Adaptation and revision of the interim noise computation methods for the purpose of strategic noise mapping – Mid-Term Report

Work Package 2

RAILWAY NOISE (Dutch method)

Task 2.1 Description of the calculation method

Part 1 - Translation

Reference:	B4-3040/2001/329750/MAR/C1
Commissioned by:	EUROPEAN COMMISSION DG Environment
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Wölfel project:	Z070/01

This mid-term report encompasses 114 pages.

1 Introduction

1.1 General considerations

The present document is a non-contextual translation of the Dutch computation method RMR 2002, a revised and adapted version of RMR 1996.

For this reason, some minor modifications to the content have been made:

- chapters 7 and 8 concerning measurement methods have not been translated, because they are outside the scope of this task
- chapter 9: reference to the European parameters for noise mapping has been added: Lden, Lday, Lnight, Levening.

chapter 10: additional information and application ; only those parts relevant to the task have been translated and have been incorporated in the relevant chapters.

In addition, all references to Dutch legislation and Dutch situations have been removed.

1.2 CONTENT OF ORIGINAL (Dutch) DOCUMENT

MEASUREMENT METHODS FOR DETERMINING NOISE EMISSION

GLOBAL EMISSION VALUE: dB(A)

EMISSION VALUE PER OCTAVE BAND

GLOBAL A-WEIGHTED CALCULATION METHOD: ARM 1

OCTAVE BAND CALCULATION METHOD: ORM

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MEASUREMENT METHODS

ACOUSTICAL SURVEY AND REPORTING

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ADDITIONAL INFORMATION & APPLICATION NOTES

CHAPTER 1.
MEASUREMENT METHODS FOR DETERMINING NOISE EMISSION

INTRODUCTION

The emission characteristics of a railway vehicle or a track are to be determined by measurement.

These characteristics are already available for:

- all railway vehicles: all Dutch vehicles and other European vehicles circulating on Dutch tracks;
- all tracks: typical characteristics of Dutch tracks.

Two procedures are given hereafter to determine the characteristics:

- procedure A: a simplified procedure to determine if a railway vehicle belongs to a category for which the characteristics already exist;
- procedure B: a more elaborate method to determine the emission characteristics directly.

An additional procedure C has been added to determine acoustical characteristics of track construction (sleepers, ballast bed, …).

PROCEDURE A: SIMPLIFIED METHOD

The use of simplified methods with reference to existing categories provides a fast allocation method. This method can also be used for new (to be constructed) vehicles on which it is impossible to carry out measurements. This can be done mainly based on the type of propulsion system (diesel, electric, hydraulic) and the brake system (disc or block).

Existing categories

Prior to the calculation of the *equivalent continuous sound pressure level* all vehicles that use an identified railway line and follow the appropriate service guidelines are divided into the following railway vehicles categories. These are primarily differentiated based on drive unit and wheel brake system.

Category 1: Block braked passenger trains

- Exclusively electric passenger trains with cast-iron blocks including the corresponding locomotive, as well as trains from the 1964 series and passenger trains belonging to Deutsche Bahn (DB);
- Electrical motor mail vehicle.

Category 2: Disc braked and block braked passenger trains

- Electric passenger trains primarily with disc brakes and additional cast-iron blocks, including the corresponding locomotives, as for example the InterCity-Material of the IMC-III, ICR and DDM-1 types,
- Passenger trains belonging to the French Railway Society (SNCF) and the Trans Europe Express (TEE);
- Electric locomotives such as those from the 1100, 1200, 1300, 1500, 1600 and 1700 series of the Belgian Railway Society (B).

Category 3: Disc braked passenger trains

Exclusively passenger trains with disc brakes and engine noise, as for example the municipal material (SGM, sprinter).

Category 4: Block braked freight trains

All types of freight trains with cast-iron block brakes.

Category 5: Block braked diesel trains

- Exclusively diesel-electrically driven passenger trains with cast-iron block brakes including the corresponding locomotive as for example the DE I, DE II, DE III types;
- Diesel – electric locomotives as for example the locomotives of the 2200/2300 and 2400/2500 series.

Category 6: Diesel trains with disc brakes

Exclusively diesel–hydraulically driven passenger trains with disc brakes and engine noise.

Category 7: Disc braked urban subway and rapid tram trains

Urban subway and rapid tram trains.

Category 8: Disc braked InterCity and slow trains

- Exclusively electric passenger trains with disc brakes including the corresponding locomotives, as for example InterCities of the ICM-IV, IRM and SM90 types;
- Electric passenger trains with primarily disc brakes and additional sinter and ABEX cast-iron blocks including the corresponding locomotives as for example the InterCities of the ICM-III and DDM-2/3 types.

Category 9: Disc braked and block braked high speed trains

Electric trains with primarily disc brakes and additional cast-iron blocks on the engine car, as for example the TGV-PBA or Thylas (HLSSouth) types.

Category 10: Provisionally reserved for high speed trains of the ICE-3 (M) (HST East) type

Vehicles not mentioned here are allocated to the next appropriate category based on their drive unit, wheel brake system or maximum speed.

Figure 1.1 shows side views of the various categories and outlines the number of individual units.

One unit of any given category determines the sound emission. In the case of drawn trains, the locomotives and carriages or railway cars act as individual units. In the case of integrated trains, the connected sections should be regarded as one unit.

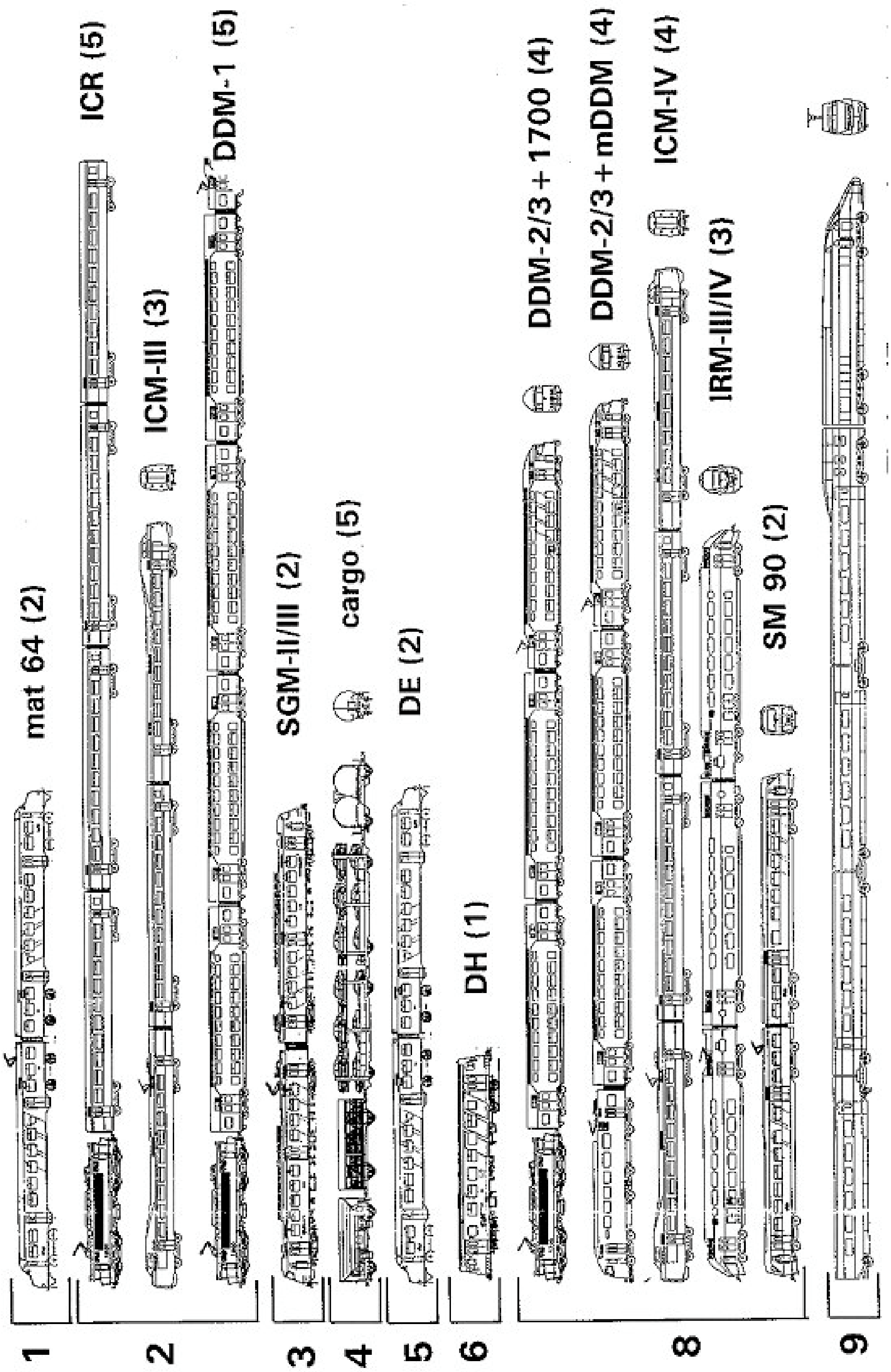
mat 64 (2)
ICR (5)
ICM-III (3)
DDM-1 (5)
SGM-II/III (2)
cargo (5)
DE (2)
DH (1)
DDM-2/3 + 1700 (4)
DDM-2/3 + mDDM (4)
ICM-IV (4)
IRM-III/IV (3)
SM 90 (2)
1
2
3
4
5
6
8
9

Figure 1.1. Train categories for the calculation and measurement guidelines for rail transport noise: type (number of units)

Assignment to an existing train category and track access test

The track type for procedure A is specified as UIC 54 rails on mono block or duo block concrete sleepers with rail pads with static stiffness of 300-500 kN/mm at 60 kN preload (e.g. 4.5 mm cork rubber pads).

The measurement equipment required is a sound level meter with octave spectrum analysis and a rail roughness measuring device (unless the site roughness is already known) according to the procedure described in pr EN ISO 3095, January 2001.

The condition of the railway vehicle should fulfil the description of § 1.2. The measurement location, measurement conditions and measurement equipment should fulfil the description of § 1.2.

The A-weighted equivalent sound pressure level in octave bands $L_{pAeq,tot,i}$ is measured at one cross-section, at 7.5 m for the track centre line and 1.2 m above the rail surface. A number of passages is performed as indicated in table 1.1.

subject	speed
Powered vehicles with traction noise	20, 40, 60, 100 km/h and if applicable 140, 250 km/h and maximum speed
Unpowered rolling stock	100 km/h and if applicable 140, 250 km/h and maximum speed

Table 1.1: Passage speeds for procedure A1.

The measured noise level $L_{pAtotij}$ will be increased by L_{diff}, with:

a. $$L_{diff} = 1 + Y \qquad (1.1)$$

- *for speeds at which rolling noise is predominant and the vehicles do not have cast-iron brake blocks that work on the wheel surface* (this means all disc braked, sinter block and composite block braked rolling stock);

where Y is a roughness correction determined as follows:

- determine the frequency f_{pmax} at which the octave spectrum of the A-weighted sound pressure level at 100 km/h is highest;
- determine the corresponding wavelength λ_{fpmax} at 100 km/h (27.8 m/s):

$$\lambda_{f_{p\max}} = \frac{27.8}{f_{p\max}} \tag{1.2}$$

- determine the correction term Y from the difference between the measured rail roughness $L_{r,tr}(\lambda)$ and the national average rail roughness, averaging over 4 third-octave bands either side of λ_{fpmax}:

$$Y = \frac{1}{9}\sum_{k=-4}^{4}\left(L_{r,tr,nl}(\lambda_k) - L_{r,tr}(\lambda_k)\right) \tag{1.3}$$

where k — third octave band index for the rail roughness L_r, and $k = 0$ for $\lambda_k = \lambda_{fpmax}$.

b.

$$L_{diff} = 1 \tag{1.4}$$

- *for speeds at which traction noise or aerodynamic noise predominate;*
- *for speeds at which rolling noise is predominant and the vehicles have cast-iron brake blocks that work on the wheel surface.*

The sound level $L_{pAeq,tot,i}$ is compared per octave band with the curves predicted by the calculation scheme for corresponding conditions. The vehicle type may be assigned to a train category if the measured curve incremented by L_{diff} is below the predicted curve in all octave bands and at all speeds.

Small isolated peaks above the level per octave band are acceptable, as long as the dB(A) noise level at a distance of 25 m and a height of 3.5 m above BS, corrected according to the octave band noise propagation calculation method, is not higher than the calculated noise level on location.

Reporting

The reporting consists of the items in § 1.2.8, except for items 6, 15, 16 & 17. The measured sound pressure level in octaves for all measured speeds will be presented and compared with the spectral data of the category into which the material will be assigned. The rail roughness addition L_{diff} is stated, along with a reason for the choice of L_{diff}.

Reporting

The reporting consists of the items 1, 2, 3, 5, 7, 8, 9, 10, 11, 13 & 14 sub § 1.2.8, except the vibration data.

PROCEDURE B: COMPREHENSIVE METHODS FOR CHARACTERISATION OF VEHICLE AND TRACK

Introduction

This procedure describes methods of obtaining emission data for rail vehicles that do not necessarily fit into an existing national train category. A so-called 'free category' is introduced to which any vehicle type can be assigned, if its noise emission is determined according to this procedure. The data obtained in this manner take into account the separation of vehicle, the track sound radiation and the wheel and track roughness. Also the type of source – traction, rolling and aerodynamic noise – and source heights are taken into account.

Measurement conditions and configuration

The measurements are carried out as mentioned in § 3 in accordance with pr EN ISO 3095, with the following additions and exceptions.

Number and condition of rail vehicles

The vehicles selected for the test must satisfy the following. For unpowered vehicles, at least four vehicles are used in the test. For powered vehicles and units, at least two units are tested. If the vehicles are part of a train with other rolling stock, the effect of adjacent vehicles must be taken into account and avoided if possible. The vehicles must have run at least 1 000 km under normal operating conditions, with the braking system in operation. Wheels must be free of damage such as flats. The vehicles should be empty and all doors and windows must be closed. Powered vehicles should have a characteristic traction load. Auxiliary equipment must be in operation during the measurements.

Tracks

A test track is selected that is not only smooth, but also radiates as little noise as possible for a given roughness excitation (low response). Such a track may be specially built over a limited length of about 100 m and could be any of the following alternatives.

Continuous concrete slab track of at least 20 cm thick, without sleepers, with ballast or other absorbent covering material and:

a. rails cast into the concrete (rail foot on one side of the rail);

b. continuously supported rails with a small rail cross-section and stiff embedding material;
c. discrete supports with stiff railpads;
d. discrete supports with soft railpads and rail dampers that are effective below 1 kHz.

A less effective, but economic alternative is ballasted track with concrete sleepers, rail dampers that are effective below 1 kHz and optimised railpads.

It is advisable to select the quietest track currently available. Track response can be characterised using the method given in § 1.3. The best track will have a low track response function $L_{Hpv,tr}$.

The consequence of using a normal track is that the vehicle noise contribution can be overestimated below about 1 kHz. This however is acceptable if the measurement data is used for emission predictions on tracks that are noisier than the test track.

The condition of the track should be good over the whole test length plus 25 m at each end: no rail joints, welds, rail damage, loose sleepers or rail attachments which can all cause impact noise.

Acoustical environment

The measurement site must offer free field conditions. The soil must be free of obstacles and there must be no reflecting objects such as walls, building, slopes or bridges nearby. The track must be in a flat environment. There should not be any obstacles near the microphones that may distort the noise field, e.g. persons. The observer must not influence the noise measurement by his position. The soil between track and measurement microphone must - as far as possible - be free of strongly absorbing surfaces such as snow, high grass, other tracks or strongly reflecting surfaces such as water. A ballast layer of 10 cm or more is allowed. The soil is described in the measurement report.

Meteorological conditions and background noise level

Measurements must only be carried out at wind speeds below 5 m/s and without precipitation (rain, snow, …). The track must be dry and free of snow or ice. Temperature, humidity, air pressure, wind speed and wind direction should be registered during the measurements and stated in the report.

Background noise that might influence the measurements must be reduced to a minimum. The measured sound pressure level must be at least 10 dB above the background level in all octave and 1/3 octave bands.

Measurement positions and quantities

The microphone is positioned at M1, which is at a distance of 7.5 m and height of 1.2 m as indicated in figure 1.2. If sources above axle height (0.5 m) are present, the microphone is positioned at a height of 3.5 m, at M2. Measurements are performed preferably at three cross-sections about 10-25 metres apart; the results will be averaged, or at one cross-section with three averages. The time signal is registered as an equivalent unweighted octave spectrum and third-octave spectrum, total A-weighted and unweighted levels. The measurement time T is also registered, which is the passage time including the 10 dB-down flanks. For a group of wagons within a train, the buffer-to-buffer time (speed/length) is taken.

Besides sound pressure, railhead vertical vibration is also measured by attaching an accelerometer to the centre of the railfoot, or underneath the railhead. This is done at the same three cross-sections, close to a sleeper. The vibration is registered as a time signal, and as an unweighted third octave equivalent level spectrum L_{veq} during measurement time T. Vibration levels should be checked on both rails to determine differences. If the difference in overall rail vibration level of both rails is less than 2 dB, it is sufficient to measure the rail vibration on the rail on the side of the microphone. Otherwise, the signals from both rails are averaged. Special care must be taken to avoid signal distortion and cut-off as high vibration levels of up to 10-100 m/s^2 can occur. Accelerometers must be firmly attached and should not be sensitive to moisture.

