technology platform for transport, infrastructure and public space

Technical Regulations for Methods of Measuring Emission

Rail Traffic 2006

- translated version -

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Foreword

The emission characteristics of a rail vehicle or of a track construction must be determined by measurement. This has already been carried out for almost all of the rail vehicles that make use of the Netherlands railway network and the characteristics have been recorded in the form of emission values in Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006.

A number of measurement methods are included in these technical regulations for the determination of the properties of non-standard rail vehicles and track constructions.

1. Procedure A (simple). This procedure can be used to determine whether a rail vehicle belongs to a category for which the characteristics are already included in the Calculation and Measurement Regulations Noise Nuisance Act.
2. Procedure B. This procedure can be used to determine the emission values of rail vehicles.
3. Procedure C. This procedure can be used to determine correction terms for new types of superstructure.

These technical regulations describe these three procedures.

These regulations have been prepared under the responsibility of the CROW steering group Calculation and Measurement Regulations. The following experts among others were involved in the preparation of these regulations:

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Contents

1 Placing in existing categories - Procedure A

1.1 Introduction

This procedure is to be used to determine whether a rail vehicle belongs to an existing rail vehicle category as described in Appendix IV of the Calculation and Measurement Regulations Noise Nuisance Act.

1.2 Passage measurements at constant speed

Measurements are made on a ballast track with 54E1 rails on monoblock or duoblock sleepers and base plates with a static stiffness of 300-500 kN/mm at 60 kN pre-stressing (for example type FC9/Tiflex/4.5mm/Cork rubber). The rail roughness must be measured and found to be lower than the average rail roughness of the Netherlands railway network $L_{rtr,NL}$ as given in Table 3.5. The track must be in a good state of repair. The maximum gradient allowed is 1:100 and the curve radius must be at least 5000 m. There must not be any breaks in the rail, welds, damage to the running surface or loose sleepers that could cause knocking noise within 25 m of the measurement site.

The condition of the train, the measurement site, measurement conditions and measurement equipment must comply with the description given in paragraph 2.2. The measurement equipment consists of a sound level meter suitable for octave band analysis.

The A weighted equivalent sound pressure level in octave bands $L_{pAeq,Tp,i}$ is measured at one measurement cross-section at a distance of 7.5 m from the track centre line and 1.2 m height above the top of the rail (BS). The measurement time is the passage time T_p from buffer to buffer (T_p= train length/speed). Measurements are made at constant speed within the following speed ranges in turn (in so far as these are not more than the maximum speed):

1. Maximum speed
2. 40-65 km/h (preferred speed 50 km/h)
3. 65-90 km/h (preferred speed 80 km/h)
4. 90-120 km/h (preferred speed 100 km/h)
5. 120-160 km/h (preferred speed 140 km/h)
6. 160-220 km/h (preferred speed 200 km/h)
7. >220 km/h

The speeds per range must differ from each other by at least 10%. Range 2 can be omitted for pulled equipment without traction. At least three passages must be measured per speed range.

A vehicle is admitted to a category if the measured sound pressure level $L_{peq,Tp,i}(v)$ at 7.5m lies under the $L_{peq,Tp,i,calculated}(v)$ level calculated in accordance with SRM2 for every measurement speed v increased by a correction term $L_{diff,i}$:

$$L_{peq,Tp,i}(v) + L_{diff,i} < L_{peq,Tp,i,calculated}(v) \quad (1.1)$$

$L_{diff,i}$ is a rail roughness correction term for the test track relative to average track and is determined as follows:

- $L_{diff,i} = 1$ at speeds where rolling noise dominates and the wheels are braked by cast-iron brake blocks
- $L_{diff,i} = 1$ at speeds where traction noise or aerodynamic noise dominates
- $L_{diff,i} = 1 + Y_i(v)$ at speeds where rolling noise dominates and the wheels are ***not*** braked by cast-iron brake blocks. Y_i is defined as:

(1.2) $$Y_i(v) = L_{rtr,NL,i}(v) \oplus L_{rveh,i,c}(v) - L_{rtr,i}(v) \oplus L_{rveh,i,c}(v)$$
for i=1,2,8 (63, 125 and 8000 Hz bands) $Y_i(v) = \min(Y_i(v), 3{,}5)$

where ⊕ stands for energetic summation, $L_{r,i}(v)$ is the roughness in octave band *i* at train speed *v*, *tr* stands for track, *veh* stands for vehicle, *NL* is the average rail roughness of the Netherlands railway network and *c* shows the train category.
The average rail roughness of the Netherlands railway network $L_{rtr,nl,i}(v)$ is given in Table 3.5 (this is energetically summed to octave bands). The measured wheel roughness $L_{rveh,i,c}$ is used if available, otherwise default wheel roughness values from Table 3.5 for known train categories are used.

It is permitted for the level per octave band (1.1) to be exceeded provided that the average of these Δ_{ave} is less than 1.5 dB. The difference $\Delta_{i,j}$ in all octave bands *i* and at all speeds *j* is used when calculating this average. The value of zero is used where there is a negative difference (no exceeding):

(1.3) $$\Delta_{gem} = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{8}\sum_{i=1}^{8}\max(\Delta_{i,j},0)\right] \quad \textit{(ave)}$$

The following relaxation applies if at least five vehicles are tested and if these have covered at least 10,000 km under normal operating conditions:
- $L_{diff,i}$ is reduced by 1 dB
- the octave bands 63, 125 and 8000 Hz are not taken into account in (1.1) - (1.3).

1.3 Report

The report consists of the items mentioned in paragraph 2.8 with the exception of 6, 15, 16, 17, 18 and 19. The measured sound pressure level in octaves for all measured speeds is also given and compared with the spectral details for the category to which the vehicle is to be allocated. The rail roughness correction term $L_{diff,i}$ is reported with a justification for the choice made for $L_{diff,i}$.

2 Full emission measurement method - Procedure B

2.1 Introduction

This procedure is to be used for the determination of the emission characteristics of new equipment. The data may only be used after the Ministry of VROM (Housing, Spatial Planning and the Environment) has given permission for this.

2.2 Organization of the measurements

Number and condition of the rail vehicles

At least four examples of freight cars and other pulled equipment must be tested. At least two examples of locomotives and combined train units must be tested, either as one train or in separate passages, whereby averaging is carried out afterwards. If the equipment to be tested forms part of a train with other equipment attention must be paid to the influence of adjacent vehicles.

The rail vehicles must have covered at least 10,000 km under normal operating conditions with the braking system switched on and at least 50 normal brakings to a standstill must have been carried out. As well as this at least 20 quick brakings to a standstill must also have been carried out.

The rail vehicles must be tested when unladen and with closed windows and doors. Traction vehicles such as locomotives must have a normal pulled load. Additional equipment that is normally in operation must also be on during the testing.

Specification of the track to be used

Measurements are made on a ballast track with 54E1 rails on monoblock or duoblock sleepers and base plates with a static stiffness of 300-500 kN/mm at 60 kN pre-stressing (for example type FC9/Tiflex/4.5mm/Cork rubber). The rail roughness must be measured and found to be lower than the average rail roughness of the Netherlands railway network $L_{rtr,NL}$ as given in Table 3.5.

The track must be in a good state of repair. The maximum gradient allowed is 1:100 and the curve radius must be at least 5000 m. There must not be any breaks in the rail, welds, damage to the running surface or loose sleepers that could cause knocking noise within 25 m of the measurement site.

The acoustic environment

The test environment must provide free field conditions. The ground must be free of obstacles and there may not be any reflecting objects in the vicinity such as walls, buildings, slopes or bridges. The track must be in a flat area. There may not be any obstacles in the vicinity of the measuring microphones that could interfere with the noise field, such as persons for example, and the observer may also not be in a position where the noise measurement would be influenced. The ground between the track and the measuring microphone must be as free as possible 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 permitted. The ground must be described in the report.

Meteorological conditions and background level
Measurements may only be made at wind speeds under 5 m/s and when there is no precipitation (rain or snow). The track must be dry and free of snow and ice. The temperature, humidity, air pressure, wind speed and wind direction must be recorded while taking the measurements and stated in the report.

Background noise that could 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.

Values to be measured and measurement position
The measurement position differs per type of measurement and is stated in the relevant paragraph. The microphone must be set up directed horizontally at the track. The sound pressure level is recorded over time and processed as the equivalent unweighted 1/3 octave spectrum and octave spectrum $L_{peq,Tp}$. The total unweighted and A weighted level and the measurement time T_p are also recorded. The measurement time T_p is the passage time from buffer to buffer and is equal to the train length divided by the speed.

Special measurements for source height determination may be necessary for equipment with traction or aerodynamic sources. This is described in the relevant paragraphs.

Rail vibrations are also measured to determine rolling noise. This is described in paragraph 2.4.

The train speed is determined using a radar-Doppler system or a system with comparable accuracy. Below 100 km/h the measured speed must be within 3 km/h of the speed to be reported; for speeds of 100 km/h and more the measured speed must be within 5 km/h of the speed to be reported.

Measurement equipment
Microphones and vibration sensors with measurement chains, a multiple channel 1/3 octave and octave analyser and multichannel recording equipment are necessary for the measurements. The vibration sensors must be resistant to moisture and be able to be properly attached. The measurement chains must be properly tuned to prevent possible overloading of the measurement signal. All measurement equipment including analysers, cables and recorders must comply with the requirements for ‘type I’ equipment in accordance with NEN-EN-IEC 61260. Microphones must be calibrated with a near enough flat frequency characteristic in the free field. The 1/3 octave filters and octave filters must comply with NEN-EN-IEC 61260. The microphones must have a wind cap. The measurement chains of the microphones and vibration sensors must be calibrated before and after each measurement series using calibrators with an accuracy of at least ±0.3 dB (class 1 in accordance with HD 556 S1) at one or more frequencies in the relevant frequency range. Measurement results must be rejected if there is a difference of more than 0.5 dB in the calibration. The frequency range is 20-10,000 Hz. The calibrators must be checked in accordance with HD 556 S1 at least once a year. The instruments must be checked at least every two years in accordance with NEN-EN-IEC 61260. The date of the most recent calibration must be reported.

