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Position Paper – Proposal on contact filters, roughness and stiffness for CNOSSOS

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Proposal on contact filters, roughness and stiffness for CNOSSOS

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Abstract

The common European method for environmental noise computations [1], to which we refer here as CNOSSOS, incorporates certain tabulated defaults for rail traffic that are partly outdated. New values are made available in this paper for contact filters, rail roughness and impact roughness. As it is recognised that modifying the default contact filters and rail roughness would unintendedly lead to an overall reduction of the rolling noise emission by 2-5 dB(A) (unless national or regional defaults are used), this paper proposes to compensate the wheel roughness defaults in order to minimise the effect on the calculated rolling noise emission. Also, the description of track stiffness may benefit from a clarification. This paper discusses the issues with the current method (section 1), proposes alternatives (section 2) and describes how these have been validated or verified (section 3). Finally, in Appendix 1 the text modifications for the Directive are given.

1 Issues

1.1 Contact filters

It has been reported in 2014 that the CNOSSOS method includes values for contact filters that are outdated[1]. A set of contact filters is needed to convert data acquired from direct measurement of rail and wheel roughness into combined *effective* roughness[2]. This filter simulates the low-pass frequency filtering effect of the contact patch.
In the CNOSSOS source model for railway and tramway noise, a contact filter (denoted $A_{3,i}$) takes part in all rolling noise calculations, see equation (2.3.7).
The contact filters of table G-2 of the Directive originate from an internal report used in STAIRRS (2000-2002). Soon after, the original developers published improved filters because the old ones underestimate the attenuating effect of the contact patch. But the old STAIRRS filters had already taken a life on their own, as they were copied in Harmonoise (2001-2004) and later in IMAGINE (2004-2006).

[1] See page 17 of *"Transposition procedure for END noise sources"*, ACOUTRAIN deliverable D1.9, E. Bongini et al, 2014

[2] 'Direct measurement' *refers to using roughness measurement instruments. If an* indirect *measurement method is used, for example by processing vertical rail vibration signals measured during wheel pass-bys, there is no need to apply a contact filter.*

Improved filters can be found in the book by David Thompson [2]. For short roughness wavelengths the STAIRRS filters underestimate the attenuating effect of the contact patch. Between about 40 mm and 10 mm the difference between the old and new filters increases from 0 dB to about 6 dB. For shorter wavelengths than 10 mm the difference is stable, around 6 dB. It is strongly recommended to refrain from using the outdated STAIRRS filters[3].

The use of the outdated contact filters in CNOSSOS, in combination with the present default roughness and transfer functions, does not necessarily lead to wrong results for rolling noise, as it is likely that the underestimation of the filter effect has already been compensated for in the choice of the wheel and rail roughness default values. This is suggested by a comparison of the CNOSSOS rolling noise with Dutch measurement data, which correspond reasonably, at least at dB(A)-level for freight trains with cast-iron braking blocks [3].
Therefore, a correction to the outdated contact filters should be accompanied by a compensating correction of other default parameters in CNOSSOS.

The main purpose of a correction of the set of contact filters in CNOSSOS, is to avoid large errors in case directly measured rail and wheel roughness is used for computations. Hopefully, this will put an end to the use of the outdated set of STAIRRS filters.

Besides this, the wording 'axle load' in the column headings of table G-2 of CNOSSOS should read: *wheel load*.[4]

1.2 Impact noise

The impact noise in CNOSSOS is calculated by (energy) adding a so-called 'impact roughness spectrum' to the total effective roughness (formula 2.3.11). In a comparison study commissioned by RIVM in 2017 it was found that the CNOSSOS impact roughness corresponds to a noise emission that is over 15 dB(A) higher than a continuously welded track [3]. Clearly this is not realistic. This high value may be related to the definition of 'joint density' in IMAGINE (number of joints per unit of track length)[5].

Without going into details of the approach given in IMAGINE, we recall that in CNOSSOS the definition of the joint density n_l is given in the text below equation (2.3.12). It states that 1 joint per 100 m of track is represented by setting n_l = 0,01.

