if it is included in one or more of the selected source regions associated with the direct, once- or twice reflected sound. A graphical interpretation of this is shown in Figure 3.2. Again, the background of Section 3.4.2.1 and eq.(3.7) can be used.

The graphical interpretation just mentioned indicates which of the k-values to be used in eq.(3.7) for the current source S_{ij}. Also, the concept of gaps and varying absorption coefficients according to Section 3.4.2.2 is applicable to the conditions in the side street. $L_{\mathrm{F\,max}}$ is calculated according to eq.(5.1) based on the direct sound contributions.

3.4.2.4 Depressed roads or parallel road barriers

These situations correspond closely to the city street situation discussed in Section 3.4.2.1, except that the receiver R is not in front of the façade A' – B', but at a certain position behind it at a greater distance from the traffic flow. The procedures of Section 3.4.2.1 can be applied, including the formalism of eq.(3.7) provided the terminology is corresponding.

The change in the receiver position R can have a significant effect on the propagation term ΔL_{ij} that enters into eq.(3.7). The propagation may now also include diffraction effects due to a screened situation. The screen is formed by the upper edge of the vertical surface denoted A' – B' (or the top of a barrier in the parallel road barrier situation). The paths of the direct sound and the reflected sound may all be screened.

It is assumed that the reflecting surfaces associated with depressed roads are vertical (or almost vertical), with sufficient heights to give proper reflections. Walls that are not vertical should normally not cause any problems regarding single or multiple reflections.

3.5 Reflection in road barriers

In the case of a barrier at one side of the road, the sound reflection to the opposite side can be treated as single reflections.
This case is similar to the city street situations discussed in Sections 3.4.2.1 and 3.4.2.2 above, except that the facade denoted A' – B' is absent. Therefore only the direct sound and the sound reflected once in the barrier are calculated. The procedures of Section 3.4.2.1 can still be used. Parameters related to second order reflections need not be calculated, i.e. S_{ij12}, S_{ij2}, r_{ij2}, $L_{W,ij2}$ and α_2. The summation in eq.(3.7) is now restricted to k-values 0,1.
Modern noise barriers are normally tested according to EN 1793, [5], which means that sound absorption data (α) are available.

The point of reflection T_{ij1} in the barrier surface should be checked according to Annex B. The sound level contribution from the reflection can be omitted if T_{ij1} is on (or near) or above the barrier top. Else, in case of low height barriers, reflections according to the Fresnel-zone correction described in [1] should be considered.

The procedure described in this section applies to all reflecting surfaces on one side of and close to the road (long building facades, dense fences, retaining walls, etc.).

4 Calculation of L_{eq}

4.1 L_E from one moving point source

A moving point source, index *j*, will during a pass-by yield the sound exposure level

$$L_{E,j} = 10\lg\left[\frac{1}{t_0}\int_{t_1}^{t_2} 10^{L_{p,j}(t)/10}\,dt\right] \tag{4.1}$$

where t_0 is a reference duration of 1 s, t_1 is the time when we start hearing the source and t_2 the time when the source is no longer audible. $L_{p,j}(t)$ is the sound pressure level from source *j* at the receiver at the time *t*.

If, at time *t*, the source *j* is in position *i*, and moves with speed v_i along a road segment with length Δx_i at a distance r_i from the receiver, (4.1) can, for a short segment, be approximated by

$$L_{E,ij} = 10\lg\left[\frac{\Delta x_i}{v_i}10^{L_{p,ij}/10}\right] \tag{4.2}$$

With (3.1) we now get

$$\boxed{L_{E,ij} = 10\lg\left[\frac{\Delta x_i}{v_i}10^{(L_{W,ij}+\Delta L_{ij})/10}\right]} \tag{4.3}$$

The total sound exposure level at the receiver during a complete pass-by by source *j* then becomes

$$\boxed{L_{E,j} = 10\lg\left[\sum_{i=1}^{m}10^{L_{E,ij}/10}\right]} \tag{4.4}$$

where *m* = the number of road segments used.

For a number n_j of sub-sources, each with a pass-by sound exposure level $L_{E,j}$, representing one vehicle of a certain category, the sound exposure level for this single vehicle of this category is given by

$$\boxed{L_{E,v} = 10\lg\left[\sum_{j=1}^{n_j}10^{(L_{E,j}/10)}\right]} \tag{4.5}$$

4.2 L_{eq} from a vehicle flow

4.2.1 General

During a specified time period, T, a certain number, N_{vc}, of vehicles belonging to a specific vehicle category will pass by, yielding the vehicle-category L_{eq}-level

$$L_{eq,T,vc} = L_{E,v} - 10\lg(T) + 10\lg(N_{vc}) \qquad (4.6)$$

For a number N_{cat} of vehicle categories in the traffic flow, the total L_{eq}-level in the specified time period T, is

$$L_{eq,T} = 10\lg\left[\sum_{vc=1}^{N_{cat}} 10^{(L_{eq,T,vc}/10)}\right] \qquad (4.7)$$

$L_{eq,T}$ is calculated for each road or road segment. The final result is then obtained by summing up all road or segment contributions according to the principles given by (4.7).

4.2.2 Several lanes

For accurate calculations the total vehicle flow should be distributed between the different lanes of the road and each lane should be handled as an individual road.

4.3 Road segment length, Δx

4.3.1 General

Each terrain profile must have its own road segment. As eq. (4.4) is a sum and not an integral, it is an approximation. Thus, if a road segment is large, it must be divided into smaller sub-segments even if the terrain profile is the same. At least at short and medium distances from the road, the sound exposure is sensitive to changes in the sound propagation conditions, i.e. by pronounced terrain variations, major changes in ground class, or the transition to or from a screened situation. This suggests that the road segment length should be relatively small.

Determining segment lengths is equivalent to the positioning of sound sources along the road as shown by eq. (4.3), with source heights and strengths according to chapter 2.2 and 2.3. The two basic principles for the positioning include that the sources are distributed equidistantly along the road, or distributed at constant view angles as seen from the receiver. A combination of the two is proposed in the following to get a practical procedure with due consideration to the density of source positions. The density should be adequate for reasons mentioned above, but at the same time kept to a minimum considering the computational time that is required. The procedure is split into two parts. First the basic road segments are determined, then sub-segments are determined if necessary.

4.3.2 Basic road segments

The basic road segments are established on basis of significant changes in:

i) the road curvature and/or road gradient, the traffic intensity, the road surface, the posted speed,

ii) the terrain profile between the road and the receiver position, including natural or artificial barriers or screens.

If the road is curved, its curvature is approximated by straight segments.
The road segments according to the parameters in i) are first established, while the parameters in ii) may lead to additional segments.
The point is to obtain homogeneous conditions regarding the parameters mentioned in i) and ii), for each of the sectors defined by the basic road segment and the receiver position. The parameters represent the minimum general input data that is required to carry through a noise level calculation.

4.3.3 Road sub-segment lengths

When the basic road segments are established according to chapter 4.3.2, they usually have to be sub-divided. The following guidance is given for the sub-segmentation, the determination of the road segment length Δx and the position of the source point:

iii) If the current road segment length Δx is smaller than $\Delta x_{\min}$, then the segment length is unchanged. Otherwise:
If the current segment angle β is greater than $\beta_{\max}$ or if the relative distance RD (the ratio $|P_1R| / |P_2R|$ of the shortest distance between the segment and the receiver to the greatest distance, see Figure 4.1) is less than $RD_{\min}$, then the current segment is divided into two parts, as follows:
If the current segment angle β is greater than $\beta_{\max}/2$, then the segment is split into two by the dividing line of $\beta/2$. Otherwise the segment is split into two at the segment midpoint.

iv) Step iii) is repeated for all new sub-segments until no new sub-segments are created.

v) The associated noise source position is as follows :
If the current segment angle β is greater than $\beta_{\max}/2$, then the source point is positioned by the dividing line of $\beta/2$. Otherwise the source point is positioned at the current segment midpoint.

The values of $\Delta x_{\min}$, $\beta_{\max}$, and $RD_{\min}$ are chosen according to practical considerations. The following values can be used as a guide :

$\Delta x_{\min}$ = 5-10m, the lowest figure is used when close to the road.
$\beta_{\max}$ = 10° (0,175 rad.),
$RD_{\min}$ = 0,75.