The train speed is measured and must be within 5 km/h of the nominal speed for speeds below 100 km/h and 10 km/h for speeds above 100 km/h.

For vehicles with traction or aerodynamic sources at heights of 2 m and above, such as locomotives and high speed trains, additional measurements are carried out at 4 m from the track axis at a height of 1.2 and 4.5 m (±0.2 m); only at one cross-section.

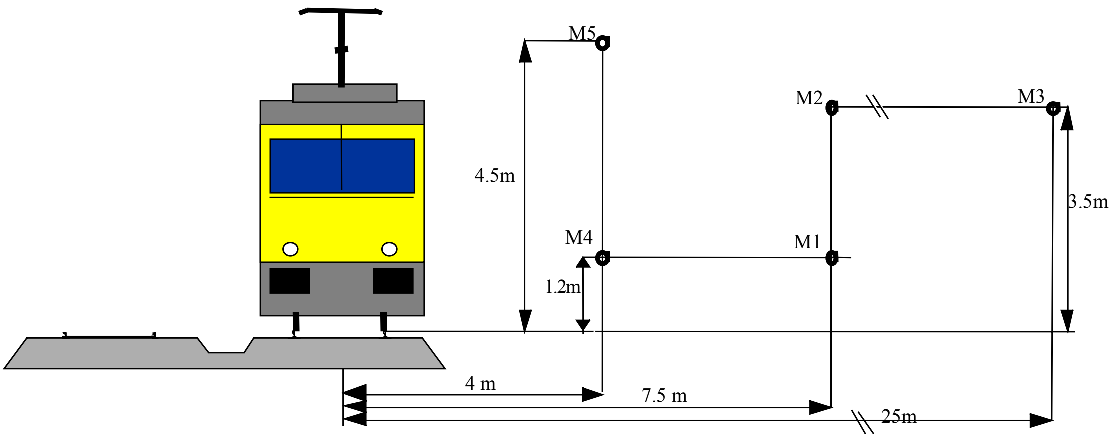

Figure 1.2. Microphone positions for passage measurements as in pr EN ISO 3095, with additional positions for source height measurement at 4 m distance.

Measurement equipment

Equipment required for the measurements consists of microphones, vibration recorders with measurement chain, together with a multi-channel 1/3 octave and octave analyser and multi-channel recorder. The vibration recorders should be moisture proof and need to be firmly attached. The measurement chains need to be well adjusted with regard to possible overload of the measured signal.

All equipment, including analysers, cables and recorders must satisfy the requirements for "type I" equipment according to EN 61260. Microphones must be calibrated with nearly flat frequency characteristic in the free field. The 1/3 octave filters and octave filters must satisfy EN 61260. The microphones must be equipped with a windshield. Before and after every measurement session, the measurement chains of microphones and vibration recorders are calibrated using calibrators with an accuracy of at least ±0.3 dB (class I according HD 556 S1), at one or more frequencies in the relevant frequency domain. Measurement results must be rejected if there is a difference of more than 0.5 dB in the calibration. The frequency domain lies between 20 and 10 000 Hz. The calibrators must be checked at least once a year according to HD 556 S1. The instrumentation must be checked at least twice a year according to EN 61260. The date of the last calibration is stated in the report.

Definitions

V	Train speed [m/s]
f	Frequency [Hz]
L(f)	Level in 1/3-octave band with frequency f, according to EN ISO 266
L_i	Level in octave band i where i = 1, 2, …, 8 with band frequencies 63, 125, 250, 500, 1k, 2k, 4k, 8kHz
L_{ptot}	Total sound pressure level of a passage [dB re 2.10^{-5} Pa]
L_{pveh}	Sound pressure level of a passage, vehicle contribution [dB re 2.10^{-5} Pa]
L_{pveh1}	Sound pressure level of a passage due to vehicle traction noise (incl. auxiliary equipment) [dB re 2.10^{-5} Pa]
L_{pveh2}	Sound pressure level of a passage due to vehicle rolling noise [dB re 2.10^{-5} Pa]
L_{pveh3}	Sound pressure level of a passage due to vehicle aerodynamic noise [dB re 2.10^{-5} Pa]
L_{ptr}	Sound pressure level of a passage, track contribution [dB re 2.10^{-5} Pa]
L_{rtot}	Total roughness level of a passage [dB re 2.10^{-5} Pa]

L_{pveh}	Sound pressure level of a passage, vehicle contribution [dB re 2.10^{-5} Pa]
L_{pveh1}	Sound pressure level of a passage due to vehicle traction noise (incl. auxiliary equipment) [dB re 2.10^{-5} Pa]
L_{pveh2}	Sound pressure level of a passage due to vehicle rolling noise [dB re 2.10^{-5} Pa]
L_{pveh3}	Sound pressure level of a passage due to vehicle aerodynamic noise [dB re 2.10^{-5} Pa]
L_{ptr}	Sound pressure level of a passage, track contribution [dB re 2.10^{-5} Pa]
L_{rtot}	Total roughness level of wheel and rail [dB re 1 micron]
L_{rveh}	Average vehicle (wheel) roughness [dB re 1 micron]
L_{rtr}	Average rail roughness of the track [dB re 1 micron]
$L_{rtr,nat}$	National average rail roughness [dB re 1 micron]
$L_{Hpr,veh}$	Response of roughness to sound pressure at the microphone position due to sound radiation from the vehicle [dB re 20 Pa/m]
$L_{Hpr,tr}$	Response of roughness to sound pressure at the microphone position due to sound radiation from the track [dB re 20 Pa/m]
$L_{Hpv,tr}$	Track vibration response, transfer function from vertical railhead vibration to sound pressure at the microphone position due to sound radiation from the track [dB re 20 Pa/m/s]
L_v	Velocity level of vertical railhead vibration [dB re 10^{-6} m/s]
D_s	Vertical spatial decay of the track [dB/m]
E	Emission index or emission term [dB(A)]
$\oplus$	Operator for energy summation: $x \oplus y = 10\lg\left(10^{x/10} + 10^{y/10}\right)$

Traction noise

If the vehicles concerned are powered, e.g. locomotives, EMU's or DMU's, the traction noise is measured separately at low speeds. Traction noise also includes the noise from auxiliary equipment.

For locomotives, measurements are performed at full acceleration from standstill to 60 km/h. Other types of powered vehicle are measured at constant speed at 20, 40 and 60 km/h. It should be verified that traction noise is indeed greater than rolling noise at the mentioned speeds. If this is not the case, this should be reported and the data at the speeds concerned should be eliminated.

Locomotives are measured at two track cross-sections, at 5 m and 20 m ahead of the starting position (front buffers). The speed at the passing of the two cross-sections is registered. The measurement time lasts from the start until the rear of the vehicle has passed the second cross-section by 20 m.

Other types of powered vehicle are measured at a single cross-section.

The equivalent sound pressure level in octave bands due to traction, $L_{pveh1,i}$ is measured at a distance of 7.5 m and a height of 1.2 m. The measurements are averaged over the passages at each speed. A spectrum as a function of train speed is derived by interpolation or a regression line between the measurement points:

$$L_{pveh1,i} = x_1(i) + y_1(i) \lg V \qquad 1.5$$

where $L_{pveh1,i}$ equivalent sound pressure level at 7.5 m due to traction, in octave band i;
$x_1(i)$ & $y_1(i)$ constants per octave band number describing the linear relation between l gV and the sound pressure level.

This spectrum for traction noise may be extrapolated to higher speeds, as long as rolling noise and/or aerodynamic noise are not included. It is permissible to use a higher order approximation for the curve if necessary.

Source height determination

Traction noise sources are allocated to heights 0.5 m, 2 m or 4 m above the rail surface.

Traction sources at axle level height are allocated to 0.5 m. Vehicle traction sources above floor level are allocated to 2 m or 4 m.

The source height can be determined by detecting the highest octave band level of the two microphones at 4 m or closer (M4 and M5 in figure 1.2). Antenna or alternative techniques may be applied to obtain more detailed information.

The traction noise level can be given a single source height or distributed over several source heights, depending on the information available. The energy sum of all of the sources must correspond to the overall traction noise $L_{pveh1,i}$.

For example, a diesel locomotive with a roof exhaust as the major source could result in:

- $L_{pveh1,i}$ (4 m) $= L_{pveh1,i}$
- $L_{pveh1,i}$ (2 m) $= 0$
- $L_{pveh1,i}$ (0.5 m) $= 0$

and an EMU with powered bogies could result in:

- $L_{pveh1,i}$ (4 m) $= 0$
- $L_{pveh1,i}$ (2 m) $= 0$

- $L_{pveh1,i}$ (0.5 m) $= L_{pveh1,i}$

Rolling noise

For the determination of the total rolling noise, the following four parameters are required:

- wheel roughness;
- transmission of wheel to noise;
- rail roughness;
- transmission of rail via track (sleepers and ballast bed).

This is described in § 1.2.4.1 to § 1.2.4.7.

Measurements are carried out at speeds of 20, 40, 60, 100, 140, 200 & 250 km/h and the maximum speed of the considered vehicle. Measurements are carried out at 7.5 m off axis and at a height of 1.2±0.2 m.

If traction noise or other sources are dominating, the test should also be performed with switched off traction, either by pulling the vehicles or by switching off during the passage.

Rail roughness (measurement or existing data)

Rail roughness L_{rtr} at the measurement site is measured in third octaves according to the procedure in pr EN ISO 3095: 2001, or is already known from a measurement no longer than 6 months previously. Rail roughness is measured as a function of wavelength. This can be converted to a function of frequency and train speed according to § 1.3.2.

Total roughness (measurement)

The total roughness L_{rtot} is derived from the vertical railhead vibration $L_v(f)$ in third octaves at a given train speed, as described in § 1.3.1. An accelerometer is attached vertically underneath the centre of the rail foot or underneath the railhead, close to a sleeper (§ 1.2.2.5).

Vehicle wheel roughness (calculation)

The average vehicle wheel roughness in third octaves $L_{r,veh}$ is derived from the total roughness L_{rtot}, and the measured rail roughness L_{rtr}:

$$L_{rveh}(f) = 10\lg\left(10^{L_{rtot}(f)/10} - 10^{L_{rtr}(f)/10}\right) \quad 1.6$$

If $L_{rtot}(f) - L_{rtr}(f) < 1$, per frequency band, then the wheel roughness is set at:

$$L_{rveh}(f) = L_{rtr}(f) - 5 \qquad 1.7$$

Note: the vehicle wheel roughness is overestimated if the site rail roughness exceeds the pr EN ISO 3095 limit curve.

It is also possible to measure the wheel roughness directly, using similar techniques as for rail roughness measurement, i.e. contact transducers on parallel lines. At least three wheels per vehicle are measured, each on three parallel lines on the wheel surface, one in the middle and one at 10 mm on either side. Averaging is done over three wheel revolutions. All these roughness data are averaged as roughness spectra to obtain an average for the whole vehicle.

Total roughness on a national average track (calculation)

The total roughness (energy sum of wheel and rail roughness) on a ‘national average’ track $L_{rtot,nat}$ is determined from the average national rail roughness $L_{rtr,nat}(f)$ and the wheel roughness of the test vehicles $L_{rveh}(f)$:

$$L_{rtot,nat} = L_{rtr,nat}(f) \oplus L_{rveh}(f) \qquad 1.8$$

with $\oplus$ energy summation.

The ‘average national rail roughness’ $L_{r,tr,nat}(f)$ is shown in § 1.3.3. It is a quantity for the whole network, and can potentially change over time.

Track and vehicle contributions to rolling noise (measurement and calculation)

The track vibration response function $L_{Hpv,tr}$ in third octaves is determined according to § 1.3.4. The procedure consists of measuring sound pressure and railhead vibration during the passage of a reference vehicle. A reference vehicle has a low vehicle response, i.e. the contribution from the sound radiation of the vehicle is much lower than that of the track. The track noise level L_{ptr} is calculated from the track vibration response and from the rail vibration due to the test vehicle:

$$L_{ptr}(f) = L_{Hpv,tr}(f) + L_v(f) \qquad 1.9$$

(all in third octaves and unweighted).

The vehicle noise L_{veh} is calculated from the energy difference between the total sound pressure level and the track noise level:

$$L_{pveh}(f) = 10\lg\left(10^{L_{ptot}(f)/10} - 10^{L_{ptr}(f)/10}\right) \quad 1.10$$

and if $L_{ptot}(f) - L_{ptr}(f) < 1$, per frequency band,

$$L_{pveh}(f) = L_{ptot}(f) - 5 \quad 1.11$$

Track response and vehicle response functions (calculation)

The track response function $L_{Hpr,tr}$ (due to roughness) is calculated from:

$$L_{Hpr,tr}(f) = L_{ptr}(f) - L_{rtot}(f) \quad 1.12$$

And the vehicle response function $L_{Hpr,veh}$ (due to roughness) is calculated from:

$$L_{Hpr,veh}(f) = L_{pveh}(f) - L_{rtot}(f). \quad 1.13$$

(all in third octaves and unweighted).

Sound radiation of vehicle and track (calculation)

The rolling noise emission of the vehicle results from:

$$L_{pveh2,nat}(f) = L_{Hpr,veh}(f) + L_{rtot,nat}(f) \quad 1.14$$

and from the vehicle:

$$L_{ptr,nat}(f) = L_{Hpr,tr}(f) + L_{rtot,nat}(f) \quad 1.15$$

Note: these two equations depend on the train speed, as the total roughness is expressed as a function of frequency. This is explained in § 1.3.

Both of these spectra are converted from third octave bands to octave bands with

$$L(f_c) = L(f_-) \oplus L(f_c) \oplus L(f_+) \qquad 1.16$$

where f_c octave band frequencies
f_-, f_+ adjacent third octave band frequencies
$\oplus$ energy summation

For the rolling noise octave spectra this results in $L_{pveh2,i}$ and $L_{ptr,i}$. The vehicle rolling noise is allocated to source height 0.5 m, the track noise to height 0 m.

Aerodynamic noise

Measurement conditions

If the vehicle(s) under test:

- have a maximum speed of more than 200 km/h,

or

- produce aerodynamic noise noticeably higher (more than 1 dB(A)) than the combined rolling noise and traction noise at high speeds,

then the aerodynamic noise is measured.

The second point can be checked as follows. The traction noise and rolling noise are extrapolated from the data obtained in § 1.2.3 & 1.2.4 as unweighted octave spectra. If the measured sound pressure (of all sources) at high speeds (above 200 km/h) exceeds the combined traction and rolling noise by more than 1 dB, aerodynamic noise is to be measured.

Aerodynamic noise is measured at two or more speeds at which it is known to be dominant, and preferably with a difference of at least 50 km/h, e.g. 250 km/h and 300 km/h.

The equivalent sound pressure level in octave bands due to aerodynamic sources, $L_{pveh3,i}$ is measured at a distance of 7.5 m and a height of 1.2 m. The measurements are averaged over the passages at each speed. A spectrum as function of train speed is derived by interpolation or a regression line between the measurement points:

$$L_{pveh3,i} = x_3(i) + y_3(i) \lg V \qquad 1.17$$

where $L_{pveh3,i}$ equivalent sound pressure level at 7.5 m due to aerodynamic sources, in octave band i;

$x_3(i)$, $y_3(i)$ constants per octave band describing the linear relation between lg V and the sound pressure level.

This spectrum for aerodynamic noise may be extrapolated to lower speeds. A higher order approximation for the curve can be used if necessary.

Source height determination

The aerodynamic noise level can be given a source height or be distributed over several source heights, depending on the information available. The energy sum of all the sources must correspond to the overall traction noise $L_{pveh3,i}$.

Aerodynamic noise sources are allocated to heights 0.5 m, 2 m, 4 m or 5 m above the rail surface. The source height can be determined by detecting the highest octave band level of the two microphones at a distance of 4 m or closer (M4 and M5 in figure 1.2):

- $L_{pn,12,i}$: 1.2 m above BS and 4 m from the centre line;
- $L_{pn45,i}$: 4.5 m above BS and 4 m from the centre line.

Some additional rules are given here for determining source height using the two microphones M4 and M5 with levels $L_{pn12,i}$ and $L_{pn45,i}$.

If $L_{pn45,i} > L_{pn12,i} + 1$, the source height is:

- h = 5 m if the vehicle has an extra high structure, e.g. a high cabin;
- h = 5 m if a pantograph is present and if the level at 4.5 m reduces by *more* than 1 dB when the pantograph is retracted;
- h = 4 m if a pantograph is present and if the level at 4.5 m reduces by *less* than 1 dB when the pantograph is retracted;
- h = 4 m if no pantograph is present.

If $L_{pn45,i} \leq L_{pn12,i} + 1$ the source height is:

- h = 2 m.

These rules provide a ‘worst case’ source height, as for example the bogies may be dominant aerodynamic sources. This would require further research by antenna or alternative techniques. Such techniques may be applied if available.

If the pantograph noise were dominant, the result would be:

- $L_{pveh3,i}$ (5 m) = $L_{pveh3,i}$
- $L_{pveh3,i}$ (4 m) = 0
- $L_{pveh3,i}$ (2 m) = 0
- $L_{pveh3,i}$ (0.5 m) = 0.

If the aerodynamic noise sources were equally distributed over the source heights, the result would be:

- $L_{pveh3,i}$ (5 m) = $L_{pveh3,i}$ - 6
- $L_{pveh3,i}$ (4 m) = $L_{pveh3,i}$ - 6
- $L_{pveh3,i}$ (2 m) = $L_{pveh3,i}$ - 6
- $L_{pveh3,i}$ (0.5 m) = $L_{pveh3,i}$ - 6.