Definitions

v = train speed [km/h]
f = frequency [Hz]
λ = wavelength of direct and effective roughness [m]
$L(f)$ = level in 1/3 octave band with frequency f, in accordance with 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} = equivalent sound pressure level of a passage, part contribution from the vehicle [dB re 2.10-5 Pa]
L_{pveh1} = equivalent sound pressure level of a passage, traction noise of the vehicle [dB re 2.10-5 Pa]
L_{pveh2} = equivalent sound pressure level of a passage, rolling noise of the vehicle [dB re 2.10-5 Pa]
L_{pveh3} = equivalent sound pressure level of a passage, aerodynamic noise of the vehicle [dB re 2.10-5 Pa]
L_{ptr} = equivalent sound pressure level of a passage, part contribution from the track [dB re 2.10-5 Pa]
L_{rtot} = total effective roughness level of wheel and rail [dB re 1 micron]
L_{rveh} = average effective wheel roughness level of the vehicle [dB re 1 micron]
L_{rtr} = average effective rail roughness level of the track [dB re 1 micron]
$L_{rtr,dir}$ = average direct rail roughness level of the track as measured with a probe measurement system [dB re 1 micron]
$L_{rtr,NL}$ = national average effective rail roughness level of the track [dB re 1 micron]
$L_{Hpr,veh}$ = transfer function of effective roughness to sound pressure at the microphone position for noise emission from the vehicle [dB re 20 Pa/√m]
$L_{Hpr,tr}$ = transfer function of effective roughness to sound pressure at the microphone position for noise emission from the track [dB re 20 Pa/√m]
$L_{Hpv,tr}$ = transfer of vertical rail head vibration to sound pressure at the microphone position for noise emission from the track [dB re 20 Pa/m/s]
L_v = equivalent level of vertical rail head vibration, vibration speed [dB re 10-6 m/s]
D_s = distance damping of the track, vertical [dB/m]
E = emission value or term [dB(A)]
N_{axle} = number of axles [-]
l_{veh} = vehicle length [m]
$\oplus$ = energetic summation: $x \oplus y = 10 \lg (10^{x/10} + 10^{y/10})$

2.3 Determination of traction noise

If the equipment has its own traction, such as with locomotives and trains with a fixed composition and driven bogies, the traction noise must be measured separately. Traction noise includes the noise of supplementary equipment that is normally in operation during running. Examples of traction noise sources are diesel engines, gear drives and cooling fans.

Measurements under *maximum acceleration* from standing still to 60 km/h are made for separate locomotives. Measurements are made with locomotives at two measurement cross-sections at 5 m, 20 m and if necessary at 30m in front of the vehicle (measured from the buffer). The speed when riding into the two cross-sections is recorded. The measurement interval lasts from the start until the back of the vehicle has passed the microphone cross-section by 20 metres. Measurements are made when accelerating from standing still and also from start speeds of 20 and 40 km/h.

Equipment with its own traction is measured at a *constant speed* with preferred speeds of 30 and 50 km/h. When doing so the traction system should supply power as it would under stable conditions on level track. A diesel power supply will then run at an average number of revolutions, but not at the minimum. Equipment with own traction is measured at one measurement cross-section. Two passages are measured in all cases and the results of these averaged.

The equivalent sound pressure level as a result of traction in octaves $L_{pveh1,i}$ is measured at 1.2 m above BS and 7.5 m from the centre line of the track. The measurement time is equal to the passage time T_p.

The measurements are averaged per speed. A spectrum as function of train speed v is determined by interpolation from the average spectra of the measurements at 7.5 distance:

(2.1) $$L_{veh,i} = x_1(i) + y_1(i)\ lg(v)$$

where:

$L_{pveh1,i}$	=	equivalent sound pressure level at 7.5 m as a result of traction in octave band *i*;
$x_1(i)$ and $y_1(i)$	=	constants per octave band number that describe the linear relation between sound pressure level and lg(v)
v	=	speed in km/h

This spectrum is extrapolated to higher speeds for the determination of the emission characteristics, unless it is known on other grounds how the traction noise depends on the speed. Attention must be given to making sure that the traction noise dominates over the rolling noise.

Source height determination

The traction noise is allocated to different source heights: axle height (0.5 m), 2 m or 4 m above BS. The source heights can be determined on the basis of known positions of physical sources, but sometimes special measurements are required to establish this objectively. A height of 0.5 m is taken for equipment with traction and sources at axle height. Some sources must be divided over two or more heights. The energetic summation of the part sources $L_{pveh1,i}(h)$ must equal the total level. The traction noise as a function of height is indicated as the octave spectrum $L_{pveh1,i}(h)$, where h = 0.5 m, 2 m or 4 m.

Traction noise sources can occur at several heights, such as for example with diesel locs or diesel train sets where the exhaust, the air intake and the engine room itself can be a source. The intake and outlet of the cooling system can be noise sources at different heights for electrically driven equipment.

A way of determining the source height is to use measurement by microphone array. Another option is a measurement with two microphones at shorter distance, for example 4m, at heights of 1.2 m and 4.5 m above BS respectively.

If safety allows it is preferable to carry out source height determination by means of measurement at less than 4 m distance, for example by measuring at 2 m distance. The source height is chosen depending on the maximum octave band value from both microphone positions. If the octave band value at 4.5 m is higher than at 1.2 m then the source height for the particular octave band is set at 4 m. If the octave band value at 4.5 m is equal to that at 1.2 m then the source is divided over 2 m and 4 m. If the octave band value at 4.5 m is less than that at 1.2 m then the source is set at 2 m.

2.4 Determination of rolling noise

Four core values are used for the determination of the total rolling noise:

1. wheel roughness
2. transfer wheel → noise
3. rail roughness
4. transfer rail → noise for a superstructure of concrete sleepers in ballast bed

These core values are derived from measurement data.

An important characteristic of Procedure B is that the rail roughness at the site of the measurements is replaced by the average roughness of the Netherlands network.

Deriving the four core values mentioned above and making the correction for the rail roughness at the measurement site to the NL roughness takes place in a number of steps. An overview of these steps is given in the flow chart below.

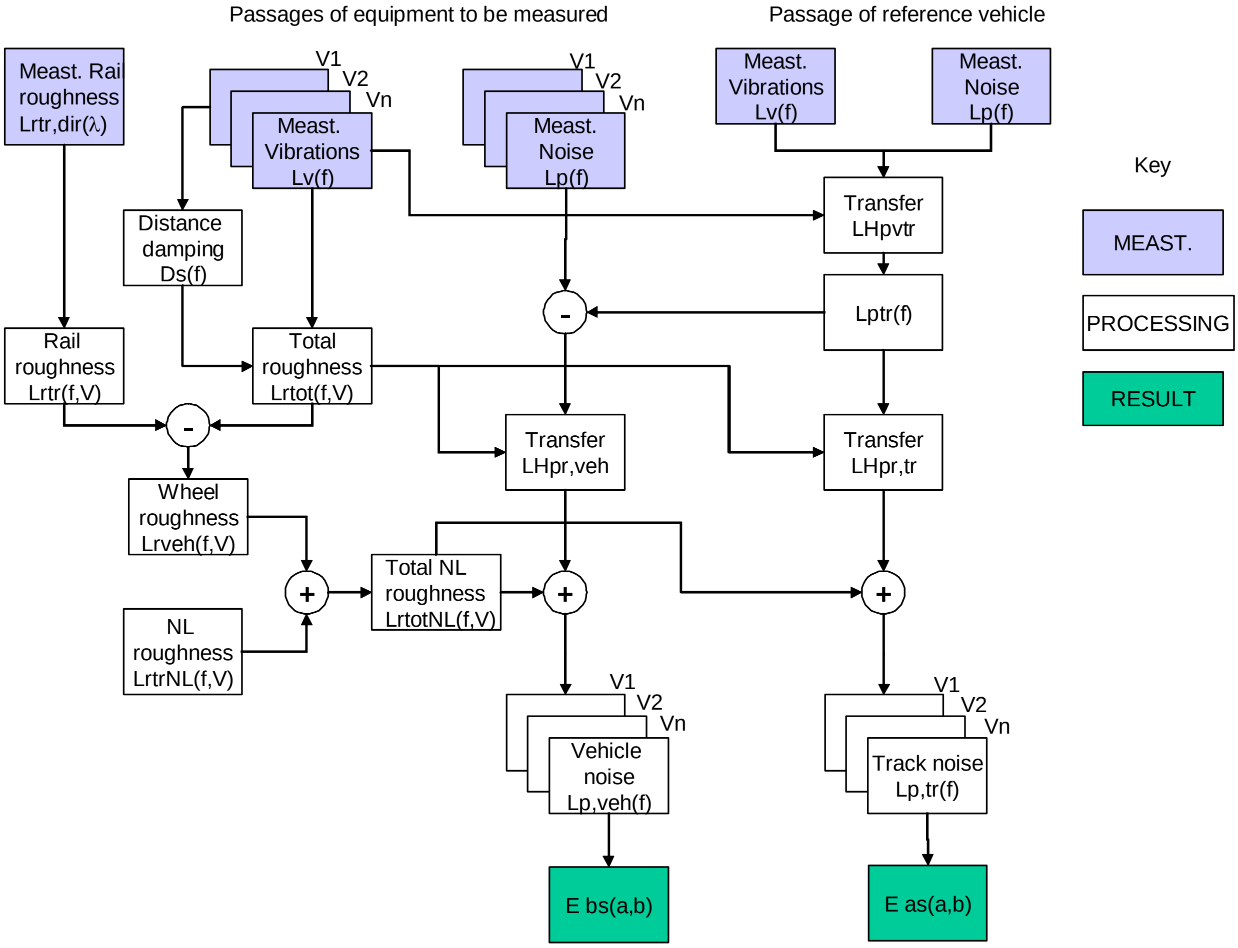

Figure 2.1 Flow chart for processing rolling noise: from measurement data to emission values