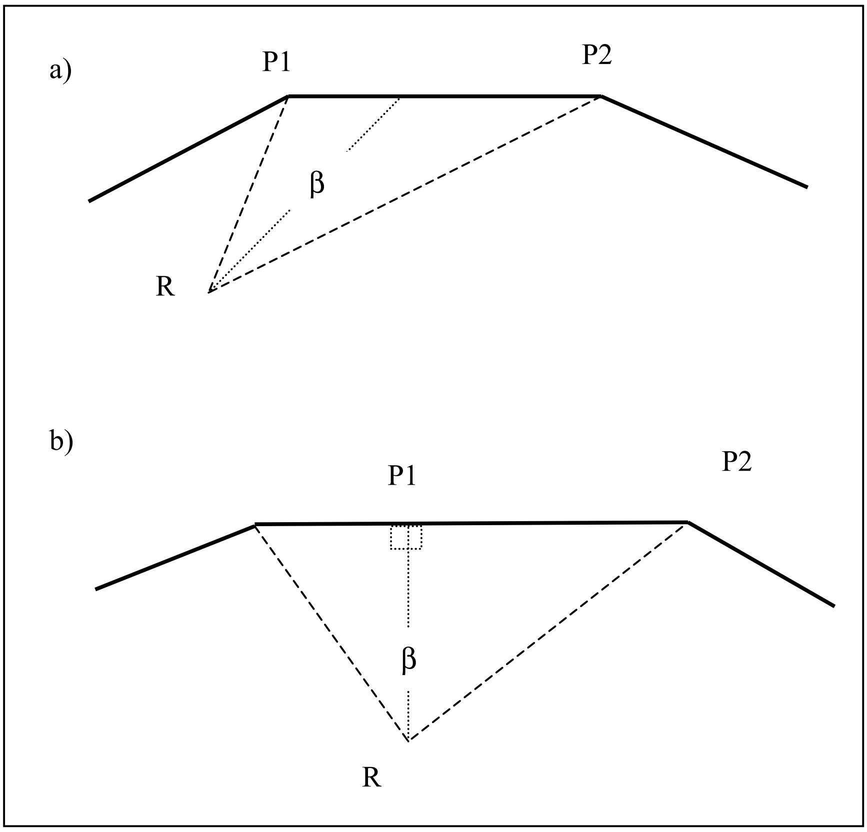

Figure 4.1 Basic road segments, segment angle β, distances $|P_1 R|$ *and* $|P_2 R|$*. Schematic plan view.*

4.4 L_{eq} from a tunnel opening

A tunnel opening is stationary and the source strength is, according to 2.14, described in terms of the sound energy level. The sound exposure level at the receiver point, due to the tunnel passage by one vehicle, is calculated for each tunnel sub-source *j* according to

$$L_{E,j} = L_{J,j} + \Delta L_{ij} \tag{4.10}$$

where ΔL_{ij} is given by eq. (3.3), *ij* indicating the location of the tunnel opening and its sub source *j*.

The sound exposure level at the receiver, radiated from the tunnel opening due to the passage of one vehicle of a certain category, then becomes

$$L_{E,v,tun} = 10\lg\left[\sum_{j=1}^{nj} 10^{(L_{E,ij}/10)}\right] \tag{4.11}$$

where n_j = the number of tunnel opening sub-sources used.

During a specified time period, T, a certain number, N_{vc}, of vehicles belonging to a specific category will pass through the tunnel, yielding the vehicle-category L_{eq}-level

$$L_{eq,T,vc,tun} = L_{E,v,tun} - 10\lg(T) + 10\lg(N_{vc}) \tag{4.12}$$

For a number, N_{cat}, of vehicle categories in the traffic flow, the total L_{eq}-level in the specified time period T, is

$$L_{eq,T,tun} = 10\lg\left[\sum_{vc=1}^{N_{cat}} 10^{(L_{eq,T,vc,tun}/10)}\right] \tag{4.13}$$

This is the contribution of the tunnel opening to the overall L_{eq}.

4.5 Day, evening, night weighting

Within the European Union it has been proposed to use L_{den}, where

$$L_{den} = 10\lg\left[\frac{1}{T_{day} + T_{evening} + T_{night}}\right] + 10\lg\left[T_{day}10^{L_{eq,day}/10} + T_{evening}10^{(L_{eq,evening}+5)/10} + T_{night}10^{(L_{eq,night}+10)/10}\right] \tag{4.14}$$

that is evening and night movements get the penalties 5 and 10 dB respectively. Alternatively the number of vehicles in the evening and at night could be multiplied by 3 and 10 respectively. Standard values for day evening and night are 07.00-19.00, 19.00-23.00 and 23.00-07.00 respectively, that is T_{day}, T_{evening} and T_{night} are 12 h(43200 s), 4 h(14400 s) and 8 h (28800 s) respectively. Each member state may decide the day, evening and night time intervals individually.

4.6 Yearly average

In order to get the yearly average some simplifications have to be made because it is too complicated to carry out calculations for each possible set of weather conditions. The approach recommended here is to divide the weather conditions into 3 different classes: *f*, *h* and *u* respectively standing for favourable (downwind), homogeneous (neutral) and unfavourable (upwind).

Using the notation p for p % of the time and L for the calculated L_{eq} and adding the different indices the yearly average is calculated from

$$L_{yav} = 10\lg\left[0{,}01\left(p_f 10^{L_f/10} + p_h 10^{L_h/10} + (100 - p_f - p_h)10^{L_u/10}\right)\right] \tag{4.15}$$

In order to get a more accurate yearly average it may become necessary to take winter tyres, wet roads and varying ground conditions into account.

5 Calculation of $L_{F\max}$

Theoretically it is complicated to determine L_{Fmax} because different frequencies will have their maxima at different times and the time weighting should be simulated properly. For long vehicles it would be required to consider the extension of the vehicle, at least for short distances. However, as can be seen from the examples in 6.2, it seems to be possible to obtain reasonably good agreement between values calculated from the sound power level and measurements simply by using the point sources at different heights (j=1:n) combined with sound propagation theory. This agreement should be satisfactory as experience has shown that the standard deviation of L_{Fmax} is also about twice as large as for SEL. Thus $L_{F\mathrm{max}}$ is calculated from

$$L_{F\max} = \max(L_{F\max}(i)) = \max\left[10\lg\sum_{j=1}^{n}10^{(L_{W,ij}+\Delta L(\varphi)+\Delta L(\psi)+\Delta L_{ij})/10}\right] \qquad (5.1)$$

where
i indicates the position of the vehicle and max(L_{Fmax}(i)) the maximum level of all positions i which the vehicle has during a complete pass-by. The maximum position i is defined as the position giving the highest A-weighted sound pressure level.

It should be noted that the horizontal directivity is included in eq. (5.1). The main reason for that additional correction is the horn effect between the tyre and the road surface. Considerably more sound will radiate in the direction of the vehicle than perpendicular to the vehicle.

6 Uncertainty

The new Nordic propagation models still needs testing and validation. Until extensive validation has taken place the uncertainty will not be known. Until further it is recommended to assume the following approximate uncertainties for $L_{\mathrm{Aeq,T}}$ values determined for a time, T, long enough to average out short time weather variations and to ensure a representative flow of vehicles, but also short enough to ensure stationary weather conditions.

Source of error	**Expected standard deviation**	
	Standard conditions	Other cases
Source data	$\sigma_s = 0,5$	$\sigma_s = 1$
Description of terrain	$\sigma_t = 1$	$\sigma_t = 2$
Favourable or homogeneous propagation, or $(h_s+h_r) \geq 0,1\ d$	$\sigma_f = 1$	$\sigma_f = 2$
Unfavourable propagation, or $(\mathrm{h_s}+h_r) \leq 0,1\ d$	$\sigma_u = 3$	$\sigma_u = 5$

Standard conditions are defined as follows:

Source data	Well defined road surface with large traffic of commonly occurring vehicle categories and with temperature variations within 10º.
Description of terrain	Smooth ground surfaces with known impedances and not more than one well-defined barrier
Favourable or homogeneous propagation, or $(h_s+h_r) \geq 0,1\ d$	Only one ground reflected ray
Unfavourable propagation, or $(\mathrm{h_s}+h_r) \leq 0,1\ d$	Receiver not in the shadow zone

As an example the total prediction error, expressed as standard deviation, is, for the most favourable conditions given by, given by:

$$\sigma_{tot} = \sqrt{\sigma_s^2 + \sigma_t^2 + \sigma_f^2} \quad = \sqrt{2,25} = 1,5 \text{ dB} \qquad (6.1)$$

The uncertainties above refer to one specific occasion. If comparisons are made with measurements averaged over several different occasions the uncertainty will improve.

7 Comparisons with the 1996 Nordic model

7.1 Background

The present Nordic prediction method is based on A-weighted sound levels only. Thus we can only compare A-weighted levels.

The result of the calculations depends on the input data and the excess sound attenuation. In the 1996 model input data are given as sound exposure and maximum sound pressure levels for light and for heavy vehicles. They are given as a function of speed. These data are used to calculate L_{Aeq} at 10 m from the middle of the road. Heavy vehicles are defined as vehicles with a mass exceeding 3500 kg. In Nord 2000 it has been decided to use sound power levels and to divide the vehicles into at least 3 major categories: Passenger cars with 4 axles, lorries and buses with 4 axles and 3 or more axles respectively. Later it is anticipated to use even more sub categories.

In the following comparisons source data and excess ground attenuation data will be compared independently. For Nord 2000 the SEL and maximum levels will be calculated from the sound power levels and then compared with the corresponding 1996 levels. For heavy vehicles both category 2 and 3 in Nord 2000 will be compared with the 1996 heavy vhicle. From the background discussions of the 1996 model it could be expected that the 1996 heavy vehicle at low speeds is similar to a new category 2 vehicle and that the same vehicle at a high speed is similar to a category 3 vehicle.

In the 1996 model the maximum level is given as an arithmetic mean value together with a standard deviation. In Nord 2000 the primary maximum level will be an energy average because it is calculated from a sound power level, which has been derived from energy averaged sound exposure levels. The energy average is likely to be about 1 dB higher.

As to the excess sound attenuation due to propagation effects Nord 2000 includes several effects, which are not included in the 1996 model. Examples of such effects are different ground impedances and wind speed components. In the 1996 model we only talk about hard and soft ground and it is stated that the meteorological conditions correspond to neutral or slightly (0-3 m/s) downwind conditions. In the following comparisons we will primarily use impedance class E (500 kRayls) for soft ground and carry out the Nord 2000 calculations for 0 – 3 m/s at 10 m in a direction downwind and along the horizontal normal to the road and with different speed standard deviations.