Braking noise

Braking noise $L_{pbr,i}$ is determined by measuring the equivalent sound pressure level in octaves during a braking passage of the vehicle(s). This is performed at four speeds, if applicable: 25, 50, 100 km/h and the maximum speed, each with one passage at a single cross-section. The speed measured may not differ more than 20% from the speeds defined above. The microphone position is at a distance of 7.5 m and height of 1.2 m above the rail surface.

If the measured levels do not exceed the levels at constant speed by more than 1 dB, then braking noise is neglected:

$$L_{pbr,i} = 0$$

Otherwise, the braking noise is determined as follows.

Least squares regression lines are determined, describing the braking noise spectrum as a function of train speed:

$$L_{pbr,i} = x_{br}(i) + y_{br}(i) \lg V \qquad 1.18$$

where $L_{pbr,i}$ sound pressure level at 7.5 m due to braking noise (equivalent octave spectrum);
i octave band number;
$x_{br}(i)$ & $y_{br}(i)$ constants per octave band describing the linear relation between the sound level and lg V. This may also be defined piecewise.

Braking noise is allocated to source height h = 0.5 m.

Calculation of emission terms

For dB(A) emission numbers

For the benefit of dB(A) emission numbers as described in § 2.1 of this document, partial contributions $L_{pvch,1,i'}$, $L_{pveh2,i'}$, & $L_{ptr,i}$ are defined at one source height, namely BS (0.25 m). The dB(A) values are determined from the octave band data. The emission term for non braking material for category $E_{nr,x}$ results from:

$$E_{nr,x} = \frac{10}{g}\left[\sum_{i-1}^{8} 10^{L_{sum,nr}/10}\right] \qquad 1.19$$

with $$L_{sum,nr,i} = L_{ptr,nl,i} \oplus L_{pveh1,i} \oplus L_{pveh3,i} \oplus L_{pveh2,nl,i} + L_{m,i} - 39 \qquad 1.20$$

The emission term for braking material for category $E_{r,x}$ is defined from:

$$E_{r,x} = \frac{10}{g}\left[\sum_{i-1}^{8} 10^{L_{sum,r}/10}\right] \qquad 1.21$$

with $$L_{sum,r,i} = \max\{L_{ptr,nl,i} \oplus L_{pveh1,i} \oplus L_{pvh3,i} \oplus L_{pveh2,nl,i}; L_{prem,i}\} + L_{m,i} - 39 \qquad 1.22$$

The emission terms for non-braking and braking material are calculated for the total speed domain relevant to the material. These values are then fitted to the following linear relation, using the method of smallest quadrants:

$$E_{nr,x} = a_x + b_x \lg v \qquad 1.23$$

$$E_{r,x} = a_{r,x} + b_{r,x} \lg v \qquad 1.24$$

Values a_x, b_x, $a_{r,x}$ and $b_{r,x}$ are then used to determine the emission number according § 2.1 of this document.

The linear fitting against speed may cause deviations of the measured values. If these deviations are larger than 1 dB(A), the speed domain should be split up. For every partial domain the values a_x, b_x, $a_{r,x}$ and $b_{r,x}$ are defined.

Emission characteristics in octave bands

The noise emission terms for the 'free category', indexed with x are derived from sound pressure contributions of the various sources in octave bands $L_{ptr,i}$, $L_{pveh1,i}$, $L_{pveh2,i}$, $L_{pveh3,i}$ at the relevant source heights as derived in sections B2-B4. These are all a function of train speed.

For constant speed, the emission terms are derived as:

$$E_{i,x}\,(0\text{ m})' = L_{ptr,nat,i} + L_{m,i} \qquad 1.25$$

$$E_{i,x}\,(0.5\text{ m})' = L_{pveh1,i}(0.5\text{ m}) \oplus L_{pveh3,i}(0.5\text{ m}) \oplus L_{pveh2,nat,i} + L_{m,i} \qquad 1.26$$

$$E_{i,x}(2\text{ m})' = L_{pveh1,i}(2\text{ m}) \oplus L_{pveh3,i}(2\text{ m}) + L_{m,i} \qquad 1.27$$

$$E_{i,x}(4\text{ m})' = L_{pveh1,i}(4\text{ m}) \oplus L_{pveh3,i}(4\text{ m}) + L_{m,i} \qquad 1.28$$

$$E_{i,x}(5\text{ m})' = L_{pveh3,i}(5\text{ m}) + L_{m,i} \qquad 1.29$$

For braking conditions, the emission terms are:

$$E_{br,i,x}(0\text{ m})' = L_{ptr,nat,i} + L_{m,i} \qquad 1.30$$

$$E_{br,i,x}(0.5\text{ m})' = \max\{L_{pveh1,i}(0.5\text{ m}) \oplus L_{pveh3,i}(0.5\text{ m}) \oplus L_{pveh2,nat,i}\,;\, L_{pbr,i}\,\} + L_{m,i} \qquad 1.31$$

$$E_{br,i,x}(2\text{ m})' = L_{pveh1,i}(2\text{ m}) \oplus L_{pveh3,i}(2\text{ m}) + L_{m,i} \qquad 1.32$$

$$E_{br,i,x}(4\text{ m})' = L_{pveh1,i}(4\text{ m}) \oplus L_{pveh3,i}(4\text{ m}) + L_{m,i} \qquad 1.33$$

$$E_{br,i,x}(5\text{ m})' = L_{pveh3,i}(5\text{ m}) + L_{m,i} \qquad 1.34$$

with:
- $E_{i,x}(h)$ = emission term in octave bands at source height h, constant speed [dB(A)];
- $E_{br,i,x}(h)$ = emission term in octave bands at source height h, for braking conditions [dB(A)];
- $\oplus$ = symbol for energy summation;
- $L_{m,i}$ = conversion term from passage sound pressure to emission term [dB] :

$$L_{m,i} = 10\lg(\frac{T}{3600}) - 10\lg n - \overline{\Delta L_i} + L_{fA,i} \qquad 1.35$$

- T — Passage time of the train or group of vehicles [s] (including –10 dB points, or buffer to buffer time for a group of wagons within a train);
- n — number of vehicles or wagons;

r	distance from the track centreline to the microphone [m];
ΔL_i	sound transmission attenuation [dB];
$L_{fA,i}$	A-weighting filter in octave bands [dB];

The emission terms for non-braking and braking material are calculated for the total speed domain relevant to the material. These values are then fitted to the following linear relation, using the method of smallest quadrants:

$$E_{nr,x} = a_x + b_x \lg v \qquad 1.36$$

Values a_x & b_x, are then used to determine the emission number according to tables 3.1.- 3.3 of this document, for braking as well as non-braking tests and for each octave band.

The linear fitting against speed may cause deviations of the measured values. If these deviations are larger than 1 dB(A), the speed domain needs to be split up. For every partial domain the values a_x, b_x, $a_{r,x}$ and $b_{r,x}$ are defined.

Test report

The following items are reported for measurement procedure B.

1. The nature of the tests.
2. Name and address of the organisation and staff performing the measurements.
3. Date and location of the measurements.
4. Description of the track: track type, fastener system, rail pad thickness, material, static stiffness, clip type, sleeper type, rail type, rail roughness according to pr EN ISO 3095.
5. Description of the site: surroundings, ground and vegetation, ambient temperature, air humidity, air pressure, wind speed and direction.
6. The track roughness response function $L_{Hpr,tr}(f)$ and/or the track vibration response function $L_{Hpv,tr}(f)$.
7. A list of the used measuring equipment and type and serial number of microphones and accelerometers, with the most recent calibration date.
8. The background noise level of the sound pressure as an octave spectrum and the A-weighted total Level.

9. Description of the vehicle(s) including the type and serial numbers used in the measurements; a statement that the measured vehicles are fully representative for all corresponding vehicles in service.
10. The running speeds and operating conditions during the measurements.
11. Description of any auxiliary equipment and its operating conditions during the measurements.
12. The positions of transducers such as microphones, accelerometers and triggering devices.
13. The measured sound pressure levels and vibration levels as overall levels and as third octave or octave spectra at the various positions and speeds.
14. The time history of the A-weighted sound pressure level and of the unweighted railhead velocity level.
15. As a function of train speed and in octave bands: the derived contributions for traction noise, rolling noise from the track, rolling noise from the vehicle, aerodynamic noise and the braking noise. The rolling noise is normalised to the average national rail roughness.
16. The derived wheel roughness and vehicle roughness response function $L_{Hpr,veh}(f)$ in third octaves.
17. The emission terms in octave bands and as a function of the train speed for the different source heights, if relevant.

MEASUREMENT METHODS FOR DETERMINING WHEEL AND RAIL CORRUGATION

Relation between vertical railhead vibration and total roughness

The total roughness, the energy sum of wheel and rail roughness, can be calculated from vertical railhead vibration using the following equation:

$$\begin{aligned} L_{rtot}(f) &= L_{veq}(f) + 10\lg\left(\frac{VTD(f)}{8.68}\right) + C_{23}(f) - 10\lg(2\pi f) \\ &= L_{vmax}(f) + C_{23}(f) - 10\lg(2\pi f) \end{aligned} \qquad 1.37$$

where	$L_{rtot}(f)$ =	total roughness spectrum in third octaves [dB re 10^{-6}m];
	$L_{veq}(f)$ =	equivalent vibration velocity spectrum in third octaves [dB re 10^{-6} m/s];
	$L_{vmax}(f)$ =	maximum vibration velocity spectrum in third octaves [dB re 10^{-6} m/s];
	V =	train speed [m/s];
	T =	passage time [s];
	$D_s(f)$ =	spectrum of the vertical spatial decay of the track [dB/m];
	$C_{23}(f)$ =	conversion spectrum for the contact filter and from roughness to contact point vibration (see [7]).

The spectrum $C_{23}(f)$ can be determined with the following expression:

$$C_{23}(f) = 10\lg\left\{\left\|\left(\frac{\frac{-f^2}{f_1^2} + 1 + jfD_1}{\frac{-f^2}{f_1^2} + 1 + jfD_2}\right)\left(\frac{1}{\frac{-f^2}{f_2^2} + 1 + \frac{jf}{f_2}}\right)\left(\frac{1}{\frac{-f^2}{V^2 f_3^2} + 1 + \frac{j\sqrt{2f}}{Vf_3}}\right)\right\|\right\} \qquad 1.38$$

with

$$D_1 = \frac{\Delta f}{f_1^2}\sqrt{10^{(R/10)}}$$

$$D_2 = \frac{\Delta f}{f_1^2}\frac{1}{\sqrt{10^{(R/10)}}}$$

where the following input values can be used for a standard Dutch track:

$R = -5{,}5$ dB
$\Delta f = 500$ Hz
$f_1 = 500$ Hz
$f_2 = 800$ Hz
$f_3 = 8$ Hz

According to equation 1.37 the roughness can be determined from the equivalent vibration level of the railhead $L_{veq}(f)$ and the spatial decay $D_s(f)$. Alternatively, it can be calculated from the vibration level peaks averaged over all wheels, $L_{vmax}(f)$. The latter method requires high signal resolution to reliably determine the peak values.

$L_r(V,f)$ - Roughness as a function of frequency, speed dependent

Roughness is usually given as a function of wavelength, $L_r(\lambda)$, independent of the train speed. This roughness is converted to a function of frequency $L_r(f)$, to allow for calculations in the frequency domain. It is then also a function of train speed. The roughness curve retains its shape, but shifts in horizontal direction with varying train speed.

The location of this curve is calculated using

$$L_r(V,f) = L_r(\lambda), \qquad 1.39$$

where $f = V/\lambda$

so for example, $L_r(\lambda=0.01\text{m}) = L_r(V=140 \text{ km/h}, f = 1250 \text{ Hz})$

For calculation, speed (v) is expressed in m/s.

Average rail roughness of the national network

For calculation purposes, the average rail roughness of the whole national network is used. This may be adjusted, as the network becomes smoother on average over the years. The national average rail roughness is designated $L_{rtr,nat}(\lambda)$, where λ is the wavelength in cm.

wave length [cm]	NL avg [-]
16	7.0
12.5	6.0
10	5.0
8	4.0
6.3	3.0
5	2.0
4	1.0
3.15	0.0
2.5	-1.0
2	-2.0
1.6	-3.0
1.25	-4.0
1	-5.0
0.8	-6.0
0.63	-7.0
0.5	-8.0
0.4	-9.0
0.315	-10.0
0.25	-11.0
0.2	-12.0
0.16	-13.0
0.13	-14.0
0.1	-15.0

Table 1.2 Example of conversion of a roughness spectrum from wavelength to frequency domain.

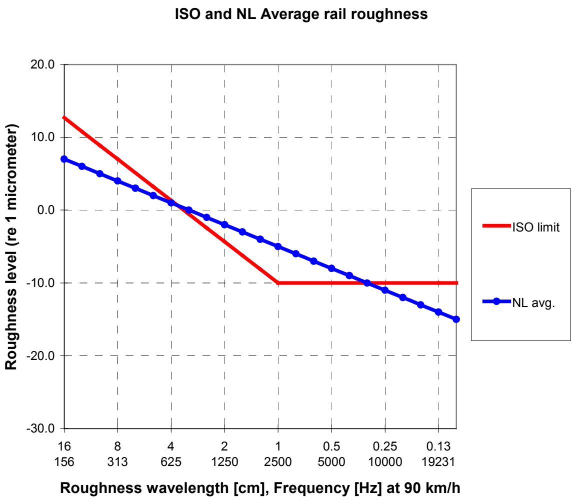

Figure 1.3 Average rail roughness of the Dutch rail network and the pr EN ISO 3095 limit curve for rail roughness at a test site.

Measurement of track response using a reference vehicle

The track vibration response $L_{Hpv,tr}(f)$ in third octaves is measured with 3-4 so-called reference vehicles. The main property of these vehicles is that they radiate substantially less sound (10-20 dB) than the track. Wagons with small massive wheels with 40 cm diameter or less and massive webs are suitable. The 'Rolling Highway' wagons (RoLa Truck transport wagons) used in the EU are an example. The wheels do not have to be very smooth but should be free of flats and excessive wear.

During the passage, the vertical railhead vibration and the sound pressure at 7.5 m are measured. The track vibration response $L_{Hpv,tr}(f)$ is the transfer function between the sound pressure and railhead vibration during the passage of the reference vehicles:

$$L_{Hpv,tr}(f) = L_{ptr,ref}(f) - L_{v,ref}(f) \qquad 1.40$$

where $L_{Hpv,tr}(f)$ track vibration response in third octaves from vertical railhead vibration to sound pressure at 7.5 m [dB re 20 Pa/m/s];
$L_{ptr,ref}(f)$ equivalent sound pressure level in third octaves at 7.5 m during passage of reference vehicles [dB re 2.10^{-5} Pa];
$L_{v,ref}(f)$ equivalent railhead vibration velocity level in third octaves during passage of reference vehicles [dB re 10^{-6} m/s].

This measurement must be performed at three cross-sections and at three speeds, over which an average is taken. The wheel and rail roughnesses are not relevant for this measurement, although extremely high roughness should be avoided.

Using the track vibration response, the sound radiation from the track can now be derived for any other test vehicle from the railhead vibration:

$$L_{ptr}(f) = L_{Hpv,tr}(f) + L_v(f) \qquad 1.41$$

where $L_{ptr}(f)$ equivalent sound pressure level due to track radiation in third octaves at 7.5 m during passage of test vehicle(s) [dB re 2.10^{-5} Pa];
$L_v(f)$ equivalent railhead vibration velocity level in third octaves during passage of test vehicle(s) [dB re 10^{-6} m/s].

ACCELERATION TEST

This test is for powered vehicles and corresponds to the description given in pr EN ISO 3095 § 6.2.2.

The track, measurement conditions and instrumentation have to be similar to procedure 1.1.2. The speed during passage should be between 40 and 60 km/h. It consists of the measurement of L_{pAFmax} of the accelerating vehicle at 7.5 m from the track centreline and at 1.2 m above the rail surface. If noise sources at a greater height are expected, an additional measurement at a height of 3.5 m is taken. The purpose of this test is to determine compliance with maximum noise limits for track access. This is primarily envisaged to restrict access for excessively noisy vehicles such as diesel locomotives of older design. An acceleration test was chosen to simulate average load conditions.

The reported data consists of all items listed in § 1.2.8, with the exception of 6, 15, 16 and 17. In addition, the measured sound pressure levels in octaves are reported for the applied speeds together with the spectrum predicted by the calculation scheme.

Vehicles with one traction unit

Measurements are carried out at the one cross section, 20 m in front of the vehicle. The vehicle starts with full acceleration from 20 m before the measurement point (= start point). The length of the measurement goes from the start point until the back of the vehicle has passed the cross section by 20 m. The traction unit has to be at the front of the vehicle.

Vehicles with distributed traction

For vehicles with distributed traction (several bogies with traction), measurements should be carried out at two cross sections.

The first section at the beginning of the vehicles; the second section in front of the vehicles with a distance of D/2, D being the distance in front of two bogies of one vehicle.

The vehicle starts accelerating at full power from the first section. (= start point). The length of the measurement goes from the start point until the back of the vehicle has passed the cross section by 20 m. The traction unit has to be at the front of the vehicle.

MEASUREMENT METHOD FOR TRACK CHARACTERISTICS

Introduction

This procedure aims to determine the track characteristics for new, renewed or different types of tracks such as the ones given in § 2 and § 3.

The noise calculation method is based on the fact that the track characteristics, in octave bands, are independent of the type of vehicle or of the speed of the vehicle. To verify this, it is necessary to perform measurements at one location at two additional speeds (difference > 20, respectively 30%). The differences in the calculated track characteristics should be below 3dB in each of the octave bands.