Details of all process steps are described in paragraphs 2.4.1 to 2.4.7. Measurements are made at constant speed in the following speed ranges in turn (in so far as these are not above the maximum speed):

1. Maximum speed
2. 40-65 km/h (preferred speed 50 km/h)
3. 65-90 km/h (preferred speed 80 km/h)
4. 90-120 km/h (preferred speed 100 km/h)
5. 120-160 km/h (preferred speed 140 km/h)
6. 160-220 km/h (preferred speed 200 km/h)
7. >220 km/h

The speeds per range must differ from each other by at least 10%. Ranges 2 and 3 can be omitted for pulled equipment without traction. It is recommended to use the same measurement speeds as far as possible for rolling, braking and traction noise.

The sound pressure is measured at 7.5 m from the centre line of the track and at 1.2 m ± 0.2 m height relative to the running surface of the rails.

If traction noise or other sources dominate at the named speeds the measurements must be carried out with the traction system switched off (pulled equipment or switched off traction).

Measurements must be made at three cross-sections along the track at distances of 10 to 25 metres from each other. The results of these measurements are averaged. An alternative is to take measurements of three passages at one cross-section and to average these.

The rail vibration level is measured vertically under the rail foot as close as possible to the sleeper at each measurement cross-section. The vibration level is recorded as a time signal and processed as equivalent unweighted 1/3 octave spectrum for the speed level L_{veq} during the measurement time T_p. Measurements must be made on both rails during at least one test in order to average any differences. If it is found that the differences lie within ±2 dB during one passage of the test vehicles then further vibration measurements need only to be made at the side with the measuring microphone. If differences of more than 2 dB in vibration level are found between both rails the average of the two signals must be taken.

2.4.1 Determination of the effective rail roughness

The rail roughness L_{rtr} at the measurement site is measured in 1/3 octaves in accordance with the procedures described in NEN-EN-ISO 3095:2005. The measurements may not be older than six months. The rail roughness is measured as a function of the wavelength in this standard.

The rail roughness should be known for wavelengths between 0.055 cm and 140 cm for a speed range of 20 km/h to 250 km/h. However, state-of-the-art rail roughness measurement systems supply roughness data in a wavelength range from 0.16 cm to 25 cm. Missing data may be determined by extrapolation.

The measured direct rail roughness must be converted to an effective rail roughness by correcting with a contact filter. This is done in the wavelength domain. A direct roughness measurement gives the direct roughness as a function of the wavelength. The weighting of the contact filter is applied to this:

(2.2) $$L_{rtr}(\lambda) = L_{rtr,dir}(\lambda) + A_3(\lambda)$$

where:
$L_{rtr}(\lambda)$ = effective rail roughness
$L_{rtr,dir}(\lambda)$ = direct rail roughness
$A_3(\lambda)$ = conversion spectrum as a result of the contact filter, see Table 2.1.

It is also permitted to use other specific details for determining the effect of the contact filter if these are available.

The effective rail roughness found as function of the wavelength from equation (2.2) is converted to an effective roughness as function of the frequency in accordance with the procedure in paragraph 3.1. This must be carried out for each speed.

Table 2.1 Conversion spectrum $A_3(\lambda)$ (contact filter) as function of the wavelength λ for different wheel diameters and wheel loading

Wavelength [cm]	360 mm / 50 kN	680 mm / 50 kN	920 mm / 50 kN	920 mm / 25 kN	920 mm / 100 kN
20	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0
12.5	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	-0.2	0.0	-0.2
6.3	0.0	-0.2	-0.5	-0.2	-0.6
5	-0.2	-0.4	-1.1	-0.5	-1.3
4	-0.5	-0.7	-1.9	-0.9	-2.2
3.15	-1.2	-1.5	-3.3	-1.6	-3.7
2.5	-2.0	-2.8	-5.0	-2.5	-5.8
2	-3.0	-4.5	-7.3	-3.8	-9.0
1.6	-4.3	-7.0	-9.8	-5.8	-12.5
1.25	-6.0	-10.3	-12.5	-8.5	-13.5
1	-8.4	-12.9	-13.8	-11.4	-13.5
0.8	-11.3	-13.6	-13.7	-12.6	-15.3
0.63	-11.9	-14.5	-15.1	-13.5	-16.4
0.5	-12.5	-15.5	-16.5	-14.5	-17.5
0.4	-13.9	-16.0	-16.4	-16.0	-18.4
0.315	-15.5	-16.5	-17.5	-16.5	-19.5
0.25	-17.0	-17.0	-17.8	-17.7	-20.5
0.2	-18.4	-17.5	-18.3	-18.6	-21.5
0.16	-19.9	-18.0	-18.8	-19.6	-22.4
0.125	-21.5	-18.5	-19.4	-20.6	-23.5
0.1	-22.9	-19.0	-19.8	-21.6	-24.5
0.08	-24.4	-19.5	-20.3	-22.6	-25.4
0.0063	-27.4	-20.5	-21.4	-24.6	-27.5
0.05	-28.9	-21.0	-21.8	-25.6	-28.4

2.4.2 Determination of the total effective roughness (measurement)

The average total effective roughness L_{rtot} is derived from the vertical rail vibration of the rail head $L_v(f)$ in 1/3 octaves at particular train speeds as described in paragraph 3.1.

The rail roughness should be known for wavelengths between 0.055 cm and 140 cm for a speed range of 20 km/h to 250 km/h. Missing data must be determined by extrapolation.

2.4.3 Determination of the effective wheel roughness of the equipment (calculation)

The average effective wheel roughness of the equipment in 1/3 octaves $L_{r,veh}$ is derived from the total effective roughness L_{rtot}, and the effective rail roughness L_{rtr}: determined by measurement.

(2.3) $L_{rveh}(f) = 10lg(10^{L_{rtot}(f)/10} - 10^{L_{rtr}(f)/10})$

If $L_{rtot}(f)$ - $L_{rtr}(f)$ is < 1 or negative then it is taken per frequency band that

(2.4a) $L_{rveh}(f) = L_{rtot}(f) -7.$
and
(2.4b) $L_{rtr}(f) = L_{rtot}(f) - 1$

Equations (2.3) and (2.4a,b) are such that the energetic sum of the wheel and rail roughness always gives the total effective roughness.

It is also permitted to measure the wheel roughness directly. This must be done in a similar way to that of the direct rail roughness using a mechanical probe. The direct wheel roughness must be measured for at least three wheels per vehicle and always on three parallel lines on the running surface - in the middle of the running surface and at 10 mm on either side of this. An average must always be made over at least three rotations. All these direct roughness values are then averaged as direct roughness spectrum in order to obtain an average direct wheel roughness for the vehicle. The directly measured wheel roughness values must be converted to effective roughness values in the same way as with formula (2.2).

The rail roughness should be known for wavelengths between 0.055 cm and 140 cm for a speed range of 20 km/h to 250 km/h. Missing data must be determined by extrapolation.

2.4.4 Determination of the total effective roughness of average Netherlands track (calculation)

The total effective roughness of average Netherlands track $L_{rtot,NL}(f)$ is determined from the average Netherlands effective rail roughness $L_{rtr,NL}(f)$ and the actual effective wheel roughness of the equipment to be measured $L_{rveh}(f)$:

(2.5) $$L_{rtot,NL} = L_{rtr,NL}(f) \oplus L_{rveh}(f)$$

$\oplus$ = energetic summation

$L_{r,tr,nl}(f)$ is determined using the average Netherlands direct rail roughness $L_{rtr,NL,dir}(\lambda)$. This $L_{rtr,NL,dir}(\lambda)$ is given in the table in paragraph 3.2. $L_{r,tr,NL}(f)$ then follows in exactly the same way as is described in paragraph 2.4.1 ‘Determination of the effective rail roughness’ and paragraph ‘$L_r(v,f)$ - Roughness as function of frequency, speed dependent' in paragraph 3.2.

2.4.5 Determination of the track and vehicle contributions to rolling noise (calculation and measurement)

The track transfer $L_{Hpv,tr}$ in 1/3 octaves is determined by the procedure described in paragraph 3.3. The track noise L_{ptr} is calculated from the track transfer and the vertical rail vibration:

(2.6) $L_{ptr}(f) = L_{Hpv,tr} + L_{v(f)}$

(all terms in 1/3 octaves and unweighted).
The vehicle noise is determined from the energetic difference between the total sound pressure level and the track noise:

(2.7) $L_{pveh}(f) = 10lg(10^{Lptot(f)/10} - 10^{Lptr(f)/10})$

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

(2.8a) $L_{pveh}(f) = L_{ptot}(f) - 7$
and
(2.8b) $L_{ptr}(f) = L_{ptot}(f) - 1$

Equations (2.7) and (2.8a,b) are such that the energetic sum of L_{pveh} and L_{ptr} is always equal to L_{ptot}.