In the 1996 model the spectrum used for the calculations has not been specified. However, some corrections has been applied to account for the change in spectrum when it is attenuated due to screening. In the following comparisons the Nord 2000 calculations have been primarily calculated for a spectrum at 50 km/h representative for a mixture of 10000 category 1 vehicles, 1000 category 2 vehicles and 200 category 3 vehicles. At 90 km/h the mixture has been 10000 category 1, 500 category 2 and 1500 category 3 vehicles.

In the following calculations the integration during vehicle pass-bys has been limited to about $\pm 80^{\circ}$.

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7.2 Emission

A comparison is made using both Danish data, primarily from category 1 road surfaces, and Swedish data, primarily category 2 surfaces. The default version of the first Nord 2000 version will be the Danish data set as it is based on many more measurements and because it is more in line with the 1996 prediction model.

7.2.1 Sound exposure level

Table 7.1 Category 1 vehicles. Comparison between Nord 2000 and the 1996 model. A-weighted sound exposure levels.

Speed, km/h	**Nord 2000 SEL, dB Swedish**	**Nord 2000 SEL, dB Danish**	**1996 model SEL, dB**
30	72,5	66,5	71,1
40	73	69,2	71,1
50	74,5	73,1	73,5
60	77,3	73,9	75,5
70	79,2	75,8	77,2
80	80,9	77,0	78,6
90	82,6	79,6	79,9
100	83,9	80,9	81,0
110	84,3	80,8	82,1

Table 7.2 Category 2 vehicles. Comparison between Nord 2000, draft version 8, and the 1996 model

Speed, km/h	**Nord 2000 SEL, dB Swedish**	**Nord 2000 SEL, dB Danish**	**1996 model SEL, dB**
30		76,1	80,5
40		77,6	80,5
50	82,4	79,1	80,5
60	83,8	81,3	82,9
70	84,2	81,5	84,9
80	86,5	83,1	86,6
90	87,2	84,5	88,2

Table 7.3 Category 3 vehicles. Comparison between Nord 2000, draft version 8, and the 1996 model

Speed, km/h	**Nord 2000 SEL, dB Swedish**	**Nord 2000 SEL, dB Danish**	**1996 model SEL, dB**
30		80,5	80,5
40		81,4	80,5
50	83,1	82,0	80,5
60	87,1	84,8	82,9
70	88	85,5	84,9
80	90,5	86,4	86,6
90	91,2	87,9	88,2

7.2.2 Maximum sound pressure level

In the 1996 Nordic model the maximum sound pressure level is given as an arithmetic mean value. In Nord 2000 the maximum level is calculated from the sound power level. As the sound power level is calculated from the energy average of the sound exposure level this means that the maximum level is an energy average. In the following comparisons the energy average of the maximum has been calculated according to

$L_{\mathrm{AFmax}}(\text{energy average}) = L_{\mathrm{AFmax}}(\text{arithmeic average}) + 0{,}115\ s^2$ (7.1)

The equation is based on empirical data from Germany.

Table 7.4 Category 1 vehicles. Comparison between Nord 2000 and the 1996 model

Speed km/h	**Nord 2000 SEL dB Swedish data**	**Nord 2000 SEL dB Danish data**	**1996 model $L_{\mathrm{AFmax,mean}}$ dB**	**1996 model $L_{\mathrm{AFmax,energymean}}$ dB**	**1996 standard deviation dB**
30	66,6	61,6	62,3	63,8	3,6
40	68,2	69,2	66,1	67,2	3,1
50	70,8	69,3	69	69,8	2,7
60	74,3	71,9	71,4	72,1	2,4
70	76,9	74,4	73,4	73,9	2,1
80	79,2	76,1	75,1	75,5	1,8
90	81,4	79,2	76,7	77	1,6
100	83,1	81,0	78	78,2	1,4
110	84	81,3	79,3	79,5	1,2

Table 7.5 Category 2 vehicles. Comparison between Nord 2000, draft version 8, and the 1996 model

Speed km/h	**Nord 2000 SEL dB Swedish data**	**Nord 2000 SEL dB Danish data**	**1996 model $L_{\mathrm{AFmax,mean}}$ dB**	**1996 model $L_{\mathrm{AFmax,energymean}}$ dB**	**1996 standard deviation dB**
30		71,2	75	76,9	4,1
40		74,2	75	76,9	4,1
50	78,9	76,6	75	76,9	4,1
60	81	79,6	77,4	78,7	3,4
70	82,1	80,3	79,4	80,3	2,8
80	84,9	82,6	81,1	81,8	2,4
90	86,1	84,4	82,7	83,2	2

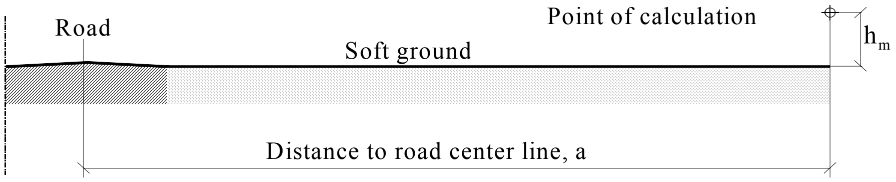
Table 7.6 Category 3 vehicles. Comparison between Nord 2000, draft version 8, and the 1996 model

Speed km/h	Nord 2000 SEL dB Swedish data	Nord 2000 SEL dB Danish data	1996 model $L_{\mathrm{AFmax,mean}}$ dB	1996 model $L_{\mathrm{AFmax,energymean}}$ dB	1996 standard deviation dB
30		75,7	75	76,9	4,1
40		78	75	76,9	4,1
50	79,5	79,5	75	76,9	4,1
60	84,3	83,1	77,4	78,7	3,4
70	86	84,5	79,4	80,3	2,8
80	89	85,9	81,1	81,8	2,4
90	90,1	87,9	82,7	83,2	2

7.3 Excess attenuation

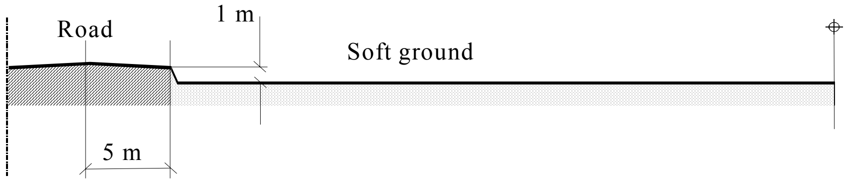
The reference for excess attenuation is the same as in the 1996 Nordic model, that is all attenuation on top of L_{eq} at 10 m. 2 m/s denotes downwind 2 m/s with no wind fluctuations. 3/1,5 m/s denotes downwind 3 m/s with a standard deviation of 1,5 m/s.

Type case 1



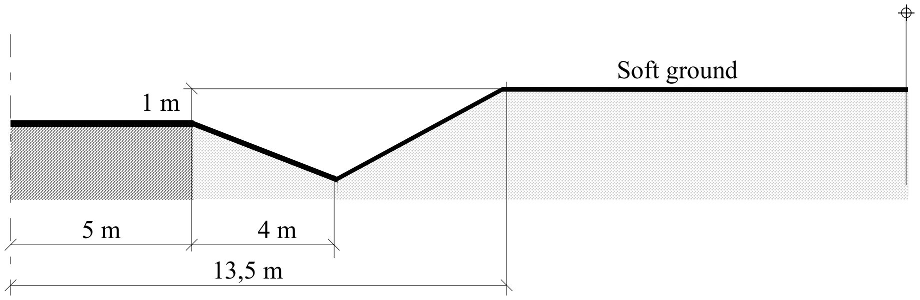
	20m/2m	20m/4m	50m/2m	50m/4m	100m/2m	100m/4m	200m/2m	200m/4m	Average
1996	-4,5	-3,5	-13	-10	-19	-16,5	-24	-22	
50 km/h									
0 wind	-7,1	-5,1	-16,0	-13,1	-22,6	-20,2	-28,4	-27,3	
0/0,5 m/s	-7,1	-5,1	-16,0	-13,1	-22,6	-20,2	-28,4	-27,3	
1/0,5 m/s	-7,0	-5,0	-15,6	-12,9	-21,7	-19,7	-24,9	-26,1	
2 m/s	-6,8	-4,9	-15,1	-12,6	-19	-21,4	-21,4	-23,9	
3/1,5 m/s	-6,7	-6,8	-14,7	-12,4	-18,7	-18,4	-18,6	-22,1	
Diff 0 m/s	-2,6	-1,6	-3,1	-3,1	-3,9	-3,8	-4,7	-5,6	-3,6
Diff 1/0,5	-2,5	-1,5	-2,6	-2,9	-2,7	-3,2	-0,9	-4,1	-2,6
Diff 2 m/s	-2,3	-1,4	-2,1	-2,6	0,0	-4,9	2,6	-1,9	-1,8
Diff 3/1,5	-2,2	-3,3	-1,7	-2,4	0,3	-1,9	5,4	-0,1	-0,7
90 km/h									
0/0,5 m/s	-7,3	-5,1	-17	-13,5	-24,6	-21,1	-31,4	-28,5	
2 m/s	-7,1	-5	-16	-12,9	-21,3	-19,8	-22,9	-25	
Diff 90-50									
0/0,5 m/s	-0,2	0	-1,0	-0,4	-2,0	-0,9	-3,0	-1,2	-1,1
2 m/s	-0,3	0,1	-0,9	-0,3	-2,3	1,6	-1,5	-1,1	-0,6