If the correction is dependent on speed, additional research has to be carried out that may lead to speed dependent characteristics.

Measurement set-up

Number and test tracks condition

To determine the correction terms for the track type, measurements are carried out on at least two sections of test tracks, equipped with the new track type, each of at least 100 m long. The construction of the test tracks is identical over this length. Adjacent to the test tracks lies a reference track of at least 100 m with a track consisting of jointless rails on concrete mono block sleepers in ballast. The construction of this reference track must be representative of the construction on which this recommendation is based, with track type correction terms equal to $C_{bb,i}$ (table 3.5), with bb=1.

For each location, the measurements are carried out on three cross-sections of the test track and on two cross-sections of the reference track. The results of these measurements are averaged over the cross-sections for both the test and reference track. The environment between assessment point and reference and test track allows no difference in noise transmission. This means that soil properties, realisation of embankment, height line, … are identical. They may however differ for the several locations.

The rail roughness of the test and reference tracks is preferably lower than the ISO maximum graphic (pr EN ISO 3095). If this is not possible, the measurements can be made with a higher rail roughness. In this case, the total roughness should be determined: this is the sum of the rail roughness and the wheel roughness. The total roughness should be as similar as possible at both the reference and test location. Some deviations in the levels per octave band are allowed but they may not lead to a difference higher than 0.5 dB(A) in the A-weighted track type correction.

Both test and reference track are horizontal and not in a curve. In order to prevent contact noises, no rail joints, welding joints, damaged paved areas or lose sleepers are allowed within a distance of 25 m from each side of the measurement cross sections. Connecting constructions between reference, test and other tracks are at least 25 m from the cross-sections.

Number and condition of the rail vehicles

To determine the track type correction terms, in each of the assessment points at least five passages of railway equipment with cast-iron block brakes and relative high rail roughness are measured. The rolling noise of the passing railway equipment has to be dominant with no other noise sources affecting the measurements. The passing railway equipment must comply with the conditions in § 1.2.2.1. The condition of the passing railway equipment is recorded, stating at least the train type, train number and the number of passing railway carriages. The number of passages to be measured on each of both assessment points may differ by 20%.

The railway equipment must pass all assessment points with a constant speed (±5%) between 100 and 160 km/h and with the brakes deactivated.

Acoustic environment

The measurement environment must comply with the conditions in § 1.2.2.3.

Meteorological conditions and background noise

The meteorological conditions and background noise must comply with the conditions in § 1.2.2.4.

Quantities to be measured and assessment point

The A-weighted equivalent sound pressure level in octave bands $L_{pAeq,i}$ is measured at the cross-sections at a distance of 7.5 m from the centre of the track and at a height of 1.2 m above BS.

Furthermore, the measurement arrangement in § 1.2.2.5 must be used, with the exception of the measurement cross-section, which must comply with that in § 1.4.2. Vibration measurements do not need to be executed, unless they are needed to determine the rail transmission (e.g. to use the measured track type to determine the properties of new railway equipment.)

Also, the rail roughness is measured according to the method in § 1.2.4.1 for both the reference and the test track.

Measurement equipment

The measurement equipment complies, as much as possible, with the conditions in § 1.2.2.6.

Determination of correction values for track characteristics

Octave band methods (ORM)

The track type correction terms of the test track in octave bands $C_{bb,test,i}$ equal:

$$C_{bb,test,i} = \frac{1}{n}\sum_{j=1}^{n}\left(L_{Aeq,test,i,j} - L_{Aeq,ref,i,j}\right) \qquad 1.42$$

with:

- $L_{Aeq,test,i,j}$ equivalent noise level during passage of train j in octave band i over test tracks, energetically averaged over the cross-sections
- $L_{Aeq,ref,i,j}$ equivalent noise level during passage of train j in octave band i over reference tracks, energetically averaged over the cross-sections
- n number of measured passages

Global dB(A) method (ARM 1)

The track type correction terms for ARM-1 depend on the material category and are calculated as follows:

a. make a model according to ORM of a simple situation with a single track on soft soil and a standard embankment of 1 m high;
b. calculate with this model the sound pressure at an assessment point, 25 m from the centre of the track and at a height of 2.5 m above BS;
c. use the correction term C_{bb} from table 3.5 with bb=1 and the ORM correction terms for the test track;
d. execute this calculation for each of the vehicle categories. For vehicle categories with a maximum speed of 140 km/h or higher, use following speeds: 80, 100 & 140 km/h. For those with a lower maximum speed, use following speeds: 60, 80 & 100 km/h. A regular train frequency is assumed, e.g. 10 carriages per hour.

The results from these calculations are used to determine the track type correction terms for ARM-1 as follows:

$$C_{b_{test},c} = \frac{1}{3}\sum_{k=1}^{3}\left(L_{Aeq,test,c,k} - L_{Aeq,concrete,c,k}\right) \qquad 1.43$$

with: $C_{b_{test},c}$ track type correction term for ARM-1 for the test track and material category c

$L_{Aeq,test,c,k}$ calculated sound pressure for the test track, material category c, speed parameter k

$L_{Aeq,concrete,c,k}$ calculated sound pressure for the reference track with jointless rails on concrete sleepers, material category c, speed parameter k

k speed parameter k=1 for calculation speed 80, respectively 60 km/h, k=2 for 100, respectively 80 km/h and k=3 for 140, respectively 120 km/h

Reporting

The reporting consists of the items in § 1.2.8, with the exception of items 6 and 15. Item 4 is recorded for both reference and test track. In addition to this, the calculated track type correction terms in octave bands are reported, including the intermediate results of the calculations on which they are based.

2 The Global DB(A) emission value

EMISSION VALUE IN DB(A) OF AN EMISSION SECTION

Main formula

$$E = 10\lg\left(\sum_{c=1}^{y} 10^{E_{nr,c}/10} + \sum_{c=1}^{y} 10^{E_{r,c}/10}\right) \qquad 2.1$$

with:

$E_{nr,c}$	per rail vehicle category for non braking trains;
$E_{r,c}$	emission term for braking trains;
c	train category
y	total number of categories present

The emission values per rail vehicle category are determined from:

$$E_{nr,c} = a_c + b_c \lg v_c + 10\lg Q_c + C_{b,c} \qquad 2.2a$$

$$E_{r,c} = a_{r,c} + b_{r,c} \lg v_c + 10\lg Q_{r,c} + C_{b,c} \qquad 2.2b$$

The standard emission values a_c, b_c, $a_{r,c}$ & $b_{r,c}$ are given in table 2.1.

Data

To calculate the emission value, the following data are needed:

Q_c	average quantity of non braking trains of the considered rail vehicle category [h^{-1}];
$Q_{r,c}$	average quantity of braking trains of the considered rail vehicle category [h^{-1}];
v_c	average speed of rail cars [km/h^{-1}];
b	track type [-]

Trains are considered "braking" when the brake system is active.

To determine the emission value E, train categories according to the list in § 1.1 are used, distinguishing between braking and non-braking trains. For material types not included in this list the emission value can be determined by measurements according to procedures A or B from § 1.

The following types of superstructures are also distinguished:

- Railway tracks with single block or double block (concrete) sleepers, in ballast bed (index code bb = 1);
- Railway tracks with wooden or zigzag concrete sleepers, in ballast bed (index code bb = 2);
- Railway tracks in ballast with non-welded tracks, tracks with joints or switches (index code bb = 3);
- Railway tracks with blocks (index code bb = 4);
- Railway tracks with blocks and ballast bed (index code bb = 5);
- Railway tracks with adjustable rail fixation (index code bb = 6);
- Railway tracks with adjustable rail fixation and ballast (index code bb = 7);
- Railway tracks with poured in railway lines (index code bb = 8);
- Railway tracks with level crossing.

$C_{b,c}$ indicates the emission difference between a railway car on a track with concrete sleepers and one on another track type under identical circumstances. Not named track types are classified as b=3, unless measurements are carried out on this track type according to § 1.

The value of $C_{b,c}$ is given in table 2.2. For railway crossings 2 dB are added to the value in table 2.2 according to the track type before and after the crossing. If these values differ, the construction with the highest values is used.

category	non-braking trains		braking trains	
	a_c	b_c	$a_{r,c}$	$b_{r,c}$
1	14.9	23.6	16.4	25.3
2	18.8	22.3	19.6	23.9
3	20.5	19.6	20.5	19.6
4	24.3	20.0	23.8	22.4
5	46.0	10.0	47.0	10.0
6	20.5	19.6	20.5	19.6
7	18.0	22.0	18.0	22.0
8	25.7	16.1	25.7	16.1
9	22.0	18.3	22.0	18.3

Table 2.1. Standard emission values as a function of railway category c

category	b=1	b=2	b=3	b=4	b=5	b=6	b=7	b=8
1	0	2	4	6	3	-	0	2
2	0	2	5	7	5	-	0	3
3	0	1	3	5	2	-	0	2
4	0	2	5	7	4	-	0	2
5	0	1	2	4	4	-	0	2
6	0	1	3	5	2	-	0	2
7	0	1	-	-	-	-	-	-
8	0	2	4	6	3	-	0	2
9	0	2	4	6	3	-	0	2

Table 2.2. Correction term $C_{b,c}$ as a function of railway category and track type/state b

structure type	structure above compound	index code bb (SRM 2)	index code b (SRM 1)
TT & U-type bridge	adjustable fixtures	4	4
plate & girder bridge	cross-ties on ballast (either wood or concrete)	1 or 2	1 or 2
	adjustable fixtures	4	4
	adjustable fixtures filled with ballast	7	7
steel deck bridge	block type fixation	4	4
	block type fixation filled with ballast	5	5
	embedded rails	8	8

Table 2.3 Correction factor for structures above various types of concrete and steel structures compounds

MAXIMUM SPEEDS

In this unit the emission level for train speeds can be determined using a maximum speed per category as shown in table 2.4. For new material measured in accordance to § 1 this maximum speed is as measured.

For vehicles not mentioned in § 1.1, the maximum speed as specified by the manufacturer applies.

category	1	2	3	4	5	6	7	8	9	10
maximum calculable speed [km/h]	140	160	140	100	140	120	100	160	300	330

Table 2.4 Maximum calculable speed per category

3 Global DB(A) noise propagation calculation method (ARM-1)

SPECIFICATION OF TERMS

Reception Point

The reception point is the point at which the equivalent sound level should be determined. When determining the noise pollution at a gable front wall, the reception point can be found at the surface of the front wall concerned.

Source Line

The line at 0.25 m above the centre of the rail which represents the position of noise propagation.

Limiting line

Lines that indicate limitations of the emission sector of the receiving point (figure 4.1).

Height with reference to railhead

The height of the head of the rail with reference to the assessment surface: h_{bs}.

Height of receiver

Height of receiver with reference to the surface level: h_w.

Distance to source line

Shortest distance between receiver and source line: r.

Horizontal distance to source line

Shortest horizontal distance between receiver and source line: d.

GEOMETRICAL DEFINITION OF SITUATION

From receiver W a connecting line to the centre of the track is drawn (length of WS = d). At distances 2d from W and parallel to WS we find the limiting line I_1 and I_2. The line through S perpendicular to WS represents the centre of the imaginary rail track (model of the real rail track).

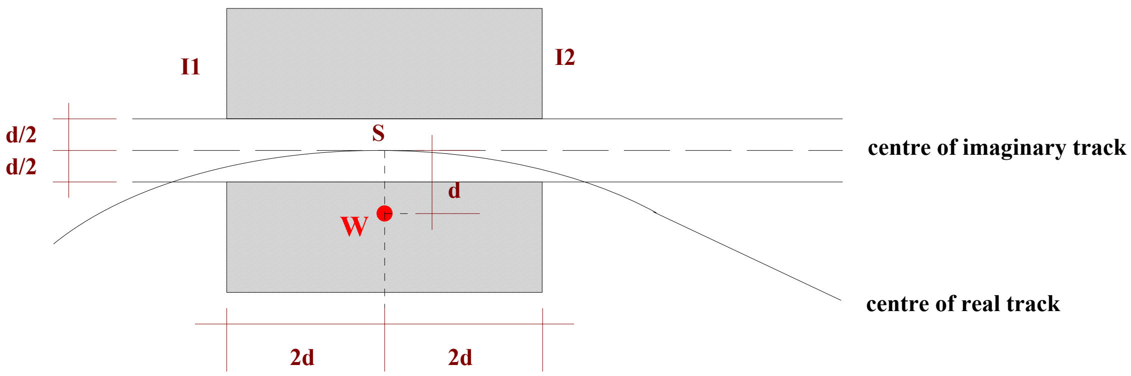

Figure 4.1. Horizontal projection of the considered area, defined to check with the application conditions

APPLICATION AREA OF THE METHOD

The A-weighted calculus method is based on a simplification of the situation, allowing -with regard to the application area of the method - to apply following conditions for the considered area between limiting lines I_1 and I_2:

- the centre of the real track may not cross the shaded areas in figure 4.1;
- the view from the receiver may not be inhibited over an angle > 30°;
- if the railway exists of more than one section, the emission values of those sections should not differ by more than 10 dB.
- the distance d from the receiver to the centre of the railway must be at least 1.5 times the distance between the external rails of the railway;
- there should be no structures on the railway within the considered area, and no height differences of more than 3 m relative to the average height.

Shielding objects and buildings between the railway and the receiver are not taken into account.

CALCULATION MODEL

The equivalent noise level L_{Aeq} in dB(A) from railway traffic is calculated with:

$$L_{Aeq} = E_S + C_{reflection} - D_{distance} - D_{air} - D_{soil} - D_{meteo} \qquad 4.1a$$

with: $C_{reflection}$ correction value for possible reflections coming from buildings or other vertical surfaces;

$D_{distance}$ weakening value, depending on the distance;

D_{air} weakening value, resulting from air absorption;

D_{soil} weakening value, resulting from soil absorption;

D_{meteo} correction value for meteorological conditions;

E_s composed emission value calculated by:

$$E_S = 10 \lg \frac{1}{127} \sum_{i=1}^{n} \phi_i 10^{E_i/10} \qquad 4.1b$$

with: E_i emission value of the section i as determined in § 2

ϕ_i angle at which the section i is seen by the receiver

n number of sections within the considered area

MODELLING THE SITUATION

Source Lines

To model the geometrical data, the baseline for vertical measures is the railhead (BS). Horizontal measures are taken from the centre of the track. The source line in the model is a line at 0.25 m above and along the centre of the track.

Reflections

In order to use the reflection value for surfaces across the track from the receiver, the following conditions must be met:

- they are acoustically reflecting;
- they are vertical and parallel to the track;
- they are higher than the receiver;
- the horizontal distance (d_r) to the source line is smaller than 100 m and also 4 times smaller than the horizontal distance (d_w) from the receiver to the source line.

Assessment positions

Assessment positions for buildings have to be at a height of 5 m above ground level. For residential buildings with 3 or more floors this position is taken at the top floor level (1 m below the ridge). To determine the exterior climate, an assessment position at 1.5 m above the local ground level is chosen.

REFLECTION TERM

The reflection term $C_{reflection}$ is calculated by:

$$C_{reflection} = f_{obj} \qquad 4.2$$

with: f_{obj} the object fraction which is - within a distance of $4(d_r + d_w)$, parallel to the track and symmetric to the receiver- the total length at the other side of the track over which the sound reflecting surfaces extend in relation to this distance of $4(d_r + d_w)$

d_r horizontal distance between the reflecting object and the source line

d_w horizontal distance between the receiver and the source line

ATTENUATION BY DISTANCE

The attenuation $D_{distance}$ is calculated by:

$$D_{distance} = 10 \lg r \qquad 4.3$$

with r the shortest distance between the receiver and the source line

ATTENUATION BY AIR ABSORPTION

The attenuation D_{air} is calculated by:

$$D_{air} = 0.016r^{0.9} \qquad 4.4$$

with r the shortest distance between the receiver and the source line

ATTENUATION BY SOIL ABSORPTION

The attenuation D_{soil} is calculated by:

$$D_{soil} = 3B^{0.5}\left(1 - e^{-0.03r}\right)\left(1.25e^{-0.75(0.6h_{bs}+0.5)} + e^{-0.9h_w}\right) + 1.6B - 1.8 - 3(1-B)\left(1 - e^{\frac{-0.01r}{h_w + h_{bs} + 0.4}}\right) \qquad 4.5$$

with B the soil factor: the part of the soil between receiver and source that is not paved

The soil factor is the part of the horizontal projection of the connection line between the receiver and the centre of the track, which lies above a not paved soil. Not paved soil is: ballast, grass, agricultural soil with or without crops, sand plains and soil without vegetation.

METEOROLOGICAL CORRECTION TERM

The meteorological correction term D_{meteo} is calculated by:

$$D_{meteo} = 3.5\left(1 - e^{-0.04\frac{r}{h_w + 0.6h_{bs} + 0.5} - 5}\right) \qquad 4.6$$

If this formula results in a negative value D_{meteo} is considered to be zero.

4 Noise propagation calculation in octave bands

5.0. GENERAL INFORMATION

The range of use for the octave band calculation method is larger than that for the global dB(A) calculation method and for the measurement methods. This method is applied when the engineer considers the other methods insufficient to provide a representative equivalent noise level for the situation concerned. As it is impossible to provide a method that covers all cases, information is given in the individual sections of the calculation method as to which conditions require further examination. Those responsible for the further examinations must possess a great measure of specific know-how as high demands are placed on their reports.