2.4.6 Determination of the track transfer function and the vehicle transfer function (calculation)

The track transfer function is determined from:

(2.9) $$L_{Hpr,tr}(f) = L_{ptr}(f) + L_{rtot}(f) + 10\lg\frac{N_{as}}{l_{veh}} \qquad (as = axle)$$

and the vehicle transfer function from:

(2.10) $$L_{Hpr,veh}(f) = L_{pveh}(f) + L_{rtot}(f) + 10\lg\frac{N_{as}}{l_{veh}}$$

(all terms in 1/3 octaves and unweighted). These transfer functions are standardized to the number of axles per metre N_{axle}/l_{veh} to make them independent of the axle density.

Each passage provides a transfer $L_{Hpr,tr}$[1]. These transfers are then averaged. This average transfer is used further in paragraph 2.4.7.

Each passage also provides a transfer $L_{Hpr,veh}$. These transfers are then averaged. This average transfer is used further in paragraph 2.4.7.

2.4.7 Determination of the contributions from track and vehicle (calculation)

The rolling noise emission from the vehicle is determined from:

(2.11) $$L_{pveh2,NL}(f) = L_{Hpr,veh}(f) + L_{rtot,NL}(f) + 10\lg\frac{N_{as}}{l_{veh}} \qquad (as = axle)$$

and for the track:

(2.12) $$L_{ptr,NL}(f) = L_{Hpr,tr}(f) + L_{rtot,NL}(f) + 10\lg\frac{N_{as}}{l_{veh}}$$

Note: these two formulas are directly dependent on the speed, because the total roughness is expressed as a function of the frequency (see paragraph 3.2).

[1] The values of these transfers will in general be close to each other. If this is not the case this indicates the presence of other noise sources or measurement errors.

These spectra are processed to octave spectra by:

(2.13) $$L(f_c) = L(f-) \oplus L(f_c) \oplus L(f+))$$

where:
f_c = octave band frequencies
f_-, f_+ = adjacent 1/3 octave band frequencies

2.5 Determination of the aerodynamic noise

Conditions and measurement circumstances
The contribution from aerodynamic sources must be measured if this is relevant for the calculations to be carried out where the equipment to be measured has a maximum speed of more than 200 km/h.

Train equipment with a lower maximum speed can also have important aerodynamic noise sources. If the total measured noise level at maximum speed is more than 1 dB(A) greater than the sum of the rolling noise and the traction noise the aerodynamic noise for this equipment must also be determined according to the procedure described here.

The aerodynamic noise is determined by making measurements between 250 km/h and the maximum speed in steps of 50 km/h. The train must be in the same configuration as for normal service during the measurements.

The pantograph(s) are off during this. The equivalent sound pressure level in octaves with passage time T_p as a result of the aerodynamic noise is measured at 25 m and 3.5 m above BS at one cross-section and for three passages per speed. The level at 7.5 m $L_{pveh3,i}$ is calculated from this.

The measurements are averaged per speed. A spectrum as function of the train speed v is determined from the average spectra of $L_{pveh3,i}$ by interpolation:

(2.14) $$L_{pveh3,i} = x_3(i) + y_3(i)\lg(v)$$

where:

$L_{pveh3,i}$	= sound pressure level spectrum at 7.5 m as a result of the aerodynamic noise
i	= octave band number
$x_3(i)$ and $y_3(i)$	= constants per octave band number that describe the linear relation between noise level and lg(v).

This spectrum may be extrapolated to lower speeds.

Source height determination
The aerodynamic noise is subdivided according to source height: 2 m, 4 m or 5 m above BS.

The aerodynamic noise as function of height is indicated as octave spectrum $L_{pveh3,i}(h)$, where h = 2 m, 4 m or 5 m.

Examples of aerodynamic sources are: the head and tail of the train set (particularly high cabins and the nose coupling), pantographs and their roof installations, bogies and components under the floor, connections between cars, voids and projecting items such as handles and hoses.

The source height can best be determined by array measurements seeing that measurements at shorter distances are usually impossible in connection with safety. Other methods are also permitted if available.

The contribution from some sources can be found by dividing up parts of the passage measurement into segments where obvious differences occur, for example the head, the pantograph, pantograph extended or retracted.

2.6 Determination of the braking noise

Braking noise is the additional noise that is released when braking the vehicle. Braking noise belongs to the vehicle. It cannot be measured directly but must be determined from the noise level measured during braking $L_{p,brake+rol}$ and the rolling noise level that is calculated for the average speed during that braking $L_{p,rol}$. This rolling noise level is calculated per octave by the least squares method.

The noise level while braking $L_{p,brake+rol,i}$ is determined by measuring the equivalent sound pressure level during the passage time T_p in octaves during a braking passage of the equipment. This must be done for five preferred speeds, 30 km/h, 50 km/h, 80 km/h, 100 km/h and the maximum speed, always with one passage at one measurement cross-section.

The measurement speeds may deviate from the above guidelines by a maximum of 20%. The speed is measured during the passage. The average speed during the passage is used for the calculations. The microphone position is at 7.5 m distance from the centre line of the track and at 1.2 m height.

The brakes must be applied at maximum setting at the moment that the front buffer of the equipment to be measured is 20 m before the measurement cross-section.

If $L_{p,brake+rol,i}$ is less than 1 dB greater than the calculated rolling noise $L_{p,rol,i}$, the braking noise is ignored in that octave band.

$L_{p,brake,i} = 0$

The rolling noise from the track $L_{p,rol,i}$ is deducted energetically from $L_{p,brake+rol,i}$ in the other octave bands.

(2.15) $$L_{pveh,brake+rol,i} = 10 \lg (10^{L_{p,brake+rol,i}/10} - 10^{L_{p,rol,,i}/10}).$$

The term $L_{pveh,brake+rol}$ is the noise that is emitted during braking by the vehicle and is therefore allocated to the source at axle height in Standard calculation method 2.

2.7 Determination of the emission characteristics

The characteristics that are used in the calculations in accordance with this regulation are determined on the basis of the measurement results. The category number of the new train category is indicated with an *x* in what follows.

2.7.1 For dB(A) emission values

The part contributions $L_{pveh1,i}$, $L_{pveh2,i}$, $L_{pveh3,i}$, and $L_{ptr,i}$ are determined at one source height, namely BS (0.25 m), for the dB(A) emission values as meant in paragraph 2.1 (of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006). The dB(A) values must be determined from the octave band data. The emission term for non-braking equipment for category $E_{nr,x}$ follows from:

(2.16) $$E_{nr,x} = 10\lg\sum_{i=1}^{8} 10^{L_{som,nr,i}/10}$$

with

(2.17) $$L_{som,nr,i} = L_{ptr,nl,i} \oplus L_{pveh1,i} \oplus L_{pveh3,i} \oplus L_{pveh2,nl,i} + L_{m,i} - 39$$ *(som = sum)*

$L_{m,i}$ = conversion term for the passage measurement (see *Formula 2.31*)

The emission term for braking equipment $E_{r,x}$ is determined from

(2.18) $$E_{r,x} = 10\lg\sum_{i=1}^{8} 10^{L_{som,r,i}/10}$$

with

(2.19) $$L_{som,nr,i} = \max\left\{L_{ptr,nl,i} \oplus L_{pveh1,i} \oplus L_{pveh3,i} \oplus L_{pveh2,nl,i} ; L_{prem,i}\right\} + L_{m,i} - 39$$

(som = sum)

The emission terms for non-braking and braking equipment are calculated for the whole speed range that is relevant for that equipment. These values are then fitted to the following linear equation using the least squares method:

(2.20) $$E_{r,x} = a_{r,x} + b_{r,x}\lg(v_x)$$

The values a_x, b_x, $a_{r,x}$ en $b_{r,x}$ are then used to determine the emission values in accordance with paragraph 2.1 (of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006).

Deviations from the measured values can arise because of the linear fitting to the speed. If these deviations are greater than 1 dB(A) the speed range must be split into parts. The values a_x, b_x, $a_{r,x}$ and $b_{r,x}$ are then determined separately for each part range.

2.7.2 Emission characteristics in octave bands

The emission characteristics in octave bands are calculated from the emission data calculated for the application in accordance with Chapter 3 (of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006).