Type case 2



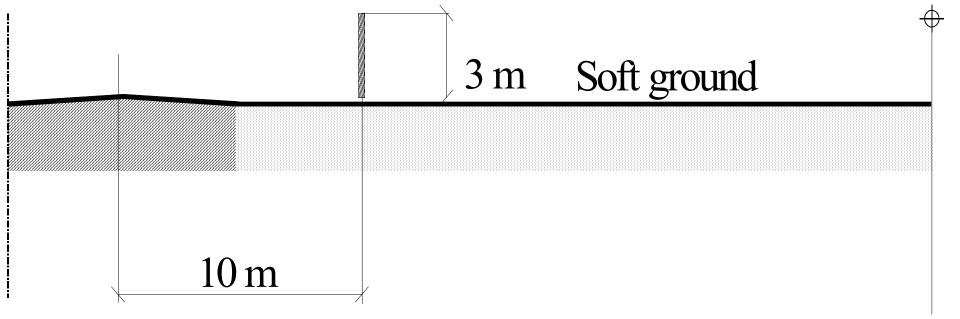
	20m/2m	20m/4m	50m/2m	50m/4m	100m/2m	100m/4m	200m/2m	200m/4m	Average
1996	-3	-3	-10	-7	-16	-13	-22	-20	
0 wind	-4,4	-2,9	-12,9	-9,8	-20,7	-17,3	-27,8	-25,0	
2 m/s	-4,3	-3,1	-11,2	-8,5	-16,2	-13,6	-19,3	-17,8	
Diff 0 m/s	-1,4	0,1	-2,9	-2,8	-4,7	-4,3	-5,8	-5,0	-3,4
Diff 2 m/s	-1,3	-0,1	-1,2	-1,5	-0,2	-0,6	2,7	2,2	0,0

Type case 5



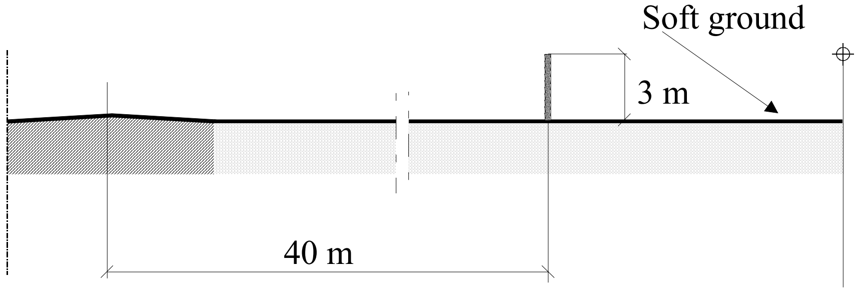
	20m/2m	20m/4m	50m/2m	50m/4m	100m/2m	100m/4m	200m/2m	200m/4m	Average
1996	-4,5	-3,5	-13	-10	-19	-16,5	-24	-22	
0 wind	-7,1	-5,0	-16,1	-13,1	-22,9	-20,3	-28,7	-27,6	
2 m/s	-6,7	-4,7	-15,1	-12,6	-19	-21,4	-21,4	-23,9	
Diff 0 m/s	-2,6	-1,5	-3,1	-3,1	-3,9	-3,8	-4,7	-5,6	-3,5
Diff 2 m/s	-2,2	-1,2	-2,1	-2,6	0,0	-4,9	2,6	-1,9	-1,5

Type case 10



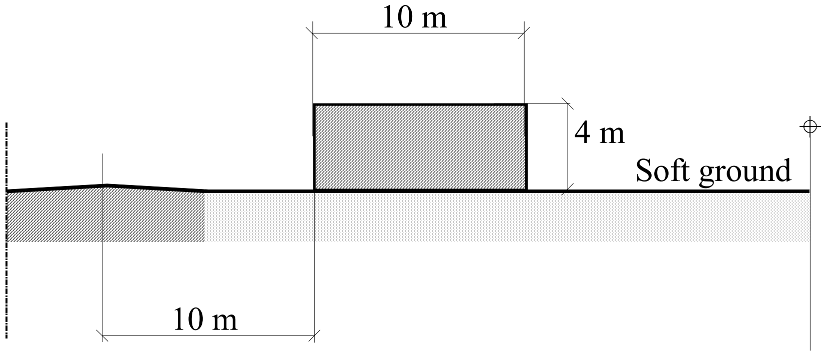
	20m/2m	20m/4m	50m/2m	50m/4m	100m/2m	100m/4m	200m/2m	200m/4m	Average
1996	-18	-13	-21	-20	-25	-23,5	-29	-28	
50 km/h									
0 wind			-23,3	-22,1	-28,1	-26,2	-33,6	-31,5	
0/0,5 m/s			-23,3	-22,1	-27,8	-26,3	-31,8	-30,9	
2 m/s			-21	-20,5	-22,6	-23,5	-22,7	-24,8	
3/1,5 m/s			-20	-19,6	-20,5	-22,1	-19,3	-21,9	
3/1			-20	-19,6	-20,5	-22	-19,3	-21,9	
3/0			-19,8	-19,6	-20,5	-22,2	-19,5	-21,9	
Diff 0 m/s			-2,3	-2,1	-3,1	-2,7	-4,6	-3,5	-3,2
Diff 0/0,5			-2,3	-2,1	-2,8	-2,8	-2,8	-2,9	-2,6
Diff 2 m/s			0	-0,5	2,4	0,0	6,3	3,2	1,9
Diff 3/1,5			1,0	0,4	4,5	1,4	9,7	6,1	3,9
90 km/h									
0/0,5 m/s			-24,0	-22,6	-28,9	-26,8	-33	-31,8	
3/1,5 m/s			-20,3	-19,9	-20,6	-22,3	-19,3	-22,4	
Diff 90-50									
0/0,5 m/s			-0,7	-0,5	-1,2	-0,5	-1,2	-0,9	-0,8
3/1,5 m/s			-0,3	-0,3	-0,1	-0,2	0,0	-0,5	-0,2

Type case 14



	20m/2m	20m/4m	50m/2m	50m/4m	100m/2m	100m/4m	200m/2m	200m/4m	Average
1996			-20	-14	-22,5	-19,5	-27	-25,5	
50 km/h									
0 wind			-23,6	-15,5	-26,4	-24,8	-31,6	-29,4	
0/0,5 m/s			-23,6	-13,4	-26,2	-24,7	-30,2	-29,0	
2 m/s			-15,8	-12,2	-18,8	-18,0	-20,9	-23,4	
3/1,5 m/s			-14,4	-11,9	-17,7	-17,6	-16,6	-20,1	
Diff 0 m/s			-3,6	-1,5	-3,9	-5,3	-4,6	-3,9	-3,8
Diff 0/0,5			-3,6	0,6	-3,7	-5,2	-3,2	-3,5	-3,1
Diff 2 m/s			4,2	1,8	3,7	1,5	6,1	2,1	3,2
Diff 3/1,5			5,6	2,1	4,8	1,9	10,4	4,4	4,8
90 km/h									
0/0,5 m/s			-24,5	-13,4	-27,1	-25,2	-31,3	-29,6	
3/1,5 m/s			-14,5	-12,1	-18,1	-18	-16,5	-20,2	
1/0,5			-18,8	-12,5	-19,6	-18,6	-23,7	-22,8	
Diff 90-50									
0/0,5 m/s			-0,9	0,0	-0,9	-0,5	-1,1	-0,6	-0,7
3/1,5 m/s			-0,1	-0,2	-0,4	-0,4	0,1	-0,1	-0,2
1									

Type case 16



	20m/2m	20m/4m	50m/2m	50m/4m	100m/2m	100m/4m	200m/2m	200m/4m	Average
1996			-20	-14	-22,5	-19,5	-27	-25,5	
0 wind			-24,7	-16,9	-27,6	-26,0	-32,6	-30,7	
2 m/s			-17,2	-13,1	-20,1	-19,1	-23,5	-24,7	
Diff 0 m/s			-4,7	-2,9	-5,1	-6,5	-5,6	-5,2	-5,0
Diff 2 m/s			2,8	0,9	2,4	0,4	3,5	0,8	1,8

7.4 Discussion and conclusions

In general the results indicate that the new Danish emission values are well in line or slightly lower than the 1996 model. The Swedish data are significantly higher. One explanation could be that the new Swedish measurements refer to category 2 roads and not to category 1 as in the 1996 model or the new Danish data. However, the Swedish data are based on a rather limited number of measurements, and it is too early to draw any firm conclusions. Before further investigations are carried out it is recommended to use the Danish data set only in Nord 2000.

As to the excess attenuation Nord 2000 will, without any wind or temperature gradients, predict lower levels than the 1996 model. This is not surprising as this model has been shown to give a rather good agreement with moderate downwind conditions. Simulating such conditions with Nord 2000 yields a rather good agreement between the two methods.

The 1996 model uses the same spectrum for all calculations of the excess ground and barrier attenuations. As Nord 2000 uses actual spectra for all speeds this will cause a diffence in excess attenuations when expressed in A-weighted levels. The limited comparisons shown in 7.3 indicate that the spectrum variations normally will affect the A-weighted excess attenuation by less than ±2 dB.

It is not meaningful to try to put a number on the differences between the two models. Nord 2000 has too many parameters to vary.

8 References

[1] Nord 2000. Comprehensive outdoor sound propagation model.
Part 1: Propagation in an atmosphere without significant refraction
Part 2: Propagation in an atmosphere with refraction

[2] Road Traffic Noise – Nordic Prediction Model, TemaNord 1996:525

[3] Proposal for a directive relating to the assessment and management of environmental noise, 10862/00 ENV 272 CODEC 609 COM (2000) 468 final

[4] NT ACOU 104, Ground surfaces: Determination of the acoustic impedance

[5] EN 1793:97 Road traffic noise reducing devices
Part 1: Intrinsic characteristics - Sound absorption

[6] K. Takagi et al., Prediction of road traffic noise around tunnel mouth. Proc. InterNoise 2000, pp. 3099-3104.