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[3] *Personal communication with David Thompson, e-mail 5 July 2018.*

[4] *This text error was pointed out by Rick Jones, e-mail 29 August 2018.*

[5] *Information by Michael Dittrich, 18 September 2018.*

In the RMR model, a jointed track (1 joint per 30 m rail) has increased noise emission by 4 and 5 dB(A) compared to a continuously welded track. This value is similar to what has been reported elsewhere [5].

1.3 Default rail roughness

The default spectrum for rail roughness in CNOSSOS, titled 'Average network (Normally maintained smooth)', is a copy of the spectrum in the Dutch computation method RMR. The Dutch spectrum is a *stylised* version of an average spectrum from rail roughness measurements on 30 track sites in the Netherlands in the 1990s. This means that the computed average of the measurement data was manipulated by hand to make it smoother, which was done probably to make it easier for the user to copy the values. The spectral fine-structure was removed from the data resulting in a straight line (slope 1 dB per one-third octave).
The problem is mainly that the shorter wavelengths of the stylised version have a roughness level that is too high, not only if it is compared to the original data but also to other data measured at different sites (during later years).
At the time, that simplification was considered not significant, because the spectrum was an average of a dataset with a considerable statistical spread. However, there is no reason to assume that a standard spectrum for rail roughness should be a straight line. This paper proposes to repair the unnecessary stylisation. We propose to use a realistic rail roughness default spectrum based on measurement data.

1.4 Pad stiffness

At several sections in the Directive the term *stiffness* is used, as 'acoustic' stiffness, of just stiffness. It needs to be clarified if this refers to dynamic stiffness or static stiffness.

2 Solutions

2.1 Contact filters

Thompson has given a generalised contact filter in table 5.2 of his book [2]. In order to derive a new set of contact filters for CNOSSOS, some post-processing on the generalised one is needed.

The contact filter[6] depends on the size of the contact patch. Generally, the contact patch between rail and wheel can be approximated by an ellipsoid, with semi-axis *a* in the rolling direction and semi-axis *b* in the lateral direction. Thompson's generalised contact filter is derived from the DPRS model. This model

[6] *When we speak about 'contact filter' we actually mean 'contact filter effect', as it refers to the filtering effect of the contact patch on the physical roughness, resulting in effective roughness.*

renders results for different input roughness spectra, different wheel loads and different wheel diameters. By averaging across various roughness inputs, and normalising the horizontal scale to λ/a, where λ is the wavelength, one generalised contact filter was found. The numerical results for the long wavelengths are preferably replaced by the filter effect as calculated by an analytic expression[3]. This resulting filter is shown in Table 1.

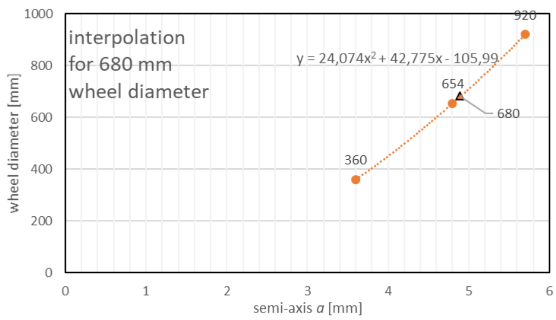
Table 1 Contact filter derived from DPRS model (source: table 5.2 of [2]).

λ /*a*	dB	λ /*a*	dB
38,8	0	3,08	-10,2
30,8	0	2,45	-14,6
24,5	0	1,94	-17,7
19,4	-0,1	1,54	-17,6
15,4	-0,2	1,23	-19,3
12,3	-0,4	0,974	-21,8
9,74	-0,8	0,774	-22,3
7,74	-1,4	0,615	-23,5
6,15	-2,5	0,488	-24,5
4,89	-4,4	0,388	-24,5
3,88	-6,7	0,308	-26,1

The values for semi-axis *a* that are relevant for CNOSSOS can be found in figure caption 5-15 of Thompson's book. They are copied below in Table 2. The value of *a* for the CNOSSOS 680 mm wheel diameter (shaded in the table) has been derived by interpolation (see the graph next to the table).