For non-braking equipment:

(2.21) $E_{bs,i,x}' = L_{ptr,NL,i} + L_{m,i}$

(2.22) $E_{as,i,x}' = L_{pveh1,i}(axle) \oplus L_{pveh3,i}(as) \oplus L_{pveh2,NL,i} + L_{m,i}$

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

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

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

and for braking equipment:

(2.26) $E_{bs,r,i,x}' = L_{ptr,nl,i} + L_{m,i}$

(2.27) $E_{as,r,i,x}' = max\{L_{pveh1,i}(axle) \oplus L_{pveh3,i}(as) \oplus L_{pveh2,nl,i} ; L_{prem,i}\} + L_{m,i}$

(2.28) $E_{2m,r,i,x}' = L_{pveh1,i}(2\ m) \oplus L_{pveh3,i}(2\ m) + L_{m,i}$

(2.29) $E_{4m,r,i,x}' = L_{pveh1,i}(4\ m) \oplus L_{pveh3,i}(4\ m) + L_{m,i}$

(2.30) $E_{5m,r,i,x}' = L_{pveh3,i}(5\ m) + L_{m,i}$

where:

$E_{h,i,x}$ =	emission terms in octave bands at the different source heights h for non-braking equipment [dB(A)]
$E_{h,r,i,x}$ =	emission terms in octave bands at the different source heights h for braking equipment [dB(A)]
$L_{m,i}$ =	conversion term for the passage measurement [dB]

(2.31) $$L_{m,i} = 10\lg\left(\frac{T}{3600}\right) - 10\lg n - \overline{\Delta L_i} + L_{FA,i}$$

where:

T =	passage time for the train or group of wagons concerned *[s]*
n =	number of wagons
r =	distance from the heart of the track to the microphone [m]
$\overline{\Delta L}_i$ =	collective term for weakening of the transfer [dB]
$L_{fA,i}$ =	A weighting filter for octave bands [dB]

The collective term $\overline{\Delta L_i}$ for the transfer is defined as:

$$\overline{\Delta L_i} = 10\lg\left(\frac{1}{25}\sum_{k=-12}^{k=12} 10^{(D_{L,i} + D_{B,i} - \Delta L_{GU}(\Phi_k))/10}\right) + 58{,}6$$

(2.32)

where:

Φ_k = the opening angle (total opening angle 25 x 5˚ = 125˚)

D_L = the weakening by absorption in the air in accordance with Standard calculation method 2

D_B = the ground damping in accordance with Standard calculation method 2

ΔL_{GU} = the geometric extension in accordance with Standard calculation method 2

The emission data described above is calculated for non-braking and braking equipment, for each octave band, for each source height and for the whole speed range that is relevant for the equipment. These values are then fitted to the following linear equation using the least squares method:

$$E = a + b \lg v \qquad (2.33)$$

The values found for the characteristics *a* and *b* for each octave band, for each source height, for both braking and non-braking equipment are then used for the new equipment category (in accordance with Table 3.1 of Appendix IV of the Calculation and Measurement Regulations noise Nuisance 2006).

Deviations from the measured values can arise because of the linear fitting to the speed. If these deviations are greater than 1 dB(A) the speed range must be split into parts. The values *a* and *b* are then determined separately for each part range.

2.8 Report

The following must be reported for the extended measurement procedure:

1. The nature and objective of the measurements.
2. Name and address of the institution and persons who have carried out the measurements.
3. Date and place of the measurements.
4. Details of the track: track type, base system (code, thickness, static stiffness), fixing, sleepers, rail type, rail roughness in accordance with NEN-EN-ISO 3095:2005.
5. Description of the measurement site: surroundings, ground with any growth, ambient temperature, humidity, air pressure, wind speed and wind direction.
6. The track transfer $L_{Hpr,tr}(f)$ and $L_{Hpv,tr}(f)$.
7. A list of the measuring equipment used and type of microphones and acceleration sensors with serial numbers and most recent calibration date.
8. The background level as octave spectrum and A weighted total level.
9. Description of the vehicle(s), with type code and the serial numbers of the equipment measured; declaration that the measured equipment is fully representative for the type of equipment.
10. The speed and the operating situation(s) during the measurements.
11. Any supplementary equipment present and the operating situation of this during the measurements.
12. If present: the positions of the vibration sensors and the measuring microphones.
13. If measured: the measured sound pressures and vibration levels as total levels and as 1/3 or octave spectra at the various positions and at the different speeds.

14. The course over time of the sound pressure level and of the unweighted vibration level (vibration speed) for some passages.
15. As function of the speed and in octave bands: the derived part contributions for traction noise, rolling noise from the track, rolling noise from the vehicle, aerodynamic noise and braking noise. The rolling noise must be standardized to the average Netherlands rail roughness.
16. The determined effective rail roughness as function of both the frequency and the wavelength.
17. The derived effective wheel roughness as function of both the frequency and the wavelength and the transfer from the vehicle $L_{Hpr,veh}(f)$ in 1/3 octaves.
18. The distance damping of the track that was used to determine the total roughness.
19. The emission characteristics for the different source heights, in so far as determined and a graph showing how the least squares result fits the measurement results.

3 Methods for determining wheel and rail roughness

3.1 Determination of relation between vertical rail vibration and total roughness

The total effective roughness can be calculated by using Formula 3.1:

(3.1) $$L_{rtot,eff}(f) = L_{veq}(f) + 10\lg\left(\frac{D_s(f)}{8.68\beta}\right) - A_2(f) - 20\lg(2\pi f)$$

where:

$L_{rtot,eff}(f)$	=	total effective roughness spectrum [dB re 10^{-6}m]
$L_{veq}(f)$	=	equivalent vibration spectrum [dB re 10^{-6} m/s]
β	=	number of axles per metre (N/l_{veh}; with N axles; l_{veh} length of wagon)
$D_s(f)$	=	spectrum of distance damping vertical rail vibrations [dB/m]
$A_2(f)$	=	conversion spectrum for the difference between the displacement of the rail at the contact point and the effective roughness

The correction spectrum $A_2(f)$ is described by the values in Table 3.1.

Table 3.1 Spectra $A_2(f)$ for the difference between displacement of the rail at the contact point and the effective roughness for three categories of rail base plates

Frequency [Hz]	Soft base plate	Medium base plate	Hard base plate
50	0.84	-5.0	-5.0
63	1.0	-3.0	-3.0
80	4.1	2.3	2.3
100	2.7	2.6	2.6
125	0.9	0.8	0.8
160	0.1	0.0	0.0
200	0.0	0.0	0.0
250	-0.6	0.0	0.2
315	-1.2	-2.6	-0.1
400	-1.3	-3.9	-2.8
500	-0.9	-4.8	-6.5
630	-0.9	-3.2	-8.1
800	-1.6	-2.6	-6.9
1000	-2.7	-4.3	-5.0
1250	-5.6	-6.2	-4.4
1600	-8.0	-7.5	-6.4
2000	-9.5	-8.8	-8.4
2500	-10.0	-9.8	-9.5
3150	-11.3	-11.2	-11.1
4000	-13.7	-13.6	-13.6
5000	-14.9	-14.8	-14.8
6300	-16.9	-16.8	-16.9
8000	-18.8	-18.7	-18.8
10000	-20.5	-20.4	-20.6

The categories soft, medium and hard base plate are defined according to Table 3.2 that shows the dynamic stiffness of a plate in vertical direction.

Table 3.2 Classification of rail base plates in three categories depending on the type of sleeper and the vertical dynamic stiffness of the plate

	Soft base plate	Medium base plate	Hard base plate
Concrete bi-block sleeper	≤ 400 MN/m	400-800 MN/m	≥ 800 MN/m
Concrete sleeper	≤ 800 MN/m	≥ 800 MN/m	-
Wooden sleeper	all	-	-

The dynamic vertical stiffness of a base plate can be derived from the spectrum of the distance damping, see paragraph 3.2. The lowest frequency where the distance damping is less than 4 dB/m is used. The stiffness can be read from Table 3.3.

Table 3.3 Derivation of the vertical dynamic stiffness of the rail base plate from the lowest frequency where the distance damping is less than 4 dB/m

	80 MN/m	200 MN/m	400 MN/m	800 MN/m	1250 MN/m	2000 MN/m
Bi-block sleepers	300	480	710	1060	1400	1950
Concrete sleepers	280	450	610-850	1100-1380	1630	2040

The effective roughness of the equivalent vibration level $L_{veq}(f)$ can be derived using the above formulas, whereby the distance damping $D_s(f)$ must be known (see paragraph 3.2).

Averaging of the total effective roughness
Every measured passage at every speed provides an estimate of the total effective roughness according to formula (3.1). This estimate becomes more precise by averaging this effective roughness in the wavelength domain for the passages at the different speeds. This averaging must be made in the wavelength domain because the effective roughness expressed as a function of wavelength is independent of the passage speed. The following procedure must be followed.

- Depending on the passage speed all estimates for the roughness are converted from the frequency domain to the wavelength domain using formula (3.2) from paragraph 3.2.
- All estimated roughness values are calculated using the same ‘one third wavelengths’ via linear interpolation. The one third wavelengths can be found in the ‘wavelength’ column of Table 3.5.
- The estimated roughness values are averaged per wavelength.
- Depending on the passage speed the average roughness spectrum is converted back from the wavelength domain to the frequency domain using formula (3.2) from paragraph 3.2.
- Interpolation on the frequency scale allows the roughness on the known one third band middle frequencies to be obtained.

3.2 Average rail roughness of the Netherlands network

An average for the Netherlands network is taken for the rail roughness. This is indicated by $L_{rtr,nl}(\lambda)$, where λ is the wavelength in cm or metres. The roughness spectrum for the Netherlands network is given in figures in Table 3.5 as a function of the wavelength.

Table 3.5 Average roughness spectrum of the Netherlands railway network as function of the wavelength

Wavelength [cm]	NL ave.
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

The conversion of $L_{rtr,NL,dir}(\lambda)$ to $L_{r,tr,nl}(f)$ follows in an exactly similar way as in paragraph 2.4.1 'Determination of the effective rail roughness' and the paragraph below *'Lr(v,f)* - Roughness as function of the frequency, speed dependent'.

Measurement procedure for the vertical distance damping
The distance damping $D_s(f)$ is the amount in dB of weakening of the vertical rail vibration per metre distance from the contact point. The distance damping can be determined in a number of ways.

Various techniques for determining the distance damping can be found in the literature. One method is given here as an example.

Two vibration sensors are placed under the middle of the rail foot at two successive sleepers. The 1/3 octave spectrum of the rail vibration as a function of time is recorded during a train passage at 80 or 100 km/h with a sampling time of 1/32 s (‘waterfall’). The level difference in dB between the two sensors is determined per frequency band from those spectra from the ‘waterfall’ that are determined in the time that the first wheel was less than 2 m from the first vibration sensor. This level difference divided by the distance between the two sensors gives the distance damping in dB/m.

The distance damping found is given in the report, as well as the method used.