[7] Svein Å. Storeheier. Enkel metode for beregning av støyutstråling fra vegtunneler. SINTEF rapport STF40 A96005, 1996.01.18.

[8] Hans G. Jonasson, Measurement and modelling of noise emission of road vehicles, SP REPORT 1999:35

[9] NT ACOU 105, Vehicles: Determination of immission relevant noise emission

[10] H. Tachibana et al., Scale model experiment on sound radiation from tunnel mouth. Proc. InterNoise 99,

Annex A - Source data

At the time of this report it has not been possible to evaluate all measurement data available. Nor has it been possible to evaluate the influence of different parameters. Thus, in this first version of Nord 2000 it has been decided to use 3 vehicle categories only without involving other additional parameters than speed. As the most comprehensive measurements have taken place in Denmark and as the Danish data do not deviate much from the data of the 1996 model these data will be chosen as the primary data base to use. These data are given in annex A.1.

In annex A.2 some Swedish data are given. There is a trend in these data to give slightly higher values than the Danish data. One explanation could be that the Swedish data primarily refer to category 2a road surfaces while the Danish data refer to category 1 surfaces. In the last 10 years in Sweden there has been a trend towards category 2a surfaces in order to reduce the wear by studded tyres. There is a possibility that the noise levels have increased. However, the number of measurement locations and vehicles has not been sufficient to allow for any firm conclusions.

A.1 Danish source data (Primary data base)

These data are given on the following 3 pages starting with category 1 and then followed by category 2 and 3.

Speed,±2,5 km/h	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155
No of samples	64	139	218	196	195	145	130	98	100	152	195	164	146	127	117	143	123	83	75	49	28	24	14	12	5	3
25	83,7	85,4	88,7	88,2	89,9	87,8	86,6	86,7	86,0	87,1	89,5	90,5	92,8	90,1	91,3	91,3	94,1	93,1	95,2	96,7	92,6	94,6	96,5	97,7	99,2	95,0
32	84,9	87,8	86,6	89,9	91,6	89,8	90,1	90,6	87,8	87,8	87,9	89,0	91,3	90,0	91,9	92,4	94,2	92,9	94,5	97,3	96,0	97,9	96,9	97,6	101,3	98,3
40	89,8	92,6	90,9	91,0	92,8	90,9	90,6	89,2	87,8	87,7	88,4	88,6	91,1	90,1	91,6	92,1	92,7	92,9	95,3	95,4	94,9	95,5	95,3	95,7	96,9	93,5
50	95,3	92,7	94,9	96,0	100,7	96,8	96,2	93,7	87,9	87,9	89,6	88,5	90,5	90,0	91,9	92,9	93,2	93,4	94,2	95,3	95,0	95,2	95,0	95,9	96,7	94,4
63	97,4	94,0	97,0	97,7	99,3	100,2	100,5	97,8	96,9	94,0	92,3	90,7	93,4	91,7	95,4	94,7	94,9	95,6	96,2	96,2	97,9	97,6	96,7	98,0	98,5	96,9
80	90,7	91,2	93,3	93,9	98,6	96,6	98,0	96,6	97,4	96,2	96,3	96,4	96,0	95,2	95,8	95,7	95,7	96,3	97,1	98,0	98,2	98,4	98,0	99,2	97,8	98,5
100	84,0	86,9	87,8	88,1	91,9	94,0	92,1	89,4	92,2	92,7	91,8	93,2	96,5	96,9	97,7	97,6	97,5	97,0	97,8	98,4	96,4	97,4	97,2	98,9	99,0	99,7
125	82,8	85,2	85,9	87,5	90,5	89,4	89,2	87,0	89,3	87,0	87,4	89,5	91,9	93,4	94,4	96,1	96,9	96,4	97,6	98,8	97,6	99,0	99,5	100,8	101,9	99,4
160	80,8	82,3	83,9	84,9	87,1	87,7	88,5	86,3	89,1	88,1	88,6	90,8	91,7	91,5	92,8	93,1	94,9	94,8	95,7	95,7	96,0	100,6	98,1	100,0	100,8	103,3
200	79,1	81,8	84,2	83,2	85,1	85,8	86,4	86,1	87,7	87,9	88,2	90,2	91,5	91,7	92,2	93,7	93,3	94,0	94,5	95,4	95,4	96,3	96,7	97,5	98,2	101,4
250	80,9	80,9	82,7	83,1	84,7	85,3	86,3	86,0	88,9	88,0	88,8	90,3	90,9	91,6	92,6	93,7	93,8	94,0	94,4	95,7	94,8	96,0	96,0	97,0	97,6	97,2
315	79,0	80,7	81,8	82,8	83,6	84,6	85,5	85,1	87,6	87,2	88,1	89,6	90,5	91,0	92,5	93,4	93,1	93,6	94,4	94,8	94,8	96,2	96,0	96,0	97,8	97,0
400	77,5	79,5	81,5	82,5	83,4	84,5	85,0	85,1	86,9	87,1	87,9	89,4	90,6	90,8	92,7	93,5	92,7	93,4	94,2	94,8	95,0	95,9	95,6	96,5	96,8	96,8
500	77,8	79,7	82,2	83,9	85,5	86,8	87,5	88,2	88,8	89,0	89,6	90,8	92,2	92,3	93,6	94,4	94,0	94,7	95,0	95,9	96,9	96,7	96,6	97,2	97,2	97,3
630	78,8	80,6	82,9	84,5	86,3	87,8	88,9	90,2	91,1	91,3	91,7	92,5	94,0	93,9	95,5	95,9	95,4	96,4	96,1	97,1	96,5	97,4	97,1	97,9	97,7	97,6
800	79,1	81,3	83,5	85,6	87,5	89,1	89,9	91,1	92,7	93,1	94,1	95,3	96,8	96,9	98,4	98,8	98,3	99,3	98,8	99,3	98,9	99,7	98,6	100,1	99,4	99,5
1000	80,1	82,9	84,9	87,3	89,3	90,9	92,0	92,9	94,4	95,5	96,4	98,3	99,8	100,0	101,4	102,1	101,6	102,8	102,2	103,1	102,9	103,0	102,7	104,1	102,7	103,8
1250	79,9	82,2	84,2	86,7	88,5	90,1	91,5	92,7	94,1	95,4	96,3	98,3	99,7	100,1	101,7	102,4	102,1	103,1	103,1	103,8	103,9	103,4	103,7	105,0	104,2	106,7
1600	80,1	81,6	83,7	85,9	87,9	89,5	90,9	92,1	93,9	95,3	96,3	97,7	99,4	99,9	101,3	102,0	101,5	102,5	102,6	103,2	103,1	103,0	103,4	104,3	104,0	105,2
2000	78,1	80,1	81,9	84,2	86,0	87,7	89,4	90,5	92,4	93,8	94,7	96,2	97,9	98,5	99,8	100,4	99,9	100,9	101,2	101,6	101,4	101,6	101,6	102,5	102,6	103,3
2500	75,8	78,1	79,9	82,0	83,8	85,3	87,6	88,8	90,3	91,4	92,0	93,6	94,9	95,4	96,6	97,2	97,1	97,7	98,3	98,9	98,5	98,9	98,9	99,9	100,0	101,6
3150	74,9	76,4	77,9	79,7	81,5	83,0	85,3	86,1	87,6	88,7	89,4	91,1	92,5	93,0	94,1	95,0	95,0	95,5	96,1	96,6	96,1	96,9	96,9	98,0	98,4	99,9
4000	73,7	75,5	76,4	77,6	79,1	80,6	82,7	84,1	85,4	86,3	86,9	88,6	90,1	90,7	91,8	92,7	92,7	93,2	93,7	94,3	93,9	95,0	94,8	95,4	96,3	97,3
5000	71,7	73,6	74,2	75,1	76,5	77,9	79,9	81,6	83,0	83,8	84,3	86,1	87,6	88,2	89,3	90,2	90,2	90,6	91,0	91,8	90,8	92,6	91,7	92,5	93,3	94,7
6300	69,9	71,8	72,7	73,3	74,4	75,5	77,4	79,3	81,0	82,0	82,6	84,2	85,5	86,1	87,1	88,1	88,1	88,4	88,8	89,5	88,4	90,5	89,4	90,4	91,5	92,9
8000	68,4	70,1	71,2	71,7	72,4	73,4	75,7	76,9	78,9	79,6	80,2	82,0	83,3	84,0	85,0	86,2	86,2	86,5	87,2	87,8	86,5	88,9	87,9	89,4	90,0	91,5
10000	67,0	68,5	69,8	70,2	70,5	71,1	73,5	74,6	76,6	76,8	77,7	79,2	80,9	81,6	82,6	83,9	84,2	84,4	85,4	86,1	84,9	87,3	86,8	87,7	89,0	90,1
A	89,2	91,1	93,0	95,1	96,9	98,4	99,8	100,9	102,4	103,5	104,3	105,9	107,5	107,9	109,3	109,9	109,6	110,5	110,5	111,2	111,0	111,2	111,2	112,3	111,9	113,3