Table 2 Wheel parameters and patch size.

load [kN]	diameter [mm]	semi-axis *a* [mm]
50	360	3,6
50	654	4,8
50	680	4,9
50	920	5,7
25	920	4,5
100	920	7,2



Using these values for *a* in combination with Table 1 will generally lead to wavelengths that are not equal to the standard one-third octave band centres. An interpolation process is needed to find these. The results of this process are shown in Figure 1. The dots in each graph are the values from Table 2. Only the horizontal position of the dots is different (wavelength shift).

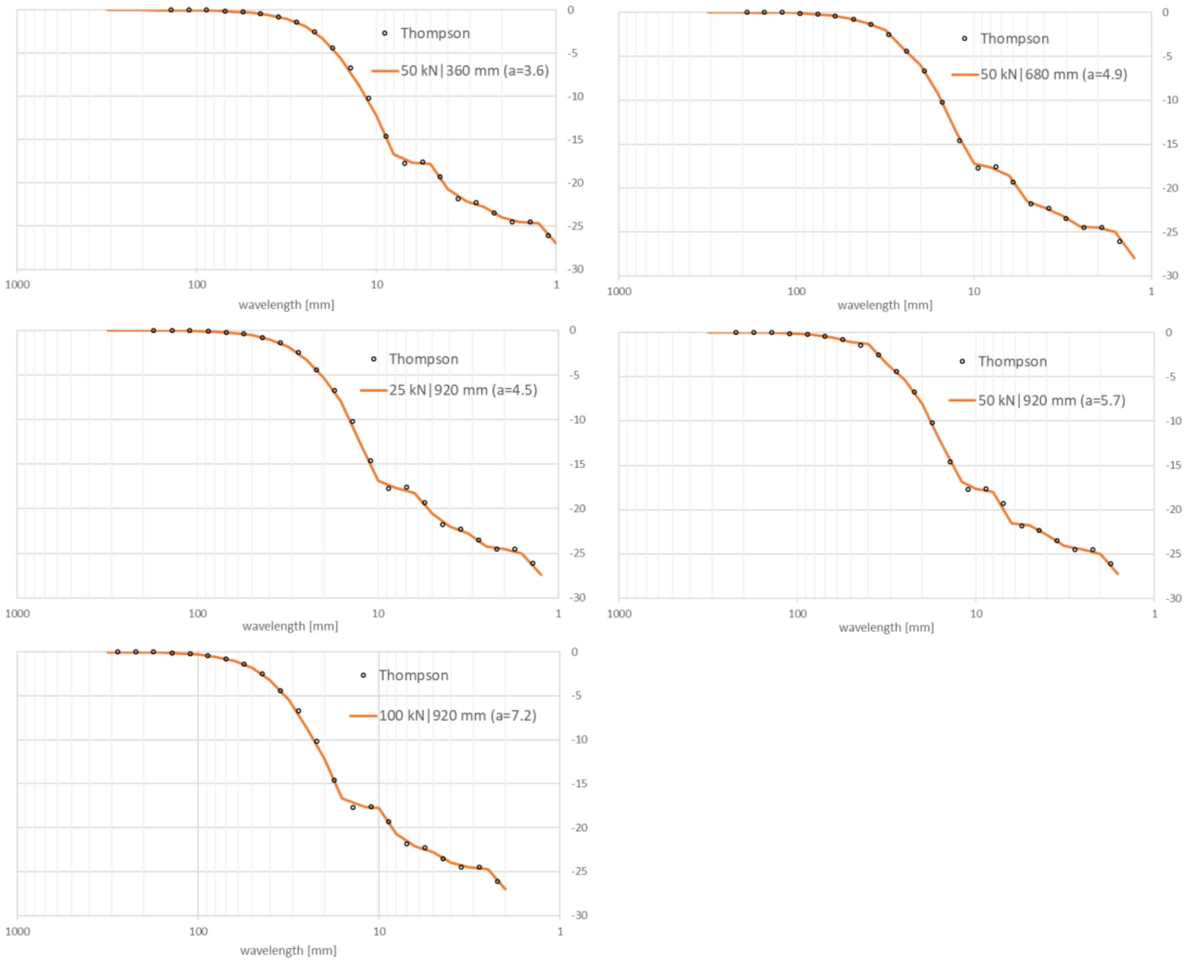


Figure 1 Fitting the contact filters (annotation: wheel load | wheel diameter) at the standard wavelength band centres.