$L_r(v,f)$ - Roughness as function of frequency, speed dependent
The roughness L_r is often quoted as function of the wavelength λ, independent of the speed. In order to be able to calculate with frequency spectra the roughness is expressed as a frequency spectrum $L_r(v,f)$, whereby the roughness is dependent on the speed. The curve remains the same, but is simply shifted in a horizontal direction for different speeds.

The exact position of the curve is calculated with $L_r(v,f) = L_r(\lambda)$ where

(3.2) $$\lambda = \frac{v}{3{,}6\,f}$$

for example: $L_r(\lambda=0.01\text{m}) = L_r(v=90 \text{ km/h}, f = 2500 \text{ Hz})$
The speed is expressed in km/h in the calculation.

Depending on the speed it can happen that the wavelengths corresponding to the frequency bands 50 Hz to 10 kHz do not exactly coincide with the one third wavelengths for which the roughness is known. Linear interpolation can be used to determine the roughness data for the particular wavelengths.

3.3 Determination of the transfer for a track with a reference vehicle

The rail vibration transfer $L_{Hpv,tr}(f)$ is the ratio between the sound pressure as a result of emission from the track and the vertical vibration of the rail head. This is determined in 1/3 octaves with the help of at least three ‘reference vehicles’.

A reference vehicle has as characteristic that its vehicle transfer L_{Hpveh} is significantly lower than average. Wagons with small solid wheels (diameter < 800 mm) have this property. The following can be used as reference vehicles for example:

-NiNa:	regional passenger train of which the middle section (4 axles) has small wheels (630 mm)
-Habbiks:	4-axle freight car, wheel diameter 680 mm
-Rola:	8- or 10-axle freight car for transport of lorries, wheel diameter 380 mm
-Megafret:	8-axle freight car, wheel diameter 780 mm
-Novatrans:	8-axle freight car, wheel diameter 730 mm
-Laekkqs547:	3-axle car transporter wagon, wheel diameter 680 mm

Vehicles with strongly damped wheels or wheel or bogie shielding are in general less suitable because these can also influence the contribution from the track. If small resilient wheels are used as in light rail, it must be shown that these only make a negligible contribution to the rolling noise emission.

The track vibration transfer is determined by measuring the sound pressure and rail vibration during the passage of the reference vehicles. By definition here it can be stated that the measured noise can be allocated to the track. This then provides the track transfer function required:

(3.3) $L_{Hpvtr}(f) = L_{ptr,ref}(f) – L_{vref}(f)$

where:

$L_{Hpv,tr}(f)$ = track transfer in 1/3 octaves from vertical rail head vibration to sound pressure at 7.5 m [dB re 20 Pa/m/s]
$L_{ptr,ref}(f)$ = equivalent sound pressure level in 1/3 octaves at 7.5 m during passage of reference wagons [dB re 2.10^{-5} Pa]
$L_{v,ref}(f)$ = equivalent level of the vibration speed of the rail head in 1/3 octaves during passage of reference wagons [dB re 10^{-6} m/s]

This transfer must be averaged over three track cross-sections and three speeds. The wheel and rail roughness are not important for this measurement. However, they must not be extreme (no wave wear or polygonization).

The emission of the particular track can be determined from the rail vibration for any equipment using the track transfer:

(3.4) $L_{ptr}(f) = L_{Hpv,tr}(f) + L_v(f)$

where:
$L_{Hpv,tr}(f)$ = track transfer in 1/3 octaves from vertical rail head vibration to sound pressure at 7.5 m [dB re 20 Pa/m/s];
$L_{ptr}(f)$ = equivalent sound pressure level as a result of track emission in 1/3 octaves at 7.5 m during passage of any equipment [dB re 2.10-5 Pa];
$L_v(f)$ = equivalent level of the vibration speed of the rail head in 1/3 octaves during passage of any equipment [dB re 10^{-6} m/s].

If the use of a reference vehicle is impossible it is also permitted to determine the transfer with the help of special techniques so far as these are proved and tested.

4 Measurement method superstructure - Procedure C

4.1 Introduction

This procedure is to be used for the determination of the superstructure correction terms for new types of superstructure, or for acoustic relevant changes to an existing type of superstructure.

4.2 Organization of the measurements

Number and condition of the test tracks

Measurements on at least two sections of test track fitted with the new superstructure, each with a length of at least 100 metres, must be carried out to determine the correction terms for the superstructure. The construction of the test tracks must be the same over this entire length. A reference track of at least 100 metres must lie adjacent to the test tracks with a superstructure construction consisting of continuous welded rails on concrete monoblock sleepers in a ballast bed. The construction of the reference tracks must be representative for the construction on which these regulations are based, with superstructure correction terms that are equal to $C_{bb,i}$ from Table 3.5 (of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006), with bb=1.

The measurements must be made at each site at three cross-sections of the test track and two cross-sections of the reference track. The results of the measurements must be averaged over the cross-sections for the reference track and the test track. The measurement environment between the position of the microphone and the section of track for the reference track and the test track must be such that there will be no differences in transfer damping. In other words, the properties of the ground, the design of the embankment, the height etc, must be the same. These may however be different for the two measurement sites.

The rail roughness values for the test tracks and the reference tracks must preferably be so low that they lie below the ISO maximum curve (see NEN-EN-ISO 3095:2005). If that is not possible the measurements may be carried out with a higher rail roughness. In that case the total roughness must be determined, that is the sum of the rail roughness and the wheel roughness. The total roughness at the reference site and at the test site must be as near equal as possible. Some deviations in the levels per octave band are permitted, but may not lead to differences of more than 0.5 dB(A) in the A weighted superstructure correction in formulas 4.1 and 4.2. The difference in noise emission as a result of differences in rail roughness between the reference site and the test site must be compensated (roughness emission correction) in accordance with formula 3.3d (of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006).

In cases where it may be assumed that the superstructure correction term is dependent on the track roughness, as for example is the case for rail dampers, the superstructure correction term must be corrected to the average NL track roughness (standardized to NL track roughness). Such a correction can be made by choosing two test sites, one with above average NL roughness and one with below average NL roughness, after which the superstructure correction term for track with average NL roughness can be determined by interpolation. In cases where a site has a track roughness that approaches that of the NL average - when the emission correction as a result of roughness is not more than 0.5 dB(A) - it is not necessary to make such a correction.

Both the test track and the reference track must be horizontal and not in a curve. There must not be any breaks in the rail, welds, damage to the running surface or loose sleepers that could cause knocking noise within 25 m on either side of the measurement cross-sections, and construction joints between reference track, test track and other tracks must be at least 25 m from the measurement cross-sections.

Number and condition of passing equipment
In order to determine the superstructure correction terms at least five train passages must be measured at each of the measurement sites with train equipment braked by cast-iron blocks and with relatively high wheel roughness. At least two categories of train equipment must be used (for example categories 2 and 4). A superstructure correction term is determined for each type of equipment used and these are then averaged to be representative for all types of train equipment.
The rolling noise of the passing train equipment must be dominant, but the equipment must, however, not have any other noise sources that could influence the measurements. The passing train equipment must further comply with the requirements in paragraph 2.2. The condition of the passing train equipment must be recorded, with at least the train types, the train numbers and the number of passing wagons being recorded. The number of train passages to be measured at both sites must be within 20% of each other.

The train equipment must pass all the measurement cross-sections at constant speed (within 5%) and with the brakes switched off. The speed of the passing equipment must be between 100 and 160 km/h.

The acoustic environment
The measurement environment must comply with the requirements in paragraph 2.2.

Meteorological conditions and background level
The meteorological conditions and the background level must comply with the requirements in paragraph 2.2.

Terms to be measured and position
The A weighted equivalent sound pressure level in octave bands $L_{pAeq,i}$ is measured at the measurement 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.

The other requirements given in paragraph 2.2 must also be complied with, with the exception of the number of measurement cross-sections.

Vibration measurements do not have to be carried out, unless it is desirable to have these available for the determination of the track transfer (for example to use the measured superstructure construction for the determination of properties of new train equipment).
The rail roughness of both the test tracks and the reference tracks must also be measured in accordance with the method given in paragraph 2.4.1.

Speed test
The method assumes that the superstructure correction terms in octave bands are independent of the type of equipment and of the speed of the passing trains. In order to check this two extra train passages must be measured at one site with deviating speeds of at least 20% and 30% respectively. The differences in the superstructure correction values may not be greater than 3 dB in each of the octave bands. If the correction is found to be dependent on the speed further research is necessary. This can result in a speed dependent correction term.

Measurement equipment
As far as is applicable the measuring equipment must comply with the requirements given in paragraph 2.2.

4.3 Determination of the superstructure correction terms

Superstructure correction term for Standard calculation method 2 (SRM2)
The superstructure correction terms for the test track in octave bands $C_{bb,test,i}$ are equal to:

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

where:

$L_{Aeq,test,i,j}$ = the equivalent noise level during the passage of train *j* in octave band *i* over the test tracks, energetically averaged over the measurement cross-sections

$L_{Aeq,ref,i,j}$ = the equivalent noise level during the passage of train *j* in octave band *i* over the reference tracks, energetically averaged over the measurement cross-sections

n = the number of train passages measured

Superstructure correction terms for Standard calculation method 1 (SRM1)
The superstructure correction terms for SRM1 are dependent on the equipment category and are calculated as follows.

1. Create a calculation model in accordance with SRM2 of a simple situation of single track with soft ground and standard embankment 1 metre high.
2. Use this calculation model to calculate the noise load at an observation point 25 metres from the centre of the track, 3.5 m above BS.