Speed,±2,5 km/	30,0	35,0	40,0	45,0	50,0	55,0	60,0	65,0	70,0	75,0	80,0	85,0	90,0	95,0	100,0	105,0	110,0	115,0
No of samples	12,0	22,0	37,0	37,0	33,0	23,0	23,0	16,0	40,0	34,0	52,0	51,0	31,0	7,0	5,0	4,0	2,0	2,0
25	89,8	91,1	95,9	97,7	96,5	93,4	97,2	101,2	96,5	97,0	97,5	100,0	103,0	99,2	101,1	101,2	102,0	102,6
32	95,5	92,5	97,5	95,0	94,8	95,0	96,1	95,7	94,2	98,4	97,6	98,9	101,0	99,4	104,3	98,5	103,7	101,9
40	93,2	92,0	95,5	100,1	95,4	96,7	104,0	93,2	95,9	96,3	97,6	98,1	100,1	101,7	99,6	99,2	97,4	100,6
50	100,8	101,6	98,3	99,8	100,0	103,7	96,8	99,2	95,4	95,3	98,2	97,9	100,0	98,8	97,0	101,1	96,6	101,2
63	97,4	106,5	103,9	101,4	102,2	102,6	105,0	107,0	98,9	101,0	99,6	103,6	104,1	99,7	98,9	101,0	97,6	100,0
80	96,9	96,2	100,4	102,3	101,3	100,7	103,6	105,0	101,5	108,0	103,7	104,0	105,4	105,6	103,3	100,0	100,4	101,7
100	90,6	92,5	94,3	94,1	94,5	96,3	93,3	99,2	99,7	103,0	102,6	105,5	103,1	102,4	100,4	101,8	106,1	104,2
125	91,1	96,3	99,9	93,9	95,0	94,6	97,4	96,5	96,5	97,0	98,4	100,3	100,2	98,7	99,6	104,1	98,3	100,6
160	90,8	91,5	95,7	95,3	95,2	93,8	94,2	95,3	95,8	97,6	97,5	98,9	98,0	98,4	97,3	101,2	98,5	99,3
200	88,6	93,1	96,2	96,9	99,1	98,1	95,1	95,5	95,3	98,6	96,9	98,4	98,1	98,5	96,8	99,2	100,6	100,0
250	86,7	89,9	92,8	93,5	94,4	97,4	101,1	101,6	99,0	99,2	99,1	99,1	99,0	99,2	98,3	98,4	97,7	99,1
315	88,5	90,8	93,8	93,4	93,3	94,7	95,6	100,2	99,8	102,6	100,8	103,2	101,6	98,9	100,1	98,9	99,2	97,4
400	90,1	91,8	93,8	95,7	96,0	98,2	100,6	100,8	99,1	101,7	101,6	102,2	103,4	102,6	102,2	100,8	99,4	100,1
500	88,5	90,3	92,2	94,1	94,5	96,6	99,0	99,3	97,5	100,2	100,0	100,7	101,8	101,0	100,6	99,3	97,9	98,5
630	88,4	90,7	92,5	95,6	95,1	96,6	97,6	99,1	99,2	100,7	101,4	102,1	102,9	101,2	102,0	101,0	98,0	101,7
800	88,7	90,0	92,6	95,7	95,5	96,8	97,4	99,2	98,8	100,1	101,3	103,5	103,6	103,1	103,7	104,5	101,7	105,2
1000	89,8	90,8	91,5	94,4	95,0	96,8	98,1	98,8	98,9	101,2	101,4	102,7	103,3	103,4	105,6	106,2	102,8	103,9
1250	90,0	89,5	90,6	93,1	93,8	96,0	97,1	98,3	98,2	100,1	100,8	101,9	102,7	103,6	105,0	104,6	101,6	102,7
1600	89,2	88,2	89,3	92,3	92,6	94,1	95,2	97,2	97,6	99,3	99,9	101,1	101,9	103,9	104,6	103,3	103,6	103,6
2000	86,8	86,6	88,3	91,6	91,1	92,2	93,6	94,8	95,8	97,7	97,9	99,1	100,1	102,3	102,5	101,9	100,8	101,5
2500	86,0	85,1	86,9	89,8	89,3	90,7	92,1	94,0	94,0	95,5	95,7	96,7	98,0	99,7	99,6	100,0	98,1	99,4
3150	84,3	83,6	85,1	88,3	88,2	88,3	89,2	91,0	92,2	93,2	93,6	94,6	95,7	97,9	97,1	97,5	96,6	98,2
4000	82,9	82,8	84,0	86,8	85,8	86,8	87,8	90,1	90,0	91,5	91,9	92,7	94,0	95,7	95,0	96,0	94,1	96,1
5000	81,3	81,6	82,5	85,3	84,3	84,8	85,7	88,3	88,1	89,5	90,1	90,7	91,9	93,3	92,6	94,2	91,9	95,6
6300	80,3	81,6	80,6	83,1	82,1	82,8	84,0	87,2	86,5	88,4	88,9	89,3	90,1	91,2	90,6	92,3	89,8	92,4
8000	79,5	79,3	78,6	81,2	81,2	81,2	82,7	85,8	84,5	86,8	87,1	87,5	88,3	89,5	88,6	91,7	89,1	92,7
10000	78,8	78,7	78,3	80,7	80,6	80,9	82,3	85,0	83,0	85,5	85,9	86,3	86,6	86,8	87,0	88,8	86,7	90,8
A-weighted	98,7	99,3	100,9	103,5	103,6	105,1	106,4	107,8	107,6	109,4	109,8	111,0	111,7	112,4	113,1	113,0	111,1	112,4

v		30,0	35,0	40,0	45,0	50,0	55,0	60,0	65,0	70,0	75,0	80,0	85,0	90,0	95,0	100,0
n		6,0	16,0	27,0	26,0	49,0	37,0	18,0	15,0	45,0	76,0	100,0	94,0	51,0	3,0	4,0
	25	93,3	93,6	96,5	96,3	99,7	98,7	95,1	96,3	97,3	99,5	99,0	105,1	104,0	99,1	100,7
	32	94,8	93,7	96,2	99,0	98,0	97,4	96,2	96,3	96,3	97,5	98,7	102,9	102,0	99,3	99,1
	40	98,1	96,4	100,5	110,5	99,8	101,1	94,7	99,2	97,9	98,2	98,4	101,9	101,3	99,3	99,7
	50	106,3	107,8	102,1	106,3	106,5	102,2	100,2	103,2	101,7	99,5	103,3	102,9	103,4	100,6	97,6
	63	106,2	103,1	107,8	105,6	110,0	106,2	117,1	107,7	106,6	106,0	107,8	105,9	106,4	102,4	100,5
	80	96,9	97,0	100,4	101,5	106,3	106,1	108,9	108,6	109,3	105,9	107,1	106,8	107,3	102,2	107,4
	100	95,2	96,7	97,7	98,1	100,4	97,9	97,7	99,5	102,6	106,7	102,0	103,6	105,6	106,1	101,8
	125	104,1	97,2	99,5	98,2	98,6	99,5	98,2	99,2	101,5	100,4	100,5	102,3	101,8	102,1	100,3
	160	98,3	96,7	99,8	98,7	99,8	100,4	97,2	100,7	100,1	99,9	98,7	100,1	101,0	102,1	98,4
	200	93,1	94,4	97,5	101,8	101,6	106,8	102,5	100,8	103,2	100,6	100,0	99,5	100,9	102,0	103,3
	250	94,7	93,5	96,1	97,4	97,1	100,2	101,9	102,4	104,6	102,8	101,0	101,7	101,2	108,1	102,0
	315	93,9	95,0	97,3	95,8	97,2	98,3	99,4	100,8	104,2	105,4	106,1	106,5	103,3	104,9	102,7
	400	93,4	93,7	97,2	96,7	98,1	98,2	100,9	100,4	102,7	102,9	103,6	106,2	104,2	107,0	101,4
	500	93,7	95,1	99,1	97,6	99,4	100,2	103,8	101,4	103,8	102,6	104,1	104,7	106,6	107,6	107,2
	630	93,4	93,9	97,0	96,8	98,6	99,7	101,5	102,7	104,0	104,3	105,6	106,3	107,7	107,4	107,3
	800	93,4	93,1	95,8	96,4	98,2	99,5	101,9	103,2	103,3	104,1	105,6	106,4	108,2	107,3	107,5
	1000	94,8	92,7	95,7	96,5	97,7	99,6	101,7	102,1	102,8	103,6	104,7	104,7	106,9	107,3	106,4
	1250	93,1	91,1	93,7	94,8	96,0	97,8	99,7	100,5	101,3	102,4	103,3	103,5	105,3	107,1	103,6
	1600	91,2	90,0	92,4	92,8	94,9	96,5	98,2	99,3	100,0	101,1	102,2	102,5	104,3	104,9	103,3
	2000	90,3	89,4	91,7	92,3	93,5	95,0	97,0	98,4	98,0	99,3	100,4	100,6	102,9	102,7	101,2
	2500	88,2	87,1	88,8	89,1	90,5	92,8	95,5	96,0	95,5	96,6	97,5	97,8	99,8	99,4	98,5
	3150	86,5	85,1	87,0	87,1	88,8	90,3	92,7	93,5	93,4	94,5	95,3	95,9	97,9	97,3	96,9
	4000	86,2	84,1	86,2	86,0	87,9	89,4	91,9	92,8	92,3	92,7	93,8	94,0	96,1	95,9	94,9
	5000	84,7	82,7	84,3	85,3	85,7	87,3	89,9	90,7	90,3	90,6	92,0	91,7	93,7	93,5	93,6
	6300	84,4	81,1	83,2	83,3	84,0	84,9	87,4	88,5	89,2	89,0	90,6	89,9	91,1	92,0	91,8
	8000	83,2	78,9	81,8	82,2	82,4	84,1	85,8	87,4	87,2	87,0	88,4	88,0	88,4	90,8	89,0
	10000	82,1	77,9	81,6	80,2	81,4	81,9	84,8	86,6	85,5	84,9	86,3	86,5	86,1	86,8	86,2
		102,7	101,8	104,6	104,8	106,3	107,8	109,9	110,4	111,2	111,8	112,9	113,4	114,9	115,4	114,1

A.2 Some Swedish measurements

The road surface is of type 2a (predominantly) and the road temperature is 18 - 40ºC.