The propagation method used in the octave band method and specifically the sections referring to ground attenuation and screen attenuation are based on the model of curved sound rays in downwind conditions. When calculating the method using Maekawa, the curve of the sound ray is taken into account in that the actual barrier is reduced by an ineffective part. The downwind conditions provided by this transmission model are not representative of meteorological averages, however. By adding a meteorological correction factor to the model, a "meteo averaged" equivalent noise level, L_{Aeq}, is attained.

In this part it is taken that the emission values for each emission section as specified by octave band are known. The geometric input data should be taken from well-detailed chart material (horizontal projections and vertical cross sections of relevant objects). For the purpose of automatic processing, this input should be taken into account schematically in the calculation (curved lines are described approximately in terms of straight sections, the height of the upper edge of the terrain is given as an average value, not acoustically important details are omitted, etc.). This changes the input to an output that requires specific acoustic insight. Specifically in the case of complex acoustic situations, the report as well as the original chart material and the schematically inputted geometry must be provided.

SPECIFICATION OF TERMS

Assessment point

This is the point at which the equivalent sound level should be determined. When determining the noise pollution in a front wall, the assessment point lays in surface of the front wall.

Sector

A volume limited by two vertical surfaces whose borders correspond with the perpendicular through the assessment point.

Sector Surface

The median surface of two limiting surfaces of a sector.

Opening Angle of a Sector

The angle between two limiting surfaces of a sector and the horizontal area.

Total Opening Angle of a Sector

The sum of opening angles from all sectors which are significant in the determination of the equivalent sound level in dB (A)

Viewing Angle

The angle from which an object (front, barrier, street, etc.) is viewed in horizontal projection from the assessment point.

Source Line

The line above the centre of the rail at a particular level above the upper edge of the tracks (BS), which represents the position of noise propagation. Depending on the vehicle type two to four linear noise sources can be differentiated.

Linear Source Segments

The straight line between the intersection points of a line source with the limiting surfaces of a sector.

Point Source

The intersection point of a sector area with a linear source segment.

BASIC FORMULA

Equivalent sound level L_{Aeq}

The equivalent sound level L_{Aeq} in dB(A) is calculated as follows:

$$L_{Aeq} = 10 \lg \sum_{i=1}^{8} \sum_{j=1}^{J} \sum_{n=1}^{N} 10^{\Delta L_{eq,i,j,n}/10} \qquad 5.1a$$

where $\Delta L_{eq.i.j.n}$ specifies the contribution in an octave band (index code i) of a sector (index code j) and a source point (index code n).

$\Delta L_{eq.i.j.n}$ includes following values:

$$\Delta L_{eq,i,j,n} = L_E + \Delta L_{GU} - \Delta L_{OD} - \Delta L_{SW} - \Delta L_R - 58.6 \qquad 5.1b$$

with
L_E emission value per source height and octave band according to § 3.2
ΔL_{GU} attenuation due to distance (§ 5.4)
ΔL_{OD} attenuation due to propagation (§ 5.5)
ΔL_{SW} screening effect, if present (§ 5.6)
ΔL_R attenuation due to reflections, if present (§ 5.7)

The octave bands with the nominal centre frequencies 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz are used when adding. The classification of sectors must be arranged in such a way, that the geometry in a given sector can be well described in terms of the sector area geometry. In order to achieve a good representation of the noise emission only one emission route per sector is allowed. The maximum opening angle of a sector is set at five degrees. The number of sectors, J, is dependent on the total opening angle of the assessment point and the required sector classification.

The number of source points, N, of a sector depends on how often the source line (segment) intersects the sector area.

MODELLING THE SITUATION

Source Lines

The starting points for modelling the geometric specifications is the railhead (BS) for vertical dimensions, and the middle of the rail for horizontal dimensions. The lines which cross the middle of the tracks at different levels to BS are represented as source lines in the model. There are two source lines, at 0 cm and at 50 cm above BS, for the material categories 1 to 8 inclusive. The track is preferably divided in emission sections, in steps of no less than 100 m. In order to model important geographic elements it is advisable to work with smaller step sizes, particularly if the above mentioned section is too large, as can occur in the case of curves, screening or in other certain situations.

Composition of the ground

The composition of the land is divided into two groups: acoustically hard and non-hard. The term acoustically hard (B=0) refers to: pavement, asphalt, concrete, other hardened / sealed ground, water surfaces and related surfaces. The term acoustically non-hard includes: ballast, grass surfaces, agricultural surfaces with or without vegetation, sandy surfaces, ground without vegetation, etc.

Ground Height Differences

The source height, object and assessment point are defined in relation to the average terrain height concerned. This average height is determined by the profile in the regarded sector area as an average area above a given horizontal distance. The average height of the ground in the source area is therefore applicable for the source and the average height of the ground within a radius of 5 m from the equivalent barrier is applicable for a barrier.

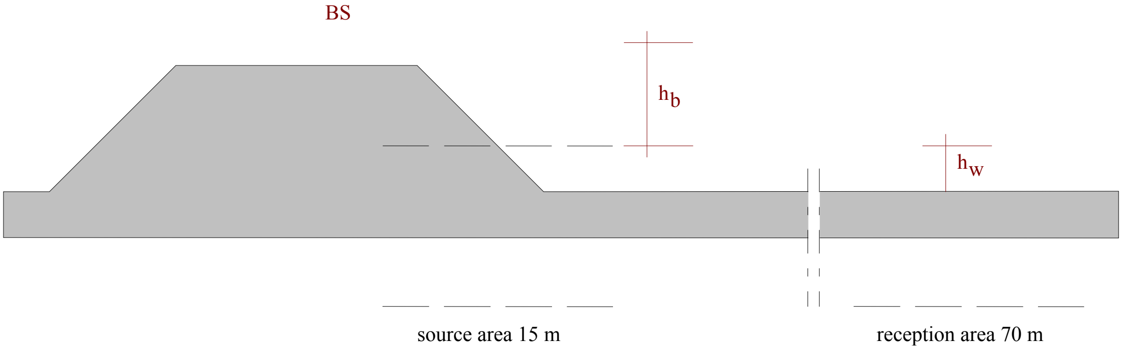

Figure 5.1 Height in relation to the average terrain level. As a result of the raised tracks the average terrain level is situated in the source area slightly above the upper edge of the terrain, near the embankment.

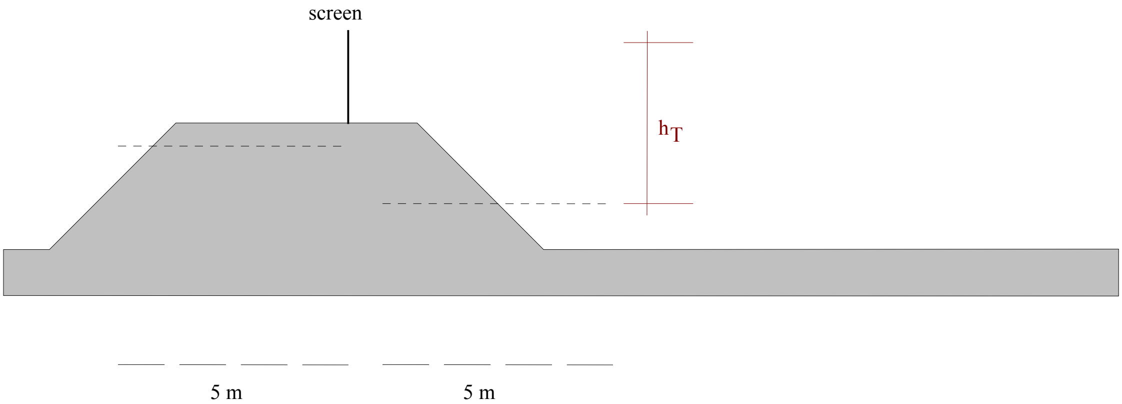

Figure 5.2 Barrier set upon an embankment; the average terrain level to the left is slightly lower than the upper edge and to the right slightly higher than close to the embankment. The situation to the right is a determining factor for h_T.

Standard Embankment

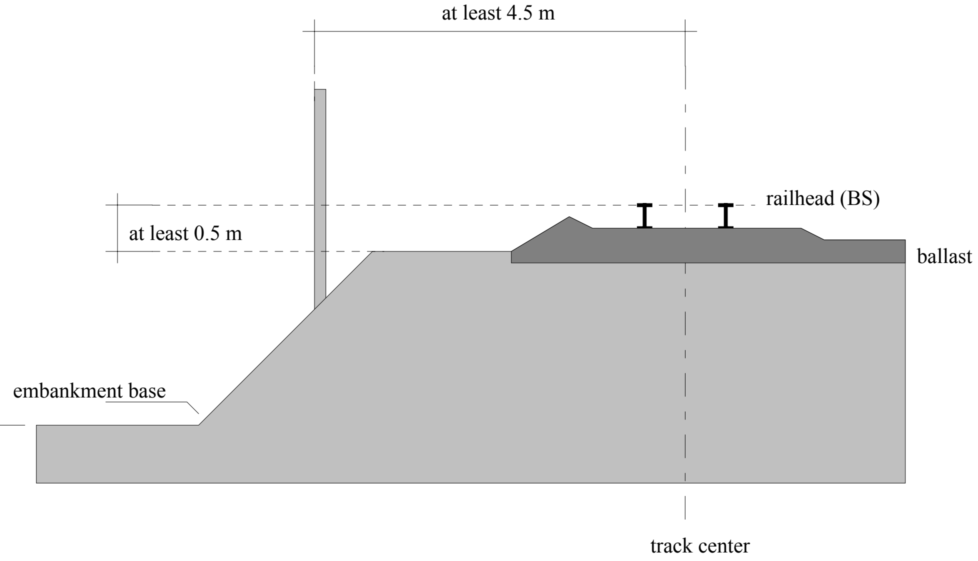

Figure 5.3 Cross-section of a standard embankment.

Figure 5.3 shows a cross–section of an actual track embankment. Figure 5.4 shows the corresponding model. The following rules apply when establishing a model:

- the lane is the centre focus of the model; a lane is modelled exactly between the tracks for each railway line (the distance between both tracks is 1.42 m)
- each lane (A) is modelled at the height of the true railhead (BS) and in the centre of the railway line (between the rails)
- a contour line and a connected obtuse barrier Cp = 2 dB (F) is modelled at a height of 0.2 metres to the right side under each railway line (the absorbing ballast is situated 0.2m beneath BS)
- the edge of the ground (KAB) is modelled as a contour line along with the connected obtuse barrier (B) at an actual height in relation to BS (b1) and the upper edge of the terrain (b2) and at a distance of 4.5 m to the next lane; if the actual distance between the centre of the tracks and KAB deviates from the above mentioned 4.5 m by more than one metre, then the actual distance concerned is modelled as b3 (in most cases the deviation falls short of one metre and in most cases KAB is situated 0.5 m beneath BS)
- a possible barrier located at the edge of the embankment is modelled as a (acute) barrier (D) with its actual height above BS (d1) and with its actual distance from the centre of the tracks (d2); (in most cases barriers are set 4.5 m from the centre of the tracks)

- the embankment base is modelled as a contour line at the height of the actual upper edge of the terrain above BS (c1) and at the actual distance from the centre of the tracks (c2);
- a ratio of 1: 1.5 is used for the gradient of the embankment. The edge of the ground corresponds to the line at which the flat section of the embankment begins to decline; this is to be found, according to definition, 4.5 m from the nearest source line.
- the edge of the ground is an obtuse, absorbing barrier (C_p = 2 dB);
- where ballast is present, the whole horizontal ground surface is absorbing (B=1) as long as the actual hard sections in the area are not wider than 1 m.

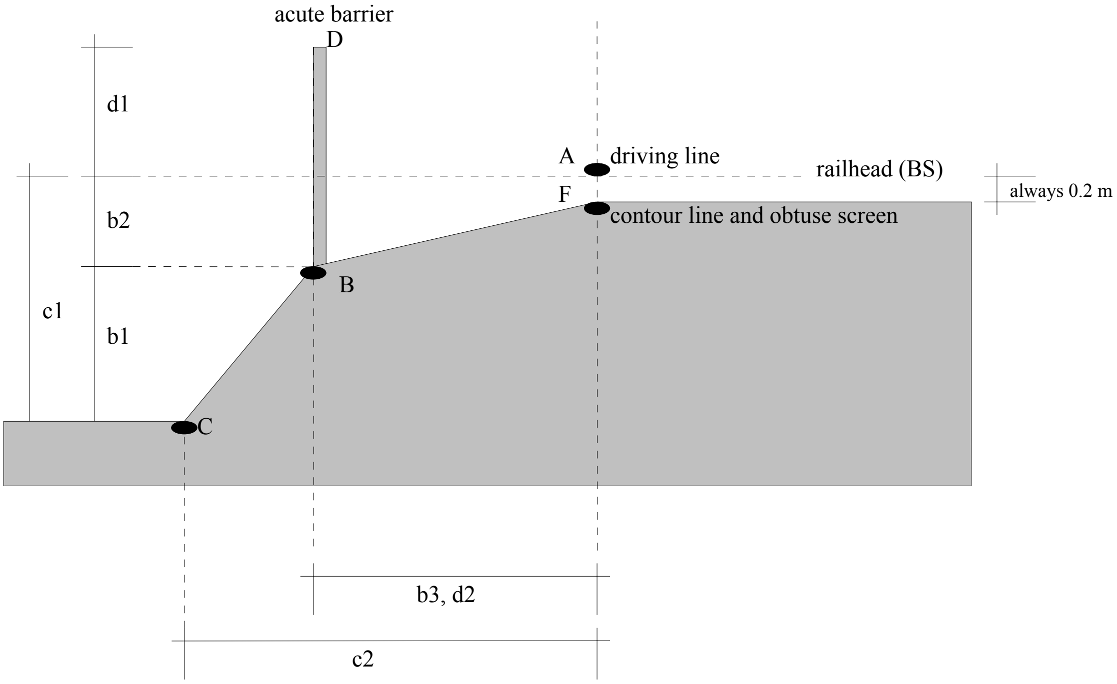

Figure 5.4 Model of a cross-section of a standard embankment

If the actual horizontal embankment dimensions (different embankment width, different gradient) deviate from the standard embankment by more than 0.5 m, the actual distances are used in the usual way.

Level crossing

The section of the railway tracks with a level crossing is modelled with the respective structure above the crossing and hard ground.

Screening slabs (U-type slabs)

The height of the walls of U-type slabs, the local height of the upper edge of the terrain and the distance are modelled corresponding to the actual values. The floor of the screening slabs is modelled at 0.2 m beneath BS. The walls are modelled as absorbing barriers with acute vertex angles (C_p = 0 dB). The correction for the structure above the tunnel depends on the respective construction concerned.

In the case of U-type slabs with absorbing wall lining (see 5.3.10) the source lines are found at the specified height above BS.

In the case of U-type slabs without absorbing wall lining, source lines which are situated lower than the upper level of the slabs are modelled at the height of the edge or related to the height of the train roof.

Generally this results in a maximum height of 4.0 m.

No source lines are modelled for the actual tunnel section.

Barriers and screening objects

In order to qualify as a screening object, an object must:

- have complete noise insulation of at least 10 dB higher than the screening effect, in other words, the mass must be at least 40 kg/m² and have no recognizable columns or openings,
- have a viewing angle corresponding at least to the opening angle of the sector in question.

Reflecting barriers near the track path which show no gradient can be modelled as an absorbing barrier. However, the effective height of the barrier above BS (=$h_{s,eff}$) is calculated as follows:

$$h_{s,eff} = h_s \qquad 5.2a$$

or

$$h_{s,eff} = h_s \frac{(1+a)}{2} \qquad 5.2b$$

with: a absorbing section of the barrier

The lowest half metre of the barrier must be absorbing in all cases.

Noise barriers close to the track path are if possible executed absorbent. § 5.3.10 describes when a barrier is considered absorbent.

In order to calculate the effectiveness of noise barriers which are mounted at the edge of embankments, a 100% absorbing barrier is presumed for octave band calculation methods. In the case of absorbing barriers the actual height above BS is modelled; in the case of noise reflecting or partially noise reflecting barriers the above-mentioned formula for calculating the effective barrier height can be used. The conditions when a real barrier can be considered absorbing are described in § 5.3.10.

The actual effect of the barrier is probably lower if the barrier being represented is situated less than 4.5 m away from the centre of the tracks or if the barrier is higher than 4.0 m above BS and more than 4.5 m away from the track path

A barrier is always modelled as a vertical barrier, even if in reality the barrier is curved, or mounted under an angle. The top of the barrier has to be modelled at the exact same position of the diffraction edge of the real barrier. The method described above then is used to determine the effective height.

Platforms

The height of the platform is set at 0.8 m above BS. Platforms are modelled with two absorbing barriers at each side of the platform and the side facing the tracks is situated 0.2 m from the centre of the tracks. In the case of the barrier near the tracks, the ground under the track (0.2 m below BS) and the relevant height of the upper edge of the terrain apply. The applicable profile dependant correction factor Cp is determined by considering whether an absorbing lining is present or not (see tables 5.4 and 5.3.10). Platforms which are open on both sides (i.e. lack of a side wall on the track side and the outer side) are not modelled as barriers. Platforms which are open on the track side only are to be considered absorbing.

Bridge constructions

In the case of bridge constructions, the actual heights and distances are modelled. The type is defined in accordance with §3.5. If the construction is not absorbing, the entire bridge floor is modelled as hard. In the case of tracks set on ballast or poured–in tracks with at least 15 cm of ballast the whole bridge flooring is modelled as absorbing ground, unless hard sections of the bridge floor are wider than 1 m. In this case the sections concerned are modelled as hard ground elements. In the case of steel bridges the bridge body is modelled as an absorbing ground element.