3. Carry out the calculation using the superstructure correction terms C_{bb} from Table 3.5 (of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006) with *bb*=1, and with the superstructure correction terms from Standard calculation method 2 for the test track.
4. Carry out these calculations for each equipment category, at speeds 80, 100 and 140 km/h for equipment with a maximum speed of 140 km/h or more and at 60, 80, 100 km/h for equipment with a lower maximum speed. A fixed train intensity, for example 10 wagons per hour, is assumed when doing this.

The superstructure correction terms for Standard calculation method 1 are determined from these calculation results as follows:

$$C_{btest,c} = \frac{1}{3}\sum_{k=1}^{3}\left(L_{Aeq,test,c,k} - L_{Aeq,beton,c,k}\right) \quad (4.2)$$

where:

$C_{btest,c}$ = superstructure correction term for Standard calculation method 1 for the test track and equipment category *c*

$L_{Aeq,test,c,k}$ = calculated noise loading for the test track, equipment category *c*, speed parameter *k*

$L_{Aeq,beton,c,k}$ = calculated noise loading for the reference track with continuous welded track on concrete sleepers, equipment category *c*, speed parameter *k.*

k = speed parameter *k*=1 for the calculation speed of 80 or 60 km/h, *k*=2 for 100 or 80 km/h, *k*=3 for 140 or 100 km/h

(beton = concrete)

4.4 Report

The report consists of the items stated in paragraph 2.8 with the exception of items 6, 11, 15-19. The description and type code of the vehicles is sufficient for item 9. Item 4 is included for both the test tracks and the reference tracks. In addition to this the calculated superstructure correction terms in octave bands and in dB(A) are reported.
A description of the determination of the roughness emission correction for the superstructure correction term in accordance with formula 3.3d in Appendix IV must be given, including the intermediate results that form the basis of this. If the effective roughness has been measured this must also be reported.

5 Explanatory notes

5.1 Procedure A: Simple method (Chapter 1)

It is stated in Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006 that all the traffic with a service number that runs over a zoned railway must be allocated to one of the named categories. When new equipment is taken into service this can be allocated to an existing category. Measurements must be carried out for this in accordance with procedure A. If it is desirable to introduce a new train category for new equipment, for example if the equipment is quieter than the existing category, then this will have to be accompanied by a more precise determination of the emission characteristics in accordance with procedure B (Chapter 2).

The objective of the method described is to allocate new equipment to an existing category. Account is taken of the roughness of the wheels and the track in the form of the correction term L_{diff}. A relaxation of the requirement relative to the requirement for new equipment applies for vehicles that have already been in normal service for at least three months, namely:

- an extra margin of 1 dB in L_{diff}
- and the requirement for the sound pressure level does not apply for the octave bands 63, 125 and 8000 Hz.

5.2 Procedure B: Full emission measurement method (Chapter 2)

The difference from the rail vehicle categories included in the regulations is that train types are no longer allocated according to external characteristics but by measured acoustic characteristics of the various part sources. When determining the noise emission a distinction is made between traction noise, rolling noise, aerodynamic noise and braking noise. In this way it becomes possible to include all sorts of equipment in these regulations according to the actual noise performances. A database of noise data forming part of the emission register can be constructed from the results of the measurements.

Explanation of the theory

The passing noise of a train consists of rolling noise from the rail vehicle and the track, and other sources such as the drive, supplementary equipment and aerodynamic noise.

In general the drive will dominate, in so far as this is present and audible, at low speeds (below about 50 km/h), rolling noise to about 200-300 km/h and aerodynamic noise above this. All the noise coming from the vehicle is termed ‘vehicle noise’ while the rolling noise coming from the track construction is termed ‘track noise’. The track noise can also include rolling noise from a structure (e.g. steel bridge). The track noise is determined in the regulations for a train running on the quietest superstructure that is available for standard use at present, namely a track on concrete mono or duoblock sleepers in ballast bed. The effect of other superstructure types is processed by applying superstructure corrections. This also applies to corrections for structures and bridges.

If a different, for example quieter, superstructure becomes available in the future this can then be processed in the calculations by carrying out the measurements in accordance with procedure B for the existing or new train categories that are to run on this superstructure. The measurements from paragraph 2.6 and/or 5 will then be carried out for the new superstructure. The emission characteristics determined on the basis of this will then only be valid for these train/superstructure combinations. Permission from the minister will be required for application.

Speed dependence for part contributions
The part combinations from traction noise, rolling noise and aerodynamic noise have different dependencies on the speed. The transitions between these ranges depend strongly on the type of equipment and the roughness of the rails and wheels. An example is given in Figure 6.1. The following are taken as guideline for the total dB(A) level:

- for traction noise: 0-20 lg V
- for rolling noise: 20-30 lg V
- for aerodynamic noise: 50-70 lg V.

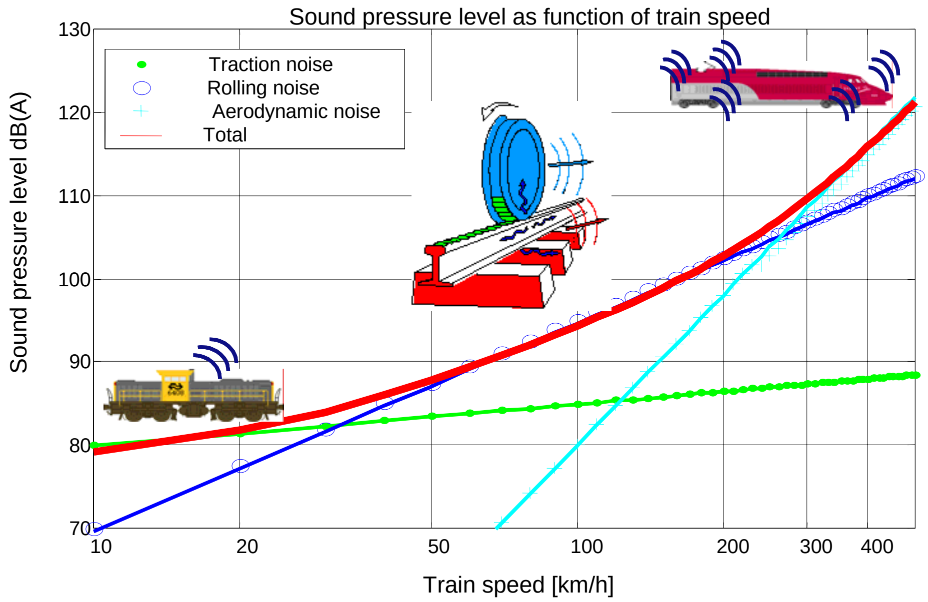

Figure 5.1 Illustration of the curves for the part contributions of traction noise, rolling noise and aerodynamic noise as function of the speed. The position of the rolling noise curve is strongly dependent on the combined wheel and rail roughness

The measurement procedure is based on the following formulas:

(6.1) $L_{ptot}(f) = L_{prol}(f) \oplus L_{ptraction}(f) \oplus L_{paero}(f)$

(6.2) $L_{prol}(f) = L_{reff}(v,f) + L_{Hpr,eff,NL}(f) + 10\ lg\ (N/L)$

(6.3) $L_{ptot}(f) = L_{ptr}(f) \oplus L_{pveh}(f)$

(6.4) $L_{rtot}(\lambda) = L_{rtr}(\lambda) \oplus L_{rveh}(\lambda)$

where:

L_p = sound pressure level [dB re 2.10^{-5} Pa]
$L_{Hpr,eff,NL}$ = transfer function of effective roughness to sound pressure, standardized for the number of axles per metre [dB re 20 Pa/√micron]
L_r = effective roughness level [dB re 10^{-6} m]
F = frequency [Hz]
λ = wavelength [m]

Key: rol = rolling noise, traction = traction noise, aero = aerodynamic noise, tot = total, tr = track, veh = vehicle

The noise emission as a result of rolling noise can be expressed in terms of the factors:
- wheel roughness, average over all wheels
- response of the rail vehicle (wheel vibration to sound pressure)
- rail roughness, average at the measurement site
- response of the track (rail vibration to sound pressure)

Knocking noise as a result of joints or points is included with the rolling noise by a correction method in accordance with Chapter 3 of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006.

Example of freight cars with composite brakes, new category
The measurement procedure for allocation to a new category in accordance with procedure B is comprehensive but can be limited to a few sections depending on the nature of the equipment to be measured and the knowledge of the characteristics of the measurement site. A freight car with composite brakes is taken as an example.

In this case no traction noise or aerodynamic noise need be determined so that the relevant paragraphs may be omitted. The rolling noise must be determined in accordance with paragraph 2.4. If the rail roughness and the transfer of the track are known then measurement of the vertical rail vibration and sound pressure at 7.5 m distance at the quoted speeds is sufficient. A number of measurements of the noise during braking must also be made. The other actions to be taken are of a technical calculation nature.

Example of freight cars with composite block brakes, allocation to existing category
The allocation procedure A for a freight wagon with composite brake blocks runs as follows.

Measurements are made at a prescribed measurement site where the rail roughness is known and is under the roughness limit. The equipment and the measurement conditions must be as described for procedure A. The sound pressure is measured at 7.5 m for passages at the speeds quoted in the regulations. The A weighted sound pressure level in octaves is fitted as a line as a function of the logarithm of the speed. If necessary, measurements are made at more speeds in order to determine the curve more precisely. This curve is compared with an SRM2 curve in octaves with the same calculation basis (train type, track type, etc.). The equipment may be allocated to the particular category if this curve obtained by measurement when increased by 1 dB lies under the curve calculated with SRM2.