Category 1a – Sound power levels

Speed (+ - 2.5) km/h	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**
# of samples	4	12	28	15	30	42	71	72	95	84	79	57	49	33	24	15
Road Temp. Range (C) 18 ~ 40																
25	93,60	91,60	89,60	92,7	93,7	94	94,6	95,4	93,3	95,2	93,2	92	96,7	94,7	90,3	96,2
31,5	92,30	89,90	88,30	91,8	92,2	92,3	92,6	94,8	91,4	93,2	90,9	90,9	93,7	92,1	90,8	95,6
40	94,40	93,10	91,30	89,5	89,8	90,6	90,6	93,7	90,2	90,6	89,2	89,7	92,4	91,2	90,5	93,2
50	94,20	95,70	95,80	95,4	92,6	94,1	92,8	94,3	89,2	90,1	89,3	89,1	91	90,4	92,1	92,8
63	93,00	93,50	92,80	91,9	94,2	95	95,4	98,3	95,8	93,3	91,9	92,2	92,2	90,8	93,2	93,8
80	86,50	85,30	92,60	88,3	88,9	90,7	93,3	97,9	94,3	96,3	94,7	95	95,6	94,7	95	94,7
100	85,90	85,40	87,60	86,7	86,2	85,4	90,8	91,3	89,5	96,4	92,6	94,5	94,5	95,2	97,4	99,8
125	82,20	83,40	84,80	83,5	84,6	85,9	87,7	89,4	87,4	90,1	90,3	92,1	92,5	97,3	94,2	97,1
160	79,60	83,20	86,50	84	86	87	87,3	91,5	87,5	91,8	90,3	92	91,8	93,2	93,5	94,6
200	80,50	82,70	82,90	83,2	86,1	86,3	87,9	91,4	88,4	90,9	90,8	92,6	92,1	93,8	93,7	95,7
250	83,80	84,30	85,70	85,4	87,9	87,6	88,7	91,1	89,7	91,8	92	93,1	93	95,1	94,3	95,6
315	81,80	83,90	84,40	84,8	87	87	88,1	91,6	89,4	91,7	91,4	92,5	93	93,8	94,2	94,5
400	81,00	82,20	83,50	84,5	86,7	86,5	88,2	89,8	89,3	91,2	91,4	92,4	93	94	94	95
500	81,90	83,60	85,50	87,1	89,2	89,4	90,4	92	91,8	93,2	93,9	94,7	95,3	95,8	96,2	96,9
630	83,40	84,80	86,20	88,3	90,9	91,2	92,4	93,8	94,1	95,5	96,3	97,1	97,9	98,2	98,9	99,1
800	86,60	87,40	88,40	89,6	93,4	93	94,7	95,9	96,3	98	99,4	100,1	101,2	101,7	102,7	103
1000	88,10	89,30	90,80	92,5	95,6	96,1	97,5	98,5	99,3	101,1	102,5	103,6	104,2	105,4	106,3	106,5
1250	85,70	88,10	89,70	90,7	94,2	94,9	96,3	97,3	98,4	100,1	101,3	102,4	103	104,2	104,8	104,9
1600	83,70	86,10	87,50	87,8	91	91,8	93	94,2	95	96,4	97,6	98,5	99,2	100,8	101,7	100,9
2000	81,00	83,90	84,90	85,1	88	89,1	89,9	91,5	92,2	93,5	94,5	95,9	96,1	97,5	98,4	98
2500	77,80	80,80	82,00	82	84,6	85,6	86,4	88,3	88,6	90,1	91	92,3	92,5	93,7	94,1	94,4
3150	74,30	76,80	78,60	78,9	81,7	82,5	83,1	85	85,4	86,9	87,7	89	89,1	90,2	90,2	90,7
4000	72,50	74,50	76,40	76,8	79,5	80,4	81,1	83,1	83,3	84,9	85,4	87,1	87	87,9	87,9	88,6
5000	70,20	72,20	74,20	74,8	77,8	78,8	79,2	81,7	81,2	82,9	83,3	84,8	84,9	85,7	85,9	86,6
6300	67,60	69,50	71,90	73,3	76	76,7	77,3	80,1	79,8	81	81,4	82,6	82,9	83,6	84,1	84,5
8000	65,40	67,40	70,10	72,8	75,4	75,5	76,1	80,3	79	80,1	80,2	81,5	81,8	82,3	83,4	83,5
10000	62,90	65,20	67,50	70,3	72,4	73	73,4	78,5	76,2	77,6	77,7	79	79,4	79,8	81,3	81,5
A-weighted	93,90	95,60	97,10	98,1	101,3	101,8	103,1	104,3	105	106,6	107,8	108,8	108	110,6	111,4	111,4

Category 1b

Speed (+ - 2.5) km/h	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**
# of samples	3	3	6	7	9	14	7	3	8	1	1	0	1
Road Temp. Range (C) 18 ~ 40													
25	94,4	87,9	89,4	99	94,2	92	96,1	99,4	95,1	89,5	96,7		94,8
31,5	90,3	86,4	88,4	96,7	92,4	91,7	94,2	98,2	92,9	87,4	95,7		98,7
40	92,2	87,2	88,6	95,3	90,7	91,2	92	95,8	92,4	91,2	98		99,9
50	92,8	86,3	100,3	94,6	90,4	95,2	91,1	95,3	93,1	96,1	100,6		98,2
63	104,7	89,3	94,6	103,9	95,6	96,5	91,8	97,5	93,4	91,1	97,8		100
80	97,2	94,3	91,2	98,1	100,2	99	102,8	96,1	96,5	93,2	98,1		100,1
100	86,4	87,1	86,8	104,5	96,3	98,6	95,4	106	94,6	99,7	98,8		101,2
125	89,2	90,7	89,2	96,1	91,3	93,8	89,5	94	92,9	98,1	100,2		99,1
160	87,5	85,2	88,5	99	91,1	92,5	94,2	93,4	93,2	94,2	97,1		98,4
200	85,9	87,6	86,9	95	90,3	92,4	90,8	94,7	92,8	93,4	97,9		97,1
250	86,7	89,8	88,3	94,6	90,9	93,4	91,6	93,9	93,2	91,2	97,7		98,6
315	90,9	86,5	88	97,2	91,7	92,7	91,5	94,4	92,5	91,3	97,9		98,3
400	86,8	86,8	87,8	94,3	92,3	94,3	92,2	99,3	93,1	92,4	97,1		97,3
500	89,4	89,6	90,3	95,9	93,8	96,2	94,5	97,6	95,9	94,1	101,2		99,2
630	94,5	90,7	92,1	96,7	95,1	98,2	96,1	98,1	98,9	98,9	103,2		101,2
800	91	92,7	94,5	98,6	97,9	101,4	99,3	102,2	102,1	101,2	106,7		105,4
1000	91,1	94,6	96,9	99,7	99,1	101,7	101	103,7	103,1	102,3	107,5		106,6
1250	90,6	93,2	96	97,2	97,8	99,9	100,1	100,9	100,8	98,9	106,3		105,4
1600	88,7	91,9	93,4	95,1	95,6	97,4	97,9	98,3	97,9	96,9	104,2		104,6
2000	86,1	90,7	90,1	92,5	92,8	94,9	94,5	96	95,6	94	101		101,6
2500	84,6	88,7	86,6	90	90	92,1	91,6	92,5	92,7	91,1	97,3		98,1
3150	81,9	86,9	83,5	88	87,1	89,7	88,4	89,7	90,2	87,7	94,1		94,6
4000	80,7	84,5	81,6	88,1	85,3	87,4	86,3	87,7	87,7	85,6	91,8		92,5
5000	79,2	81,9	79,9	85,1	83,6	86,1	85,3	86,9	86,2	84,1	89,9		92
6300	77,9	79,2	77,9	83,5	82,5	85,2	84,2	86,9	84,7	82,4	88		90,9
8000	76,9	75,7	76,6	83,4	81,8	84,9	83,2	87	83,7	81,1	86,5		87,9
10000	74,8	73,9	73,6	79,3	78,3	82	80,2	84,1	81,1	79,1	85,1		85,1
A-weighted	99,5	101,6	102,9	106	105,4	107,9	107,2	109,2	108,7	107,6	113,7		113,2