In the case of steel girder bridges, T-beam bridges and solid plate web bridge, the bridge is modelled as an absorbing obtuse barrier (see table 5.4 and §5.3.10).

In the case of U-type bridges and M-type constructions, the border is to be modelled with two absorbing obtuse barriers on both sides of the border. For the barrier near the track, the ground under the tracks (-0.2 m BS) is to be used as the reference surface level.

The profile dependent correction factor Cp is determined by considering whether an absorbing lining is present or not (see table 5.4 and §5.3.10).

In the case of concrete constructions, barriers can be modelled to a height of 2.0 m according to barrier regulations. For higher barriers, the direct noise reflection of the construction can lead to contributions that cannot be calculated without further information and a closer acoustic examination must be carried out.

In the case of steel constructions with screening walls, the effect of the screening cannot be calculated. The extra charge for bridges must however be applied.

Noise absorbent construction

Linings or constructions of screening objects, platforms, and tunnel walls are to be considered absorbing if the track specific absorption is larger than or equal to 5 dB (A). This absorption is referred to in further detail in §5.7.

Reflections

If objects are found inside a sector that complies with the following conditions, L_{Aeq} is also determined by means of reflected noise that reaches the assessment point.

The contribution of reflections to L_{Aeq} is calculated as follows: The sector situated in front of the reflecting surface, when viewed from the assessment point, is substituted with its transposition on the reflecting surface.

In order to qualify as a reflecting surface, the surface must:

- be vertical;
- have a viewing angle that corresponds to the opening angle of the relevant sector;
- be situated at least two metres above the upper edge of the terrain, when the entire sector angle is taken into account;
- have an absorption coefficient of <0,8;
- be so distanced from the track path, that screening and reflection of passing trains do not have to be taken into consideration.

The influence of the reflections on L_{Aeq} has to be more closely examined, if:

- the reflecting surface forms an angle greater than 5 degrees with the vertical;
- the reflecting surfaces have irregularities that are of the same magnitude as the distance between the surface and assessment point or the distance between the surface and the source point.

In the case of multiple reflections, the reflection is taken repeatedly. The contribution of source points, where the noise reaches the assessment point after four or more reflections, is not to be taken into account. In rural areas one reflection is often enough.

Residential buildings and assessment points

The average height of a single storey in a residential building is set at 3 m. An inclined roof is also considered a whole storey. However modelling a sloping roof as a whole storey should not result in unrealistic reflections in the direction of the assessment point.

Assessment points in front of buildings should be selected at the level of the first storey (this corresponds to a height of 5 m above the upper edge of the terrain) and in the case of residential buildings with three or more storeys, at the height of the top storey (i.e. 1 m beneath the roof ridge). An assessment point 1.5 m above the upper edge of the terrain can also be chosen for accessible ground, for rating of outside temperatures and for rating of screening effects.

Assessment points must be modelled so that reflections against the façade in front of an assessment point do not contribute to the sound (pressure) level.

Objects in front of the first building line which are higher than 1 m above BS must be modelled. Small objects such as bays or small sheds do not have to be taken into consideration.

ATTENUATION BY DISTANCE ΔL_{GU}

Data

In order to calculate the geometric propagation factor the following data is necessary:

r	distance between source and assessment point, measured along the shortest connection line [m];
ν	angle between sector area and section of the source line [in degrees];
ϕ	opening angle of the sector [in degrees].

Calculation

The calculation of ΔL_{GU} is as follows:

$$\Delta L_{GU} = 10 \lg \frac{\phi \sin \nu}{r} \qquad 5.3$$

Conclusion

If the angle ν takes on a value smaller than the opening angle of the sector concerned, further examinations must be carried out to determine ΔL_{GU}.

ATTENUATION BY PROPAGATION ΔL_{OD}

Losses on the transmission path ΔL_{OD} are composed of the following factors:

$$\Delta L_{OD} = D_L + D_B + D_M \tag{5.4}$$

where D_L air attenuation
D_B ground attenuation
D_M meteorological correction factor.

Air attenuation D_L

The given values for δ_{air} are derived from the third band spectrum ISO-DIS 3891 at 10° C and relative humidity of 80%. Specifically in the case of the high frequency bands, certain compensations for the intense dispersion character of the absorption have been added.

Data

In order to calculate D_L the following data is necessary:

r the distance between source and assessment point, measured at the shortest connection line [m]

Calculation

Calculation is as follows:

$$D_L = r\delta_{air} \tag{5.5}$$

where δ_{air} air absorption coefficient

The values for δ_{air} can be found in Table 5.1

Octave band index code [-]	Octave band medium frequency [Hz]	δ_{air} [dB/m]
1	63	0
2	125	0
3	250	0.001
4	500	0.002
5	1000	0.004

6	2000	0.010
7	4000	0.023
8	8000	0.058

Table 5.1 Air absorption coefficient δ_{air} as a function of the octave band (i)

Ground attenuation D_B

Subdivision into three ground areas is required due to the fact that, in the model of curved sound radiation, ground reflections near the source and the observer occur and also, if the distance between source and observer is large enough, in the area in between. Each of these areas may present different ground compositions, in which case three different absorption factors are necessary for the calculation.

The term acoustically hard here refers to: pavement, asphalt and other sealed surfaces, water surfaces etc. The term acoustically non-hard refers to: grass surfaces, agricultural ground with or without vegetation, sandy surfaces, ground without vegetation etc.

When determining the ground attenuation $D_{B,}$ the horizontally measured distance between source and assessment point (Symbol r_o) is divided into three areas: source area, assessment area and middle area. The source area has a length of 15 m and the assessment area a length of 70 m. The remaining section of the distance r_o between the source and assessment point forms the middle area.

If the distance between the source and assessment point is less than 85 m, the length of the middle area is zero.

If the distance r_o is less than 70 m the length of the assessment area is equal the distance r_o.

If the distance r_o is less than 15 m both the length of the source area and the length of the assessment area is equal to the distance r_o.

The (ground) absorption factor is calculated for all three areas. The absorption contribution corresponds to the ratio of the section length of the area concerned, if it is not acoustically hard, divided by the total length of the area concerned. If the length of the middle area is zero, the absorption contribution is one.

Data

To calculate ground attenuation the following factors are necessary:

r_o	horizontally measured distance between source and assessment point [m];
h_b	height of the point source above the average terrain level inside the source area [m];
h_w	height of the assessment point above the average terrain height inside the assessment area [m];
B_b	absorption factor in the source area [-]
B_m	absorption factor in the middle area [-]
B_w	absorption factor in the assessment area [-]
S_w	effectiveness of ground attenuation inside the assessment area [-]
S_b	effectiveness of ground attenuation inside the source area [-]

If h_b is less than zero, the value zero is given to h_b, and the same applies for h_w.

If a barrier does not apply to the sector concerned, both S_w and S_b are given a value of one. If a barrier is applicable, S_w and S_b are calculated using equations 5.9a and 5.9b as shown in § 5.6.

Calculation

Equation 5.6a to 5.6e are based on the equations in table 5.2 .

octave band index [-]	octave band centre frequency [Hz]	soil attenuation [dB]			
1	63		$-3\gamma_o(h_h+h_w,r_o)$		-6
2	125	$[(S_h\gamma_2(h_h,r_0)+1)B_b]$	$-3(1-B_m)\gamma_o(h_h+h_w,r_o)$	$+[(S_w\gamma_2(h_h,r_0)+1)B_w]$	-2
3	250	$[(S_h\gamma_3(h_h,r_0)+1)B_b]$	$-3(1-B_m)\gamma_o(h_h+h_w,r_o)$	$+[(S_w\gamma_3(h_h,r_0)+1)B_w]$	-2
4	500	$[(S_h\gamma_4(h_h,r_0)+1)B_b]$	$-3(1-B_m)\gamma_o(h_h+h_w,r_o)$	$+[(S_w\gamma_4(h_h,r_0)+1)B_w]$	-2
5	1000	$[(S_h\gamma_5(h_h,r_0)+1)B_b]$	$-3(1-B_m)\gamma_o(h_h+h_w,r_o)$	$+[(S_w\gamma_5(h_h,r_0)+1)B_w]$	-2
6	2000	B_b	$-3(1-B_m)\gamma_o(h_h+h_w,r_o)$	$+B_w$	-2
7	4000	B_b	$-3(1-B_m)\gamma_o(h_h+h_w,r_o)$	$+B_w$	-2
8	8000	B_b	$-3(1-B_m)\gamma_o(h_h+h_w,r_o)$	$+B_w$	-2

Table 5.2 Equation 5.6a to e inclusive for determining ground attenuation D_B as a function of the octave band (i). Symbols printed in italics correspond to the values which must be substituted for variables x and y in $\gamma(x,y)$.

The functions are defined as follows:

for $y \geq 30x$ $$\gamma_o(x,y) = 1 - 30\frac{x}{y}$$

for $y < 30x$ $$\gamma_o(x,y) = 0 \qquad 5.6a$$

$$\gamma_2(x,y) = 3.0\left[1 - e^{-y/50}\right]e^{-0.12(x-5)^2} + 5.7\left[1 - e^{-2.8\,10^{-6}y^2}\right]e^{-0.09x^2} \qquad 5.6b$$

$$\gamma_3(x,y) = 8.6\left[1 - e^{-y/50}\right]e^{-0.09x^2} \qquad 5.6c$$

$$\gamma_4(x,y) = 14.0\left[1 - e^{-y/50}\right]e^{-0.46x^2} \qquad 5.6d$$

$$\gamma_5(x,y) = 5.0\left[1 - e^{-y/50}\right]e^{-0.90x^2} \qquad 5.6e$$

The values in brackets following the functions concerned in equation 5.6.a to 5.6.e inclusive (in italic) are used to substitute variables x and y.

Meteorological correction factor C_M

Data

In order to calculate the meteorological correction factor $C_{M,}$ the following information is necessary:

r_o	horizontally measured distance between source and assessment point [m]
h_b	height of the source point above the average terrain level inside the source area [m]
h_w	height of the assessment point above the average terrain level inside the assessment area [m].

Calculation

The calculation is as follows:

$$C_M = 3{,}5 - 35\frac{h_b + h_w}{r_0} \qquad 5.7a$$

where $r_o > 10(h_b + h_w)$

$$C_M = 0 \qquad 5.7b$$

where $r_o \leq 10(h_b + h_w)$

ATTENUATION FACTOR FOR SCREENING ΔL_{SW}

(including factors S_w and S_b from the ground attenuation equation 5.6.a to 5.6.e inclusive).Description

If objects found inside a sector have at least a viewing angle that corresponds with the opening angle of the sector concerned and if we can presume that these objects interfere with sound transmission, the attenuation factor ΔL_{SW} is taken into account, along with reduced ground attenuation (expressed in terms of S_w and S_b in accordance with Equation 5.5).

The formula for calculating the attenuation contributed by an object of variable shape contains two factors. The first factor describes the screening by an equivalent idealised barrier (a thin, vertical plane). The height of the equivalent barrier corresponds to the height of the obstructing object. The upper edge of the barrier corresponds to the highest edge of the obstacle. If it is possible to place the barrier in various positions, the position at which the highest attenuation occurs is chosen.

The second factor is of importance only if the profile, deviates from that of the idealised barrier. The profile is defined as the cross-section of the sector plane of the attenuating object. The attenuation of the object is equal to the attenuation of the equivalent barrier minus a correction factor C_p depending on the profile. If several attenuating objects are present in a sector, only the object that - in the absence of the others - would cause the most attenuation is taken into account.

Data

In order to calculate attenuation the following data is necessary:

z_b	height of the source relative to the reference height (= horizontal plane where z = 0) [m]
z_w	height of the assessment point relative to the reference height (= horizontal plane where z = 0) [m]
h_b	height of the point source above the average terrain level inside the source area [m]
h_w	height of the assessment point above the average terrain level inside the assessment area [m]
h_T	height of the upper edge of the idealised barrier relative to the average terrain level in a 5 m range around the barrier. If the values on both sides of the barrier differ, h_T represents the highest of the two values [m]

r	distance between the source and assessment point measured along the shortest connection line [m]
r_w	horizontally measured distance between the assessment point and the barrier [m]
r_o	horizontally measured distance between the assessment point and the source point [m]
-	profile of the screening object

Calculated results

- the reduced ground attenuation expressed by factors S_w and S_b from Equation 5.6a to 5.6.e.
- screening effect ΔL_{SW}.

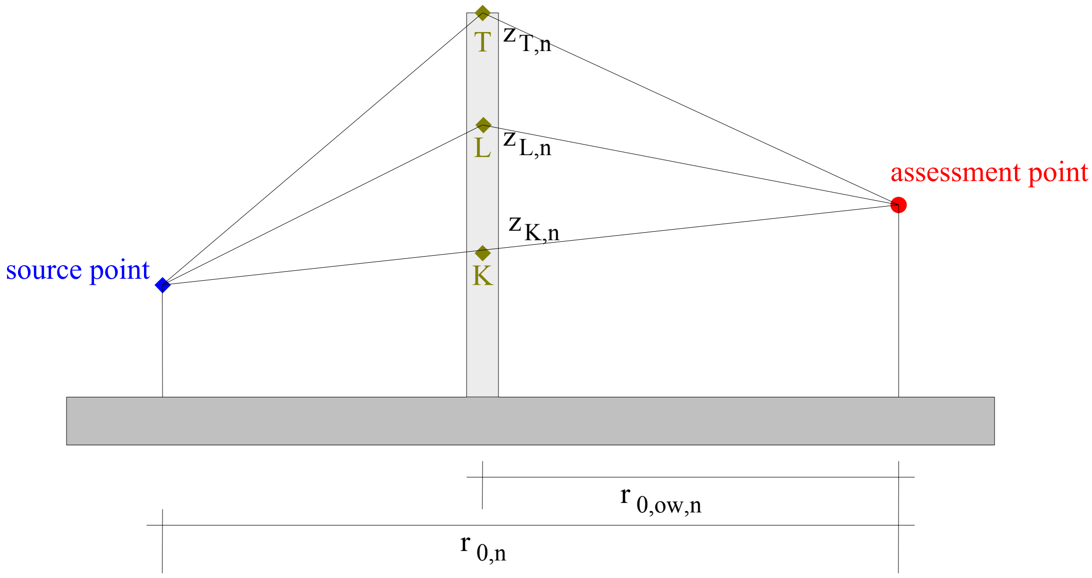

Figure 5.5 A sector area with an idealised barrier, points K, T and L are shown.

For the calculation, three points on the barrier are determined (see figure 5.1)

K	intersection point of the barrier and the line of sight (= directly between the source and assessment point)
L	intersection point of the barrier and a curved sound ray, that reaches the assessment point from the source point in downwind conditions
T	upper edge of the barrier

The broken line BLW is a schematic representation of the curved sound ray under downwind conditions.

These three points are to be found at the heights Z_K, Z_L and Z_T respectively above the reference height. The distance between point K and L is calculated as follows:

$$Z_L - Z_K = \frac{r_W (r_O - r_W)}{26 r_O} \tag{5.8}$$

Also:

r_L	is the sum of the partial distances BL and LW
r_T	is the sum of the partial distances BT and TW.

Factors S_w and S_b taken from equation 5.5a to h inclusive are calculated as follows:

$$S_w = 1 - \frac{r_O - r_w}{r_O} \frac{3h_e}{3h_e + h_W + 1} \tag{5.9a}$$

if $h_e < 0$ then $S_w = 1$

$$S_b = 1 - \frac{r_w}{r_O} \frac{3h_e}{3h_e + h_b + 1} \tag{5.9b}$$

if $h_e < 0$ then $S_b = 1$

h_e is the effective barrier height calculated as follows:

$$h_e = Z_t - Z_L \tag{5.10}$$

The attenuation factor ΔL_{SW} is calculated as follows:

$$\Delta L_{SW} = HF(N_f) - C_p \tag{5.11}$$

where

H	screening performance
$F(N_f)$	function with argument N_f (= Fresnel number)
C_p	correction factor depending on the profile

If the attenuation factor ΔL_{SW} as calculated with equation 5.11 is negative, the following applies $\Delta L_{SW} = 0$.

H is determined as follows:

$$H = 0.25 h_T 2^{i-1} \qquad 5.12$$

where i octave band index

The maximum value of H is 1.

The definition of the function F can be taken from equation 5.13a to f inclusive, as shown in table 5.3. The values for C_p can be found in table 5.4

valid for interval N_f from	to	definition $F(N_f)$
$-\infty$	-0.314	0
-0.314	-0.0016	$-3.682 - 9.288 \lg \lvert N_f \rvert - 4.482 \lg^2 \lvert N_f \rvert - 1.170 \lg^3 \lvert N_f \rvert - 0.128 \lg^4 \lvert N_f \rvert$
-0.0016	+0.0016	5
+0.0016	+1.0	$12.909 + 7.495 \lg N_f + 2.612 \lg^2 N_f + 0.073 \lg^3 N_f - 0.184 \lg^4 N_f - 0.032 \lg^5 N_f$
+1.0	+16.1845	$12.909 + 10 \lg N_f$
+16.1845	$+\infty$	25

Table 5.3 Definition of function F with variables N_f for 5 intervals of N_f (Equation 5.13a to f inclusive)

C_p	Object (T = top angle in degrees)
0 dB	▪ thin wall with a vertical angle ≤ 20° ▪ Ground elevations where 0° ≤ T ≤ 70° ▪ all ground elevations with thin walls, if the total height is less than twice the wall height ▪ all buildings
2 dB	▪ edge of a filled land site ▪ ground elevation where 70° ≤ T ≤ 165° ▪ all ground elevations with thin walls, if the total height is more than twice the wall height ▪ noise absorbing edge of the railway side of a platform ▪ edge of the platform not facing the railway track ▪ edge of a railway line situated on a viaduct or bridge, except U-type bridge or M-track ▪ noise absorbing edge of a U-type bridge facing the railway line ▪ edge of a U-type bridge not facing the railway line ▪ absorbing edge of a M-track facing the railway line ▪ edge of a M-track not facing the railway line

5 dB	▪ edge (non-absorbing[1]) of the side of a platform not facing the railway line ▪ edge (non-absorbing[1]) of the side of a platform facing the railway line U-type bridge ▪ edge (non-absorbing[1]) of the side of the M-track facing the railway line

Table 5.4 Correction factor C_p depending on profile. T is the upper angle of the cross-section of the object.