The new contact filters are tabulated in Table 3.

Table 3 New contact filters.

	50 kN	50 kN	50 kN	25 kN	100 kN
wavelength	360 mm	680 mm	920 mm	920 mm	920 m
1000 mm	0	0	0	0	0
800 mm	0	0	0	0	0

630 mm	0	0	0	0	0
500 mm	0	0	0	0	0
400 mm	0	0	0	0	0
315 mm	0	0	0	0	0
250 mm	0	0	0	0	0
200 mm	0	0	0	0	0
160 mm	0	0	0	0	-0,1
125 mm	0	0	-0,1	0	-0,2
100 mm	0	-0,1	-0,1	0	-0,3
80 mm	-0,1	-0,2	-0,3	-0,1	-0,6
63 mm	-0,2	-0,3	-0,6	-0,3	-1
50 mm	-0,3	-0,7	-1,1	-0,5	-1,8
40 mm	-0,6	-1,2	-1,3	-1,1	-3,2
31,5 mm	-1	-2	-3,5	-1,8	-5,4
25 mm	-1,8	-4,1	-5,3	-3,3	-8,7
20 mm	-3,2	-6	-8	-5,3	-12,2
16 mm	-5,4	-9,2	-12	-7,9	-16,7
12.5 mm	-8,7	-13,8	-16,8	-12,8	-17,7
10 mm	-12,2	-17,2	-17,7	-16,8	-17,8
8 mm	-16,7	-17,7	-18	-17,7	-20,7
6.3 mm	-17,7	-18,6	-21,5	-18,2	-22,1
5 mm	-17,8	-21,5	-21,8	-20,5	-22,8
4 mm	-20,7	-22,3	-22,8	-22	-24
3.15 mm	-22,1	-23,1	-24	-22,8	-24,5
2.5 mm	-22,8	-24,4	-24,5	-24,2	-24,7
2 mm	-24	-24,5	-25	-24,5	-27
1.6 mm	-24,5	-25	-27,3	-25	-27,8
1.25 mm	-24,7	-28	-28,1	-27,4	-28,6
1 mm	-27	-28,8	-28,9	-28,2	-29,4
0.8 mm	-27,8	-29,6	-29,7	-29	-30,2

The differences between the old and new filters are shown in Figure 2. For freight trains the most relevant filter will be the green one (920 mm, 100 kN[7]). For trams, the grey filter is usually applicable (680 mm, 50 kN), except that the speed will be about half the shown speed. Note that for 45 km/h the grey curve must be shifted one octave to the left.

[7]*For passenger trains (with axle load 10 to 18 tonnes), the wheel load is in the range of 50 to 90 kN.*

In practical cases, replacing the old contact filters without changing any other parameter will lead to 2-4 dB(A) less noise emission.

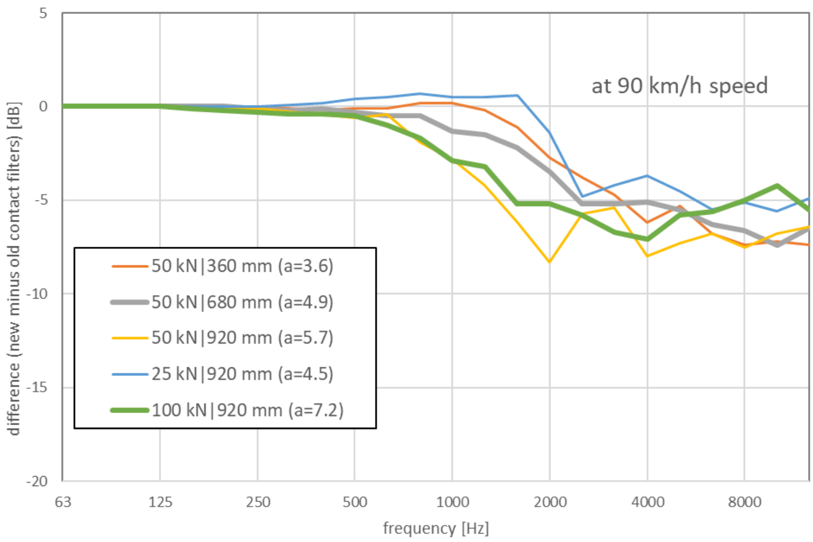


Figure 2 Spectral differences between old and new contact filters, as evaluated at 90 km/h.