Condition of the test track (paragraph 2.2)
An ideal test track has a noise contribution that is at least 10 dB less than that of the vehicle over the whole frequency range. This is difficult to achieve in practice and therefore it is recommended to use a test track that has as low a track response as possible. This can be determined from a limited number of single measurements of different track constructions in the field.

The acoustic environment (paragraph 2.2)
If there is doubt about the suitability of the measurement environment the free field condition can be checked with the aid of a small artificial source on the track that produces broadband sound. When the microphone distance is halved the level must increase by 6 dB.

Rail vibrations (paragraph 2.2)
When measuring the vertical rail head vibrations attention must be paid to the signal conditioning to prevent distortion of the signal (overload). There can be a very large dynamic range of the vibration signals from the rail due to passing trains. High peak values of 10-100 m/s^2 can occur at high speeds.

Examples of determination of source height of traction noise (paragraph 2.3)
Two examples of the source height determination are given as illustration.

Diesel loc with exhaust on the roof as the dominant traction noise source
$L_{pveh1,i}$ (4 m) = $L_{pveh1,i}$
$L_{pveh1,i}$ (2 m) = 0
$L_{pveh1,i}$ (axle) = 0

A passenger train with electrically driven bogies has as result:
$L_{pveh1,i}$ (4 m) = 0
$L_{pveh1,i}$ (2 m) = 0
$L_{pveh1,i}$ (axle) = $L_{pveh1,i}$

Roughness of the test track for rolling noise (paragraph 2.4)
A low roughness of the test track is prescribed for the measurements. If the test track exceeds this limiting curve the vehicle roughness will be overestimated. In order to measure equipment with smooth wheels it is therefore of importance to comply with this low roughness for the test track.

Determination of aerodynamic noise (paragraph 2.5)
If the aerodynamic noise only makes a slight contribution to the total noise level it is neglected in these regulations.

In theory the unweighted spectrum of the aerodynamic noise increases with the sixth power of the speed. This equals 60 lg *v* or 18 dB for a doubling of the speed. The dB(A) level will not always follow this law precisely because of the properties of the weighting filter. An almost linear relationship between the sound level and lg *v* is assumed in the regulations. If the measurements give reason to do so however a higher order relationship can be used.

The regulations assume the worst case where there is a lack of information when determining the source height. This means, for example, that if it is not known whether the source is at 4 m or 5 m, 5 m is taken, or whether the source is at axle height or at 2 m, then 2 m is taken. If additional data is available which allows the source height to be shown, for example antenna measurements or other suitable techniques, a further distribution over the source heights axle (0.5 m), 2 m, 4 m and 5 m can be made. The energetic summation of the part sources $L_{pveh3,i}(h)$ must equal $L_{pveh3,i}$ at 7.5 m.

Examples:
If the pantograph noise is dominant the result is:
$L_{pveh3,i}$ (5 m) = $L_{pveh3,i}$
$L_{pveh3,i}$ (4 m) = 0
$L_{pveh3,i}$ (2 m) = 0
$L_{pveh3,i}$ (axle) = 0

If the aerodynamic noise is distributed evenly over the different source heights (this can only be shown by further research) then the result is:
$L_{pveh3,i}$ (5 m) = $L_{pveh3,i}$ - 6
$L_{pveh3,i}$ (4 m) = $L_{pveh3,i}$ - 6
$L_{pveh3,i}$ (2 m) = $L_{pveh3,i}$ - 6
$L_{pveh3,i}$ (axle) = $L_{pveh3,i}$ - 6

Determination of braking noise (paragraph 2.6)
The braking noise is regarded as a linear function of lg *v*. If the measurements give reason to do so the speed range may be split into part ranges within which the linear relationship is applied.

Determination of emission characteristics (paragraph 2.7)
The emission characteristics calculated in this paragraph are valid for a track construction with index *b*=1 for SRM1 and *bb*=1 for SRM2 respectively. The superstructure corrections from these regulations are applied for other track constructions unless there is reason to believe that these are not correct for the new category. In that case extra measurements must be made for the particular superstructure.

5.3 Methods for the determination of wheel and rail roughness (Chapter 3)

According to the formulas in paragraph 3.1 the roughness is calculated from the equivalent vibration level $L_{veq}(f)$, whereby it is assumed that the distance damping $D_s(f)$ is known. The distance damping $D_s(f)$ is the amount of dB weakening per metre from the contact point. The data included is valid for a standard Netherlands track.

The distance damping can be derived from measurement data. Methods of measurement are available for this that can be divided into:
- impact response measurements along the track (without train)
- derivation from the vertical rail vibrations during train passages.

Measurement software is also available that is capable of determining the distance damping from a signal for a single vibration sensor. A possible method is described below that makes use of two vibration sensors by a train passage.

Two vibrations sensors are placed under the middle of the rail foot at the position of two successive sleepers. The 1/3 octave spectrum of the rail vibration is registered at short intervals, e.g. 50 milliseconds, during a train passage at 80 or 100 km/h.

The slope of the 20 lg of the amplitude of the signal of an approaching and departing train is determined per frequency band.

The gradients of these slopes (dB/metre) per frequency band equal the distance damping $D_s(f)$.

Validation and monitoring of equipment characteristics

In order to further reduce the measurement uncertainty or to check the emission after some time it is possible to collect more data by monitoring. To do this measuring is carried out at an assigned measurement site that complies with the requirements in paragraph 2.2 (low rail roughness, fixed track type). The sound pressure at 7.5 metres and the vertical rail vibration are registered continuously, and the train speed is also measured.

A picture of the variation in wheel roughness, as far as this exceeds the rail roughness, can be obtained from the total roughness. The total roughness can be derived from the vertical rail head vibration and the speed using the procedures in 2.4.

The sound pressure can be used to measure the variation in the total noise, however this variation will also depend on the variation in wheel roughness. The distribution of the drive noise or the aerodynamic noise can only be determined if these strongly dominate the noise.

Another method of monitoring the distribution in various examples is to measure the transfer between the vertical rail vibration and the sound pressure at the same measurement site. This eliminates differences as a result of wheel roughness.

Monitoring is not compulsory and is not a replacement for the full measurement procedure B. The results of monitoring can, though, form a reason for carrying out a full or partial type approval measurement again.

Background documents

Reference is made to the following if more information is required:

[1] F.G. de Beer, H.W. Jansen, M.G. Dittrich: ‘STAIRRS Level 2 measurement methods: Indirect roughness and transfer function’, TNO-TPD report, Delft, July 2002.

[2] M.H.A. Janssens, H.W. Jansen, M.G. Dittrich: ‘Evaluation of the interim measurement protocol for railway noise source description’, Proceedings IWRN 2004, Buxton

[3] M.H.A. Janssens, M.G. Dittrich, F.G. de Beer, C.J.C. Jones, ‘Railway noise measurement method for pass-by noise, total effective roughness, transfer functions and track spatial decay’, proceedings IWRN8, Buxton, 2004.

[4] TSI Noise for conventional rail, AEIF, Brussels.

5.4 Superstructure measurement method (Chapter 4)

A measurement method is described in this paragraph for a new or changed type of superstructure. This is a fairly simple difference measurement between the new type of superstructure and the standard superstructure used by ProRail (continuous welded track on concrete sleepers in ballast bed).

The term superstructure means the construction by which the rails are fixed to the substructure (the body of the earthwork or a structure). The method is used to test the noise correction term for this construction. This is particularly of importance for determining the rolling noise of the trains. Seeing that the rolling noise is strongly dependent on the roughness of both the rails and the wheels it is of importance to keep these parameters in particular under control. The method is based on having the total roughness of the rails and wheels together for the test track and the reference track equal to each other. This is achieved by making the roughness of the rails as low as possible, but the roughness of the wheels instead relatively high. The method is thus expressly not aimed at mapping the effect of a different rail roughness. The effect of the rail roughness can be taken into account in accordance with paragraph 3.4 of Appendix IV of the Calculation and Measurement Regulations Noise Nuisance 2006.

The measurement method described assumes that the superstructure correction terms in octave bands are independent of the type of equipment and of the speed of the passing trains. This assumption can be checked as far as the speed is concerned by making a limited number of check measurements at deviating speeds. In order to check the independence from the equipment type equipment with a completely different wheel would have to be used (for example a very different wheel diameter), but there are major practical objections to this.

That the superstructure correction is independent of the speed is an empirical fact. An example where a dependence on the speed is expected is a superstructure fitted with a noise measure that is specifically tuned to a particular frequency, for example a tuned rail damper. If this damper is tuned to trains passing at 140 km/h, for example, this damper will very likely show different noise reduction properties in a station environment where the trains run much slower. In that case extra measurements must be carried out if it is to be used in the station area. A different rail profile to the standard rail profile 54E1 can also show frequency dependent behaviour, and therefore have a correction term that is dependent on the train speed.

The correction terms are determined by carrying out a difference measurement between the track with the new superstructure and a reference track. When making the measurements a check must be made that the reference track is representative for the superstructure construction from these regulations formed by continuous welded track on concrete sleepers in ballast bed. This can be done by checking the technical construction of the reference track, such as the make and type of the base plates and the other important parameters (see NEN-EN-ISO 3095:2005, Annex E for this). Another possibility is to compare the measurement results for the reference track with calculations in accordance with SRM2.

The superstructure correction terms for SRM2 can be determined directly from the measurement results. Account must be taken of the frequency dependence of both the superstructure correction and the equipment properties when determining the correction term for SRM1. Therefore the correction terms for SRM1 are determined on the basis of noise calculations with the aid of SRM2. Calculations for this are made at a point close to the track, and at three different speeds of passing equipment. The average correction term from these three speeds is used as a representative value for calculations on the basis of SRM1.