N_f is determined as:

$$N_f = 0.37\varepsilon 2^{i-1} \qquad 5.13$$

where ε acoustic pathway, defined as follows:

for $z_T \geq z_k$ $\varepsilon = r_T - r_L$ 5.14a

for $z_T < z_K$ $\varepsilon = 2r - r_T - r_L$ 5.14b

In cases where the profile of the screening object does not correspond to a profile in table 5.4, the attenuation of the object must be determined by means of further examination.

If the sound insulation is less than 10 dB above the calculated attenuation ΔL_{SW}, the complete noise reducing effect of the object must be determined by means of further examination.

[1] see §5.3.10

DETERMINING RAILS SPECIFIC ABSORPTION

The absorption coefficients α will be averaged using a weighting factor. As weighting factor the averaged A-weighted 1/3 octave spectrum of the traffic spectrum is used.

Following this, ΔL can be read from all third octave bands by means of formula 5.16 of absorption values, with the weighted average value of α. ΔL is rounded off to the full dB and has a maximum value of 10 dB(A).

Thirds [Hz]	Railway traffic Spectrum [dB]	Spectrum [dB]	Ki [-]
100		-24.0	1
125	-16,2	-21.0	2
160		-19.2	3
200		-17.0	5
250	-10,0	-15.0	8
315		-13.2	12
400		-11.7	17
500	-6,1	-10.8	21
630		-10.4	23
800		-10.0	25
1000	-4,9	-9.7	27
1250		-9.4	29
1600		-9.4	29
2000	-5,0	-9.4	29
2500		-10.6	22
3150		-17.1	5
4000	-15.0	-21.0	2
5000		-24.0	1

Table 5.5 Weighting factors Ki for railway noise to be used in the calculation of a unit value in dB(A) for the absorption value of sound barriers.

Where for railway traffic: Σ Ki = 261

The traffic specific absorption can be expressed in dB(A) with the help of equation 5.15.

$$\Delta L_{A,\alpha,\text{traffic}} = -10\lg\left(\frac{\Sigma(K_i * a_i)}{\Sigma K_i}\right) \qquad 5.15$$

REDUCTION OF LEVELS AS A RESULT OF REFLECTIONS ΔL_R

Data

In order to calculate level reductions as a result of absorption caused by reflections, the following data is necessary:

N_{ref}	number of reflections (see also § 5.3) between source point and assessment point [-]
-	type of reflecting object

Calculation

The calculation is as follows:

$$\Delta L_R = N_{ref} \delta_{ref} \qquad 5.16$$

where δ_{ref} level reduction by means of reflection.

Results

For buildings $\delta_{ref} = 0.8$ is valid for all octave bands. For all other objects $\delta_{ref} = 1$ is valid for all octave bands, unless the object is proven to be sound absorbing. In this case, $\delta_{ref} = 1 - \alpha$ per octave band is valid, where α is the sound absorption factor of the object in the octave band concerned. The highest value for N_{ref} is 3.

THE OCTAVE BAND SPECTRUM OF THE EQUIVALENT NOISE LEVEL

For a precise determination of the equivalent noise level in residential buildings, it is preferable to have access to the octave band spectrum that is used in the case of noise fields valid for facades. By means of the method described, approximately eight values are obtained for the equivalent noise level in the various octave bands. The A-weighting is already included. In all reports it is necessary to specify the relevant octave spectrum along with the equivalent noise level in dB(A).

The dependent equivalent sound level A in octave band i, symbol $L_{eq.i}$, is calculated as follows:

$$L_{eq,i} = 10 \lg \sum_{j+1}^{J} \sum_{n=1}^{N} 10^{\Delta L_{eq,i,j,n}/10} \qquad 5.17$$

where the definitions of the values and their effects are the same as in equation 5.1a.

5 Noise propagation calculation method for Noise mapping (ARM 1.5-method)

INTRODUCTION

This method is used for noise mapping of certain areas. The accuracy of the method lies between the A-weighted (ARM-1) and octave band method (ORM) and is designed to determine the noise levels at a large number of assessment points in a simple, reproducible and fast manner. Iso-lines can be determined by interpolation over a grid of these assessment points.

NOISE EMISSION

For the benefit of the calculation, the track is divided into sections (source line parts) with a length L [m], with a noise emission of:

$$L_{w,n} = E_{ARM,n} + 10\log(L_n) + 9 \qquad 6.1$$

with L_n length of source line part with index n into which the line source is divided [m]

$E_{ARM,n}$ noise emission of the source line part with index n conforming to the calculation method in § 2 [dB(A)]

n index of a part of the track with a length of L meter [-]

Length L_n depends on the distance from the source line part with index n to the nearest assessment point. Without the presence of barriers, L_n is a maximum of three times the distance between the nearest assessment point and the source line part. Beside this the length L_n depends on the presence of barriers between this source line part and the assessment points, influencing this source line part. The considered area for an assessment point is four times the distance from the assessment point to the track. When a barrier influences the transmission from the source line part to the assessment point, the distance L_n equals 25 m.

If the noise transmission over the source line part varies, the source line is divided into smaller line parts with length L_i and a constant noise emission $E_{ARM,i}$. This noise emission is calculated with equation 6.1, replacing index n by index i. The emission of these smaller line parts is added logarithmically resulting in the emission $L_{w,n}$ over the source line part with index n, taking into account the length of the line parts as weighting factors.

The source height lies at 0.25 m above BS (this is the average source height of the emission by rail and wheel). For high speed trains (category 9) at speeds over 200 km/h, the noise emission is divided over several source heights. This division is determined by calculating the emission in octave bands per source height, according to § 3, followed by summation per source height over octave band values. The proportion ratio between the calculated emissions is to be used for the division of the emission as determined in dB(A) according to § 2. This calculation method is worked out below:

$$L_{E,n}{}^{bs} = \oplus_i L_{E,n,i}{}^{bs} \qquad 6.2a$$

$$L_{E,n}{}^{as} = \oplus_i L_{E,n,i}{}^{as} \qquad 6.2b$$

$$L_{E,n}{}^{2m} = \oplus_i L_{E,n,i}{}^{2m} \qquad 6.2c$$

$$L_{E,n}{}^{4m} = \oplus_i L_{E,n,i}{}^{4m} \qquad 6.2d$$

$$L_{E,n}{}^{5m} = \oplus_i L_{E,n,i}{}^{5m} \qquad 6.2e$$

with $\oplus$ energetic sum
i octave band index [-]
$L_{E,n,i}{}^{bs}$ calculated emission for each source point, according to § 3
$L_{E,n,i}{}^{as}$
$L_{E,n,i}{}^{2m}$
$L_{E,n,i}{}^{4m}$
$L_{E,n,i}{}^{5m}$

$$L_{E,n}{}^{total} = \sum \oplus_{height} L_{E,n,i}{}^{height} \qquad 6.3$$

with height = bs, as, 2m, 4m & 5m

The correction on the total emission according to equation 6.1 for each source height equals:

$$C_{L_{w,n}}{}^{bs} = L_{E,n}{}^{total} - L_{E,n}{}^{bc} \qquad 6.4a$$

$$C_{L_{w,n}}{}^{as} = L_{E,n}{}^{total} - L_{E,n}{}^{ac} \qquad 6.4b$$

$$C_{L_{w,n}}{}^{2m} = L_{E,n}{}^{total} - L_{E,n}{}^{2m} \qquad 6.4c$$

$$C_{L_{w,n}}{}^{4m} = L_{E,n}{}^{total} - L_{E,n}{}^{4m} \qquad 6.4d$$

$$C_{L_{w,n}}{}^{5m} = L_{E,n}{}^{total} - L_{E,n}{}^{5m} \qquad 6.4e$$

The emission at each height for a source point n follows from:

$$L_{w,n}{}^{bs} = L_{w,n} - C_{L_{w,n}}{}^{bs} \qquad 6.5a$$

$$L_{w,n}{}^{as} = L_{w,n} - C_{L_{w,n}}{}^{as} \qquad 6.5b$$

$$L_{w,n}{}^{2m} = L_{w,n} - C_{L_{w,n}}{}^{2m} \qquad 6.5c$$

$$L_{w,n}{}^{4m} = L_{w,n} - C_{L_{w,n}}{}^{4m} \qquad 6.5d$$

$$L_{w,n}{}^{5m} = L_{w,n} - C_{L_{w,n}}{}^{5m} \qquad 6.5e$$

NOISE PROPAGATION

The noise propagation from each source line part (with a length of L m) can be described by that of a point source. The middle of the source line part with index n is considered point source$_n$. The propagation attenuation for point source$_n$ (T_n) is:

$$T_n = 10\log\left(4\pi r_n^2\right) + 20\log\left(\frac{r_n}{d_n}\right) + D_{air,n} + D_{meteo,n} + D_{barrier,n} + D_{urban,n} + D_{soil,n} - C_{reflection,n} \qquad 6.6$$

with	r_n	distance between point source and assessment point [m]
	d_n	distance perpendicular to the (continuation of) the source line part to the assessment point [m] (figure 6.1)
	$D_{air,n}$	air attenuation for point source$_n$ [dB(A)]
	$D_{meteo,n}$	meteorological attenuation for point source$_n$ [dB(A)]
	$D_{barrier,n}$	screening effect for point source$_n$ [dB(A)]
	$D_{urban,n}$	attenuation in urban area for point source$_n$ [dB(A)]
	$D_{soil,n}$	soil attenuation for point source$_n$ [dB(A)]
	$C_{reflection,n}$	= 0 (no correction for reflection) [dB(A)]

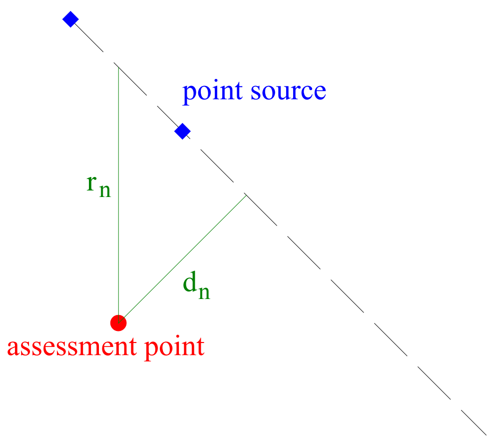

Figure 6.1. Distance perpendicular to the continuation of the source line part to the assessment point (d_n)

NOISE EMISSION AT ASSESSMENT POINT

The noise emission at the assessment point is determined by the energetic sum over the contribution of different point sources:

$$L_{A,eq} = S_n \left(L_{w,n} - T_n\right) \qquad 6.7$$

AIR ATTENUATION D_N

The air attenuation is calculated with the following formula:

$$D_{air,n} = 0.0042 \times r_n \qquad 6.8$$

with r_n shortest distance between point source$_n$ to the assessment point [m]

METEOROLOGICAL CORRECTION D_{METEO}

The meteorological correction is calculated with the following formula:

$$D_{meteo,n} = 3.5 - 35 \times \left(\frac{\left(h_b + h_w\right)}{r_{0,n}}\right) \qquad 6.9$$

with $r_{0,n}$ measured horizontal distance between source point$_n$ and assessement point [m]

h_b height of the topside of the rail (BS) above ground level + 0.25 m[2] [m]

h_w height of the assessment point above ground level [m]

---

2 With exception of aerodynamically induced sources at high speeds (category 9). In this case, these high sources have to be taken into account.

SOIL ABSORPTION D_{SOIL}

$$D_{soil,n} = \left(S_{b,n}\gamma_{4-6}\left[h_b, r_{0,n}\right]+1\right)B_b - 3\gamma_0\left[h_b + h_w, r_{0,n}\right]\left(1-B_m\right) + \left(S_{w,n}\gamma_{4-6}\left[h_w, r_{0,n}\right]+1\right)B_w - 2 \qquad 6.10$$

with $r_{0,n}$ measured horizontal distance between source point$_n$ and assessment point [m]

h_w height of the assessment point above ground level [m]

$h_{b,n}$ height of the source point$_n$ above ground level [m]

B_b, B_m, B_w 0.8 average absorption factor for source, middle and assessment area [3] [-]

$S_{b,n}$ effectiveness of soil absorption in the source area (equation 6.11) [-]

$S_{w,n}$ effectiveness of soil absorption in the calculation area (equation 6.12) [-]

γ_0, γ_{4-6} intermediate functions where the values between square brackets must be substituted as x and y (equations 6.13 & 14) [-]

$$S_{w,n} = 1 - \left(\frac{\left(r_{0,n} - r_w\right)}{r_{0,n}}\right)\left(\frac{3h_{e,n}}{\left(3h_{e,n} + h_w + 1\right)}\right) \qquad 6.11$$

with $h_{e,n}$ effective barrier height as defined in equation 6.19b

If $h_{e,n} < 0$, then $S_{b,n} = 1$ (no screening effect).

$$S_{b,n} = 1 - \left(\frac{r_w}{r_{0,n}}\right)\left(\frac{3h_{e,n}}{\left(3h_{e,n} + h_w + 1\right)}\right) \qquad 6.12$$

For the intermediate function γ_0 and γ_{4-6} the following applies:

$$\gamma_0 = 1 - 30\left(\frac{x}{y}\right) \qquad 6.13$$

$$\gamma_{4-6} = e^{-0.46x\text{^}2}\left(1 - e^{-y/50}\right)\left(2.8 + 2e^{-0.44x\text{^}2}\right) \qquad 6.14$$

---

[3] This approach is allowed as long as the source area is almost completely absorbent. For railway tracks, this is the standard situation. If this – under special conditions – is not the case, higher assessment differences (±2 dB) may occur. In these situations, the real soil absorption is to be used in the calculation.

REFLECTION TERM $C_{REFLECTION}$

Generally, reflections do not play a part in calculating railway noise. Therefore, this calculation method does not take into account the influence of reflections, or:

$$C_{reflection} = 0 \qquad 6.15$$

SCREENING EFFECT $D_{BARRIER}$

To calculate $D_{barrier,n}$ the following terms are relevant:

r_n	shortest distance between point source$_n$ and assessment point [m]
$r_{0,n}$	measured horizontal distance between source point$_n$ and assessment point [m]
$r_{0,ow,n}$	measured horizontal distance between barrier and assessment point [m]
z_w	height of assessment point relative to the reference level (horizontal plane where z=0) [m]
$z_{b,n}$	height of source point$_n$ relative to the reference level [m]
$z_{T,n}$	height of the barrier relative to the reference level at the intersection of the barrier and the shortest distance between source point$_n$ and the assessment point [m]

For the benefit of the calculation, three points are defined on the barrier (figure 6.2)

K	intersection of the barrier with the view line (straight line between source and assessment point)
L	intersection of the barrier with the curved noise ray, running from source to assessment point under down wind conditions
T	top of the barrier

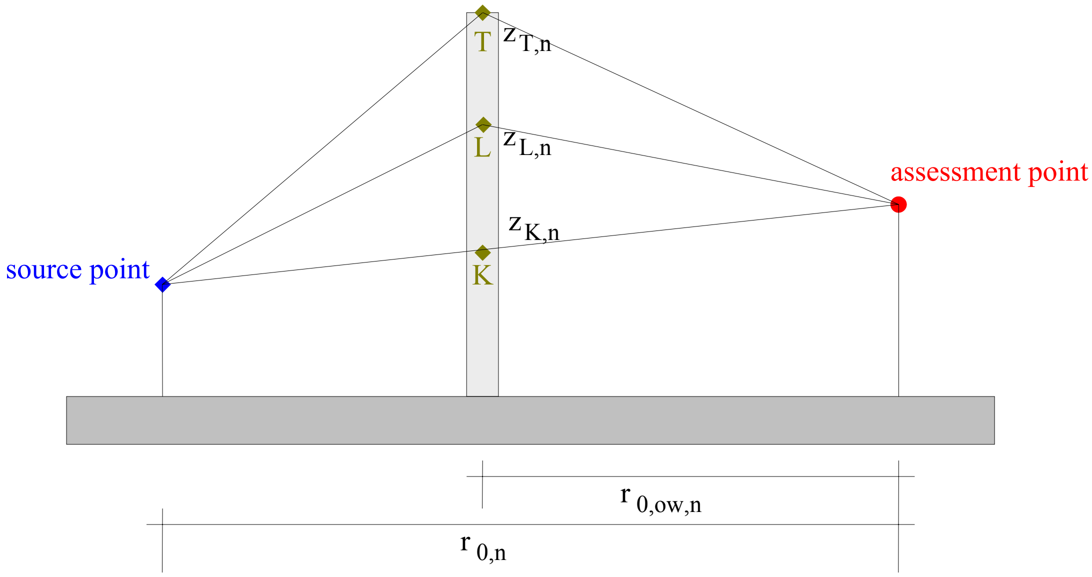

Figure 6.2. Cross section of a source point$_n$ to the assessment point with indication of points K, L & T

These three points are at heights $z_{K,n}$, $z_{L,n}$ and $z_{T,n}$ above the reference level. Height $z_{T,n}$ is known. For height $z_{K,n}$ the following applies:

$$z_{K,n} = z_{b,n} + \left(\frac{(r_{0,n} - r_{0,ow,n})}{r_{0,n}} \right) (z_w - z_{b,n}) \qquad 6.16$$

The line from source point$_n$ through L to the assessment point is a schematisation of the curved noise ray under following wind conditions. For the distance between points K and L, the following applies:

$$z_{L,n} - z_{K,n} = \frac{(r_{0,ow,n}(r_{0,n} - r_{0,ow,n}))}{26 r_{0,n}} \qquad 6.17$$

Combining equations 6.16 and 6.17 results in $z_{L,n}$.