2.2 Impact noise

In this paper we will propose a new default spectrum for impact noise. This default will be derived from the Dutch RMR model. The impact noise in the RMR model has been based on noise measurements (of which the original measurement report is not available any more). We will verify the new default spectrum by a comparison with results of the theoretical impact noise model by Wu and Thompson [6].

2.2.1 RMR-based impact roughness spectrum

In the RMR model, joints are represented empirically by an extra spectral term (denoted by the RMR parameter *bb*=3) that is added to the normal source spectrum. The overall effect of this extra term is between 4 and 5 dB(A), depending on train speed and joint density. This is in the same range of what has been reported elsewhere [5].

In CNOSSOS, the impact noise is represented by an impact roughness spectrum which has to be added to the total effective rail and wheel roughness. In order to derive a Dutch impact roughness spectrum, a process of fitting and iteration is applied. This yielded an impact roughness spectrum for CNOSSOS of which the excess noise matched the RMR excess noise of jointed track [3]. The result is shown in Figure 3.

The impact roughness in this graph refers to a track with 1 joint per 30 m. The green curve is taken from IMAGINE/CNOSSOS while the red one has been derived from the Dutch RMR model. The other curves, representing the total effective roughness for cast-iron and disk braked trains, are shown for comparison.

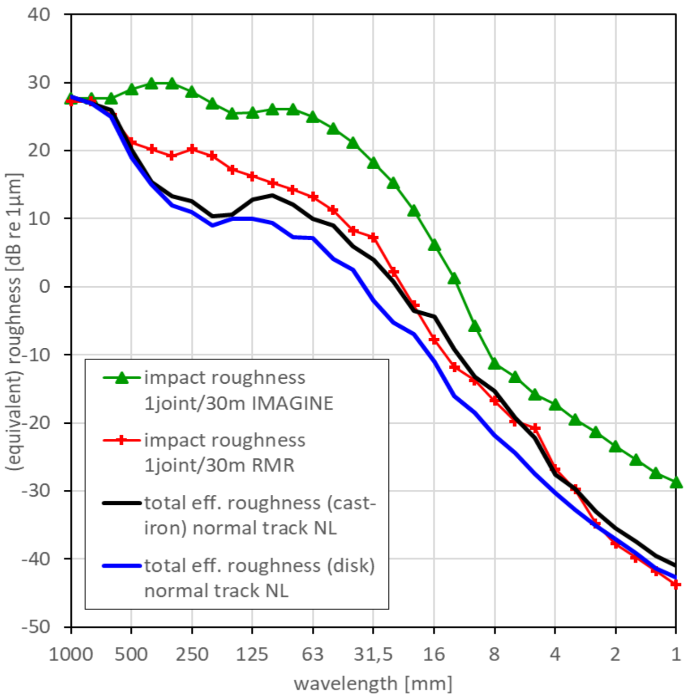


Figure 3 Impact roughness compared with wheel+rail roughness.

Note that the default impact roughness in CNOSSOS (and IMAGINE) is given for a situation of 1 joint per 100 m track, instead of 1 joint per 30 m. Therefore, the shown impact roughness is 5,2 dB higher (=10 log (100/30)) than the default for 1 joint per 100 m.
The RMR-based impact roughness produces more reliable results than the present IMAGINE/CNOSSOS default. This is demonstrated here by a verification of the impact roughness using the modelling approach of Wu and Thompson.

2.2.2 Verification using approach of Wu and Thompson

Figure 4 gives the equivalent roughness spectrum for different speeds. The equivalent roughness is derived by Wu and Thompson from a model simulation of the impact of a wheel passing over a joint. The simulation refers to the first 0,125 seconds of the impact. After this time the impact force has completely returned to its static value. The shown equivalent roughness does not yet take into account the wheel and rail roughness and therefore it should be (energy) added to the total effective roughness to give the total (rolling and impact) noise during this short period of 0,125 s. The strength of the equivalent roughness depends, among others, on the gap size, the gap depth, and the level difference between the both sections of the rails (step-up or step-down).