Category 2b

Speed (+ - 2.5) km/h	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
# of samples	2	4	10	9	19	14	12	8	5	2	1
Road Temp. Range (C) 18 ~ 40											
25	90,2	97,3	100,7	98,7	99,3	95,8	98,2	96,8	101,9	98,1	101,0
31,5	89,3	97,4	99,9	99,9	98,1	96,6	103,9	97,5	100,9	98,4	99,8
40	88,0	101,1	96,5	103,3	99,3	103,1	102,5	100,6	100,1	95,6	100,2
50	88,9	93,8	97,0	99,8	104,0	99,9	102,2	97,2	100,1	104,4	101,3
63	106,4	103,3	108,4	109,6	108,5	99,9	99,4	96,7	100,3	100,0	102,9
80	108,5	100,7	101,7	106,4	109,4	105,7	103,7	104,7	101,1	100,4	101,3
100	95,0	96,5	94,8	97,7	102,3	103,5	102,9	103,0	100,3	102,5	101,2
125	95,1	97,0	95,5	98,4	96,9	97,2	100,0	100,0	102,2	98,6	102,2
160	95,2	96,2	95,0	96,9	96,1	96,0	99,5	100,3	99,2	97,5	100,4
200	95,0	97,0	97,6	98,8	97,6	97,5	99,9	99,3	99,8	98,6	99,2
250	96,8	95,6	97,4	97,2	96,7	96,8	99,1	100,0	101,8	97,5	97,5
315	96,0	96,6	99,4	98,8	98,1	98,6	102,4	103,2	99,1	98,4	96,5
400	94,2	96,2	96,8	98,5	100,0	100,9	101,8	100,0	102,5	98,8	96,8
500	95,5	96,1	97,5	98,6	98,4	100,0	101,0	102,0	103,4	101,1	97,7
630	98,8	98,9	99,8	101,8	101,2	102,2	103,7	104,3	104,8	104,3	99,9
800	98,8	99,3	100,7	102,4	102,7	103,7	105,6	105,1	106,4	106,4	106,5
1000	98,8	98,8	101,1	102,7	101,8	102,9	105,4	104,9	106,7	107,2	107,6
1250	96,9	96,8	99,8	100,7	99,9	101,4	102,9	102,8	104,8	106,9	105,8
1600	94,1	94,3	97,2	99,6	98,4	99,6	100,9	100,6	102,5	102,7	103,4
2000	91,7	91,4	95,8	97,4	95,4	96,7	97,9	97,4	99,5	98,9	98,9
2500	89,4	89,4	92,2	92,6	92,4	94,0	94,7	94,8	97,2	96,1	96,4
3150	85,5	87,9	87,6	89,7	89,6	90,5	91,4	91,8	94,0	92,5	93,9
4000	84,3	86,1	86,5	88,3	88,6	89,3	90,6	90,4	92,2	91,2	91,3
5000	83,2	85,7	86,7	88,1	87,7	88,5	90,2	89,7	91,0	89,0	90,1
6300	83,1	85,9	84,3	87,0	86,3	87,2	89,6	89,7	89,7	86,9	89,8
8000	82,1	87,6	85,5	87,9	87,5	88,2	91,0	89,9	90,5	85,8	90,0
10000	78,6	85,9	82,1	85,3	84,9	85,0	89,2	87,4	88,2	83,1	85,7
A-weighted	105,7	106	108,1	109,6	109	110,2	111,9	111,7	113,2	113,4	113,1

Category 3b

Speed (+ - 5) km/h	**50**	**60**	**70**	**80**	**90**	**100**
# of samples	4	6	15	11	1	1
Road Temp. Range (C) 18 ~ 40						
25	91,4	97,8	98,7	100,0	97,7	93,7
31,5	91,5	96,7	97,6	97,3	105,3	95,1
40	92,0	101,9	100,7	98,1	100,5	97,3
50	89,3	97,4	101,6	100,3	103,6	95,5
63	106,9	105,5	102,7	101,0	101,9	98,1
80	96,5	103,9	108,6	108,6	112,7	104,6
100	92,4	97,6	101,3	101,0	114,9	102,5
125	94,8	100,1	98,1	101,5	105,0	96,6
160	93,3	98,2	96,4	100,5	104,3	97,5
200	95,8	99,8	98,3	101,2	107,6	97,4
250	94,0	104,2	97,4	99,9	102,4	96,9
315	93,9	101,1	98,6	99,8	102,0	97,2
400	95,4	99,7	99,2	101,9	102,1	96,4
500	98,1	101,3	99,3	103,3	105,1	99,2
630	100,4	103,3	102,7	105,7	105,7	102,4
800	99,9	103,0	104,2	107,3	107,2	108,2
1000	98,7	102,9	103,7	106,5	107,2	109,8
1250	97,0	103,1	101,4	104,3	105,2	107,0
1600	95,3	100,9	100,1	102,0	102,5	103,1
2000	92,0	97,6	96,8	98,8	99,4	98,3
2500	88,4	94,6	92,4	95,0	96,8	95,4
3150	85,2	92,3	89,1	91,5	93,6	93,1
4000	84,1	89,8	88,1	90,3	91,6	90,5
5000	82,5	88,4	86,8	88,9	90,3	88,6
6300	79,8	86,9	85,0	88,7	89,5	87,8
8000	79,1	86,7	87,3	89,5	88,6	86,6
10000	76,9	85,0	83,8	89,4	84,0	83,9
A-weighted	106,3	110,9	110,4	113,1	113,9	114,4

Category 3c + 3d

Speed (+ - 5) km/h	**60**	**70**	**80**	**90**
# of samples	14	35	29	4
Road Temp. Range (C) 18 ~ 40				
25	97,5	97,7	99,6	102,1
31,5	95,2	97,3	99,8	101,3
40	98,9	98,0	100,2	103,8
50	100,7	100,2	102,8	103,2
63	103,6	106,4	106,2	104,0
80	101,7	102,2	106,1	106,2
100	97,3	103,4	105,1	108,0
125	97,4	100,0	102,2	104,6
160	98,4	98,9	100,9	102,9
200	99,0	101,2	101,6	103,9
250	99,3	100,3	100,9	102,4
315	100,5	101,3	101,1	101,4
400	100,3	101,4	104,1	104,1
500	100,8	103,1	105,2	106,2
630	103,7	105,8	108,7	109,5
800	105,0	106,7	110,1	111,2
1000	105,0	106,3	109,5	111,1
1250	102,4	104,0	107,1	108,5
1600	100,1	101,4	104,6	105,9
2000	96,7	97,9	101,0	102,5
2500	92,8	94,7	97,8	99,5
3150	89,3	91,3	94,3	95,6
4000	87,7	89,4	92,9	93,2
5000	86,5	87,5	91,8	91,5
6300	84,9	86,3	92,4	91,6
8000	85,5	87,2	93,7	92,8
10000	83,1	85,2	92,0	89,5
A-weighted	111,2	112,8	115,9	117,1

Annex B: Calculation of mirror source position and point of reflection

B1 Mirror source position

B1.1 General

The position of the source, S, the receiver R and the reflecting surface are given :

(XS,YS,ZS) are the (x,y,z)-coordinates of the source position,
(XR,YR,ZR) are the (x,y,z)-coordinates of the receiver position,
(XA,YA,ZA) are the (x,y,z)-coordinates of the first upper corner (A) of the of the reflecting surface.
(XB,YB,ZB) are the (x,y,z)- coordinates of the second upper corner (B) of the reflecting surface.
The position of the *mirror source S'* given by the (x,y,z)-coordinates, is calculated by :

$$XS' = XS-2(XS-(YS+XS/F1-YA+F1\cdot XA)/(F1+1/F1))$$
$$YS' =YS+(XS-XS')/F1$$
$$ZS' = ZS$$

Key :

$F1 = (YB-YA)/(XB-XA+\Delta)$
Δ = is a small number supplied to avoid numerical problems (f.ex. 10^{-6}).

B1.2 Application to city streets

The receiver position R is in front of the façade A' – B'. The façade on the opposite side is denoted A – B. The current source point (sub-source j, position i) is denoted S_{ij}.

The first order mirror source S_{ij1} regarding the reflection surface A – B is calculated using the coordinates of the source S_{ij}.
The first order mirror source S_{ij12} regarding the reflection surface A' – B' is calculated using the coordinates of the source S_{ij}.
The second order mirror source S_{ij2} regarding the reflection surface A – B is calculated using the coordinates of the mirror source S_{ij12}.

The coordinates of the facades A - B and A' - B' are not critical provided they represent the surface of the respective facades.

B1.3 Application to side streets:

For the selected sources S_{ij} which contribute to 1.order reflections, and the selected sources S_{ij} which contribute to the 2.order reflections, the procedure is analogous to that described in Section A1.2, provided the corresponding terminology is applied.

B2 Point of reflection

B2.1 General

The position of the *point of reflection T* in the reflecting surface (or its extension) given by the (x,y,z)- coordinates, is calculated by:

$$XT = (YS'-YA+XA\cdot F1-XS'\cdot F2)/(F1-F2)$$
$$YT = (YA-F1\cdot(XA-XT))$$
$$ZT = ZS+(ZR-ZS)\cdot F3/F4$$

Key :
$F2 = (YR-YS')/(XR-XS'+\Delta)$
$F3 = ((XS'-XT)^2 + (YS'-YT)^2)^{0.5}$
$F4 = ((XS'-XR)^2 + (YS'-YR)^2)^{0.5}$

The definition of the coordinates is given in section B1.1.

B2.2 Application to city streets:

The receiver position R is in front of the façade A' – B'. The façade on the opposite side is denoted A – B. The first and second order mirror sources S_{ij1}, S_{ij12} and S_{ij2} are calculated according to section A1.2.
The first order reflection point T_{ij1} in the façade A – B is calculated using the coordinates of the mirror source S_{ij1}, facade A – B and receiver R.
The second order reflection point T_{ij2} in the façade A – B is calculated using the coordinates of the mirror source S_{ij2}, facade A – B and receiver R.
The first order reflection point T_{ij12} in the façade A' – B' is calculated using the coordinates of the mirror source S_{ij12}, facade A' – B' and receiver T_{ij2}.

B2.3 Application to side streets

For the selected sources S_{ij} which contribute to 1.order reflections, and the selected sources S_{ij} which contribute to 2.order reflections, the procedure is analogous to that described in Section A2.2, provided the corresponding terminology is applied.