Furthermore:

$r_{L,n}$	distance from the source point$_n$ through point L to the assessment point [m]
$r_{T,n}$	distance from the source point$_n$ through point T to the assessment point [m]

With these two numbers the acoustic deviation ε_n is calculated:

for $z_{T,n} \geq z_{K,n}$ $$\varepsilon_n = r_{t,n} - t_{L,n} \tag{6.18a}$$

for $z_{T,n} < z_{K,n}$ $$\varepsilon_n = 2r_n - r_{t,n} - t_{L,n} \tag{6.18b}$$

This leads for $D_{barrier,n}$ to:

$$D_{barrier,n} = 10\log(95\varepsilon_n + 3) - C_p \geq 0 \text{ and } \leq 25 \tag{6.19a}$$

The screening effect is minimum 0 dB(A) and maximum 25 dB(A). The term C_p is the profile dependent correction term as stated in table 5.4. For effective barrier height h_e, relevant for soil attenuation, the following applies:

$$h_e = z_{t,n} - z_{L,n} \tag{6.19b}$$

SCREENING EFFECT IN URBAN AREA D_{URBAN}

To calculate $D_{urban,n}$ the following terms are relevant:

h_w	height of the assessment point above the ground level [m]
h_{ridge}	average height of the ridge relative to the ground level [m]

The following terms are calculated:

$D_{total\text{-}barrier,n}$	maximum screening effect of a normal barrier and urban front [dB(A)]
$D_{normal\text{-}barrier,n}$	screening effect of a normal barrier [dB(A)]
$D_{front\text{-}barrier,n}$	screening effect of an urban front [dB(A)]
$D_{closed\text{-}barrier,n}$	screening effect of an urban front if this were 100% closed [dB(A)]
$D_{front\text{-}density}$	correction for the openness of the urban front [dB(A)]
p_n	density fraction of the urban front [-]
$D_{urban\text{-}ridge\text{-}3m}$	attenuation between the reference point at 3 m above the ridge and a point at 3 m below the ridge [dB(A)]
D_{urban}	attenuation between the reference point at 3 m above the ridge and a point on the floor where the sound pressure level is calculated [dB(A)]
A_{urban}	average distance between buildings [m]

This attenuation term can be applied if there are 10 or more buildings on a surface of at least 10 000 m². Less than 10 buildings on 10 000 m² is considered open space. To calculate the sound pressure level in an urban area (D_{urban}) this is firstly done at 3 m above the average ridge height in the considered area. Next, D_{urban} is subtracted (equation 6.23) in order to get the sound pressure level at the assessment points within the urban area.

To calculate the sound pressure level at the reference point, the presence of a "normal" barrier between source point$_n$ and the reference point is investigated, and whether the screening effect of the urban front is present in the reference point.

The maximum screening effect defines $D_{total\text{-}barrier,n}$:

$$D_{total-barrier,n} = \max\left(D_{normal-barrier,n}, D_{front-barrier,n}\right) \qquad 6.20$$

with $$D_{front-barrier,n} = 10\log\left(10^{-0.1D_{front-density,n}} + 10^{-0.1D_{density\ front-barrier,n}}\right) \qquad 6.21$$

with $D_{density\ front\text{-}barrier,n}$ being the screening effect of the urban front if this would be completely closed. This is calculated according to the $D_{barrier}$ equations mentioned above. The barrier height of the urban front is based on the average height of building in the urban area. This is only possible if the building height is reasonably uniform, limiting the variation of D_{house} to 2 dB. In case of higher variations, separate D_{house} areas should be defined, allowing them to be considered as a uniform area and treated separately. Individual buildings towering over the average building height are the exception. They can be entered as separate barriers.

$D_{front\text{-}density,n}$ accounts for the openness of the urban front:

for no clearly closed front: $$D_{front-density,n} = 0 \qquad 6.22a$$

otherwise $$D_{front-density,n} = 10\log\left(1 - p_n\right) \qquad 6.22b$$

After determination of the sound pressure level at the reference point, that at the assessment point is calculated, subtracting the value of D_{urban}:

$$D_{urban} = D_{urban-ridge-3m} + 0.66\left(h_{ridge} - h_w - 3\right) \qquad 6.23$$

$D_{urban\text{-}ridge\text{-}3m}$ is calculated based on the average building distance A_{urban}. The following applies:

for $A_{urban} < 125$ m $$D_{house,ridge-3m} = 11.7 - 4.5\log\left(A_{urban}\right) \qquad 6.24a$$

for $125 \leq A_{urban} \leq 175$ m $$D_{house,ridge-3m} = 32.9 - 14.6\log(A_{urban}) \qquad 6.24b$$

for $A_{urban} > 175$ m $$D_{house,ridge-3m} = 0 \qquad 6.24c$$

The average building distance is determining by counting the number of intersection of a regular grid adjusted to the urban area. The grid lines will intersect several times with the buildings. Figure 6.3 shows this in detail.

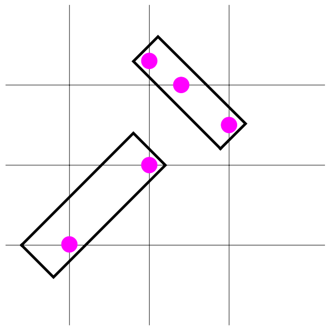

Figure 6.3. Grid lines and intersection to determine the average building distance

Next, the total length of the grid lines within the D_{house} area is determined. The average building distance is found by dividing the total length by the number of intersections.

It is possible that within the urban areas, the average building distance varies so much that the areas are to be considered as separate D_{house} areas.

6 Emission register and noise mapping

INTRODUCTION

This chapter includes additional information in comparison with the original Dutch text:

§ 9.1 translation of the original text;

§ 9.2 guidelines given in annexe of the original text;

§ 9.3 additional information about its use for strategic noise mapping and reporting according to END terminology;

§ 9.4 summary

EMISSION REGISTER

The emission register contains all parameters required for determination of the emission values:

a. a map with indication of the track position for the considered region;
b. a description of the tracks with start and end point, and if present all stations and their position;
c. the track intensity in units per hour, averaged over a year, for day, evening and night period, with a distinction between braking and non braking trains and vehicle category;
d. the average speed per vehicle category per section, and if necessary per period;
e. a description per track of the track construction and if present all bridge constructions, level crossings, switches and/or other particularities;
f. an overview of emission characteristics of vehicles and track constructions not belonging to the types in § 1.1.

If the data are to be used for strategic noise mapping, the emission data should fulfil the criteria of the EC directive: average data over one year period.

Considering the fact that these data need to be directly used for acoustical surveys, they need to comply with the minimum requirements for accuracy. With this the efficiency should not be neglected: collecting and storing data requires a certain amount of effort that can increase exponentially if the requirements become too strict.

For each type of data mentioned above, the minimum requirements are described below.

Map

The map must state a unique link between the gathering of data and the track route. A certain scale level is not imposed as it depends on the complexity. In most cases a scale of 1/25 000 is sufficient, but in some urban areas 1/10 000 is necessary. A stepless adjustable electronic version must for each route provide the link with the data.

Tracks

The start and end of each track must accurately be stated in metres. For a multi track route the type of track must be stated. For the position of stations a global indication with an accuracy of 100 m and the name is sufficient.

Vehicle intensity

Use of the track must be stated per track, in units per hour, rounded up to 0.1 unit. The statement is done per vehicle category according to § 1, over day, evening and night period.

Speed profile

Speeds on the route, averaged over a year, are stated per vehicle category, including indication where the vehicles at normal conditions in the service use their brakes. If several speed profiles need to be used, an indication of which part of the vehicles use which profile is necessary (see also intensities). Speeds are to be rounded up to the nearest 5 km/h.

Track

The position – beginning and end – of the constructions described in § 1 are indicated with an accuracy of 1 m. In very complex situations (several switches over distances less than 100 m) an indication of the number of joints over the complex situation is sufficient, depending on the total number of switches.

If a new type of vehicle – any vehicle not listed in § 1.1 – uses a part of the track, emission characteristics need to be known. Because the evaluator is obliged to send the results, these can be included in the register.

Barriers

If the position of barriers is included in the register, the following data should be stated:

a. beginning and end [m];
b. track along which it is placed;
c. indication whether it is placed on the left or the right side of the track;
d. height [m].

Height (not mandatory)

The height must be given with an accuracy of 0.1 m for each section of 100 m.

EMISSION VALUES

Emission values are determined per emission section, i.e. per section of the railway for which the emission value of the train noise remains more or less constant. Before the emission value can be calculated, the location of the emission section must be determined, or in other words: the positions on the railway line at which the transitions between emission sections occur.

Generally, these transitions are located at points where one or more of the fundamental conditions for emission calculation change to an extent significant for the end result.

In practice, this means the transition points between emission sections are located:

a. at points where the intensity of the traffic changes, i.e. at switches or at points where tracks join or separate.

b. at points where the average travelling speed changes, as happens at the beginning and end of speed limited zones. In the case of these sections, the average speed travelled in these sections must be taken into account when calculating the emission.

c. at points where the type of rail fixture changes. The various types are: wooden or concrete sleepers (where zigzag concrete is equal to wood as far as noise emission is concerned) and direct rail fixtures mounted on concrete or steel foundations.

d. 30 metres in front of and behind a railway section with discontinuous welded rails.

e. 30 metres in front of and behind the outermost disconnection of a railway section, with two or more switches with a distance of less than 50 m from each other.

As a result, emission sections that are shorter than one tenth of the distance between section and assessment point, do not have to be taken into account. A further result is that a minimum emission section has not been fixed. This does not only depend on the distance to the adjacent section, and consequently the relative viewing angle, but also the sound path.

At points where an area with track disconnections begins or ends, for example rails with joints, switches and crossings, the distance of 30 m can be reduced as much as necessary if the transmission points from one emission section to another occur within too short a distance of each other. If using Global (dB(A)) Method 1 to calculate, the emission values are defined over a length four times the horizontal distance between the assessment point and the railway; this length is symmetric to the normal distance from the assessment point to the railway. The emission for the entire railway area inside the observation area is recognised in this way.

Two groups of emission values are determined for each emission section: one value for the calculation described in § 2 in dB(A) and for § 3, eight (octave) values for two source heights.

This means, 16 values per section for the calculation described in § 3. In the case of simple situations (1 or 2 rails close to each other) one value or a series of values is always given. It is presumed that the noise is emitted from the centre of the railway tracks. The centre line of the railway forms the driving lane, as is to be used in the model calculation. If more than one lane is to be included in the calculation and if more precise information is not present, then the emission value concerned is divided evenly between both lanes. In the case of complex or asymmetric situations the emission values for the driving lanes are specifically provided. This part of the guideline provides the formulas for calculating the emission values, based on intensity, vehicle category, brake system and the condition of the railway.

The emission value per octave band is calculated for several source levels. This refined method is particularly appropriate when calculating attenuation. When trains with so called block brakes brake, the source of noise emission relocates noticeably upwards. The various correction factors for railways depend on the type of trains . However the various factors cover all types of railway. An exception can be found in the form of steel viaducts, for which clear regulations have not yet been given. When determining the emission value for this type of viaduct, the correction factor for the railway must be determined by comparative measurements.

Specifically relevant in this guideline is the high-speed trains (the "Thalys", Category 9). Due to its aerodynamic sound, sources are differentiated at levels of 2, 4 and 5 m. The source at BS is for Thalys without emission. The composition of the Thalys is always the same: 8 wagons and 2 engines (10 units). Although the emission levels are different, the units can still be considered as one category. If necessary, however, the engine units can be individually calculated when the emission identifiers concerned are known.

The emission value on steel bridges, on other constructions and railway constructions not mentioned in this guideline can be ascertained by means of measurement. The standard calculation can be used as a starting point. A position along a section with a known emission value is then chosen as a reference point for measurement; the other microphone is positioned along the section of the railway, which is to be measured. Both microphones are positioned the same distance from the railway, vertically and horizontally.

The emission value for diesel material and certain electrical engines contains no contribution of sound production when accelerating or when stopped. Due to the fact that the exhaust and ventilator noise is emitted at high levels, it must be taken into account that positioning a barrier at points where train vehicles is regularly accelerated or rotates at a stopped position makes no sense if this noise is not considered. The calculation method doesn't provide for the determination of noise pollution in these cases. In this situation it would be better to work with the methods described in "Guidelines for the Calculation and Measurement of Industrial Noise".

STRATEGIC NOISE MAPPING

The calculated noise levels at the assessment points fulfil the criteria for strategic noise mapping if the emission register contains corresponding data:

for L_{day} yearly average of vehicle density during day period for each vehicle category;
for $L_{evening}$ yearly average of vehicle density during evening period for each vehicle category;
for L_{night} yearly average of vehicle density during night period for each vehicle category.

The global evaluation parameter L_{den} is then calculated according to the procedure in EC-document 6660, annex I.

$$L_{den} = 10\lg\frac{1}{24}\left(12*10^{L_{day}/10} + 4*10^{L_{evening}+5/10} + 8*10^{L_{night}+10/10}\right) \qquad 9.1$$

with: L_{day} A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods of a year
$L_{evening}$ A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods of a year
L_{night} A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year

As meteorological conditions, similar to the other interim calculation methods, following hypotheses are assumed:

- down wind:
  - day period: 50%;
  - evening period: 75%;
  - night period: 100%.

The assessement points are to be situated:

- height: 4 m;
- distance to façade: 2 m;
- calculation without reflection on the considered façade.

SUMMARY OF INPUT DATA FOR CALCULATION METHOD

A list of input data requested for the above defined calculation method is summarised hereafter.

Introduction

The Dutch statutory calculation scheme for Rail-traffic Noise requires a description of the situation in terms of:

Emission data

- Track type
- Passing trains:
  - number and types of passing trains;
  - driving speeds of the trains;
  - braking actions.

Assessment data

- Co-ordinates, in a user defined rectangular co-ordinate system of:
  - tracks;
  - obstacles like buildings;
  - observation point(s);
- Sound absorbing surfaces:
  - fraction of the soil between track and observer that is sound absorbing;
  - other surfaces, such as sound barriers.

Emission data

Track sections

If the characteristics of the track, of the rolling stock or of driving conditions depend on the position along the track, different straight track sections are defined by the positions of their outer points. The characteristics and conditions should be virtually homogeneous along a section. Track type (1-9) and density of rail joints (1-4) are specified for each section.

Track type (1-9)

1. track with concrete single block or twin block sleepers in ballast bed;
2. track with wooden or zigzag concrete sleepers in ballast bed;
3. track with ballast bed and
   - rails with joints ;
   - rails with not more than two crossings with joints within 50 m;
4. track with blocks;
5. track with blocks and ballast bed;
6. track with controllable rail fixation;
7. track with controllable rail fixation and ballast bed;
8. track with poured-in rail;
9. track with level crossing.

Density of rail joints (1-4)

1. jointless rail (fully welded) with or without jointless switches and crossings;
2. rails with joints;
3. switches and crossings with joints, 2 per 100 m;
4. more than 2 crossings per 100 m (the number of crossings can be stated).

Vehicle specifications

Category:

1. passenger train with tread brakes;
2. passenger train with both disc brakes and tread brakes;
3. passenger train with disc brakes;
4. goods train with tread brakes;
5. diesel train with disc brakes;
6. underground or express tramway vehicle with disc brakes;
7. intercity train with disc brakes;
8. high speed trains with disc brakes and/or tread brakes.

For each category:

1. vehicle intensity (number of passing trains per hour) [1/h];
2. driving speed (for trains that are passing at constant speed) [km/h];
3. percentage of braking vehicles [%];

Sound power levels of non-standard vehicles (not fitting within categories 1-7): in decibels re 1 pW, at track height and at 0.5 m above railhead, for the octave bands with centre frequencies 63-8000 Hz.

Assessment data

Buildings

Specified are:

- sizes (by the positions of the corners, in the co-ordinate system that has been chosen);
- height (ride height in case of a peaked roof) [m];
- reflection factor of façades [%].

Sound barriers

Specified are:

- height [m];
- shape types: sharp or obtuse top (angle between 0° and 70° or between 70° and 165°);
- reflection coefficients of barrier surfaces (standard or customised).

Soil

Specified are:

- fraction of sound absorbing soil surface between track and observer [-];
  or
  hard and sound absorbing areas are specified separately by stating the character of each area (reflecting or absorbing) and the positions of the border lines.
- height of ground surfaces [m].

Assessment point

For each point is specified:

- position [m];
- whether or not it is on a façade or in an open field.

Maximum number of reflections per sound ray

The maximum number of reflections per sound ray is specified. A possible sound transmission path – sound ray – is only taken into account if it can be constructed with not more than the specified maximum number of reflections.