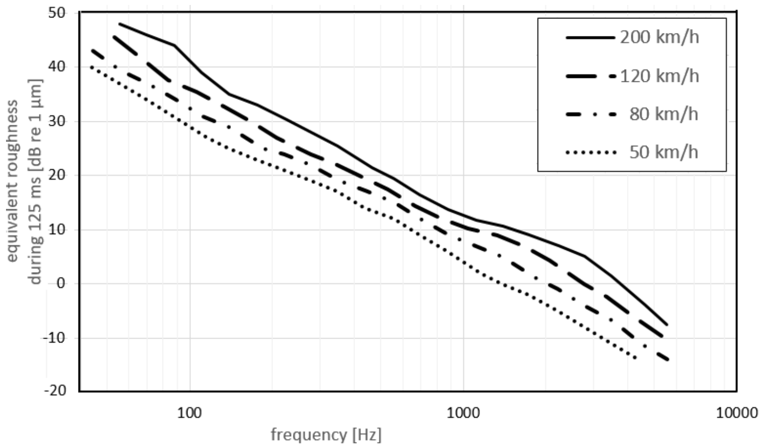


Figure 4 Equivalent roughness. Gap 7 mm, dip 5 mm, step-up 1 mm. Source: [4]

2.2.3 Wavelength spectrum

The speed dependency vanishes if the equivalent roughness is transferred to the wavelength domain. Figure 5 (left graph) shows this. The original curves of Figure 4 almost coincide. These spectra are evaluated over 100 m of track, instead of during 0,125 s. The black circles give the average spectrum for this joint (5 mm dip), independent of speed. In the graph on the right the same is done for a simulation given in reference [6] for a joint with 10 mm dip.

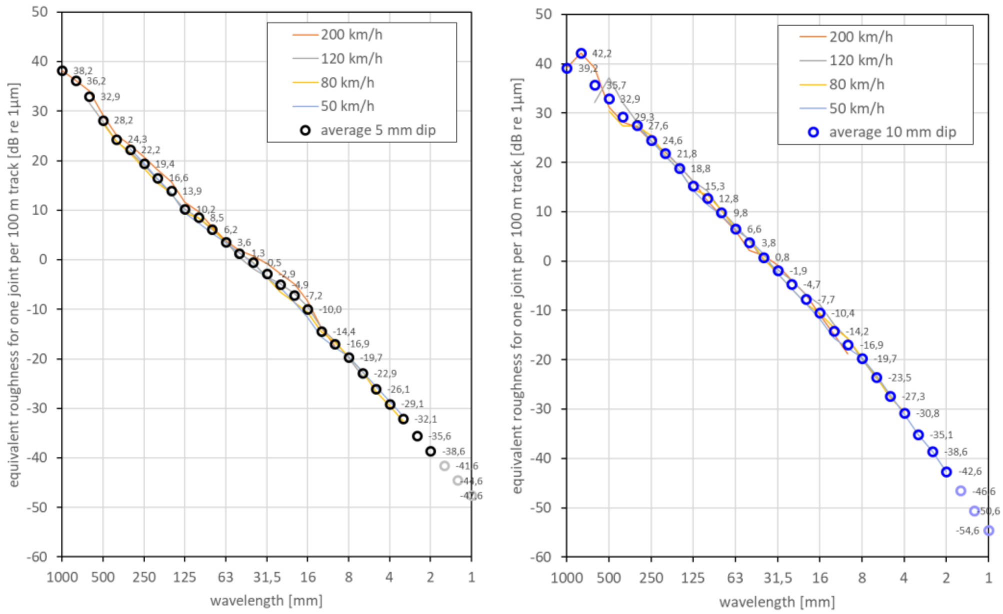


Figure 5 Equivalent roughness for 1 joint per 100 m track. Left 5 mm dip, right 10 mm dip.

As remarked before, these equivalent roughness spectra are solely the result of the impact forces, they are independent of the wheel and rail roughness.

For comparison, the newly derived equivalent roughness spectra are plotted with the present IMAGINE/CNOSSOS default spectrum and with the Dutch RMR model's equivalent, shown in Figure 3. The result is shown in Figure 6. The roughness refers to a jointed track made out of 30 m long pieces of rail.

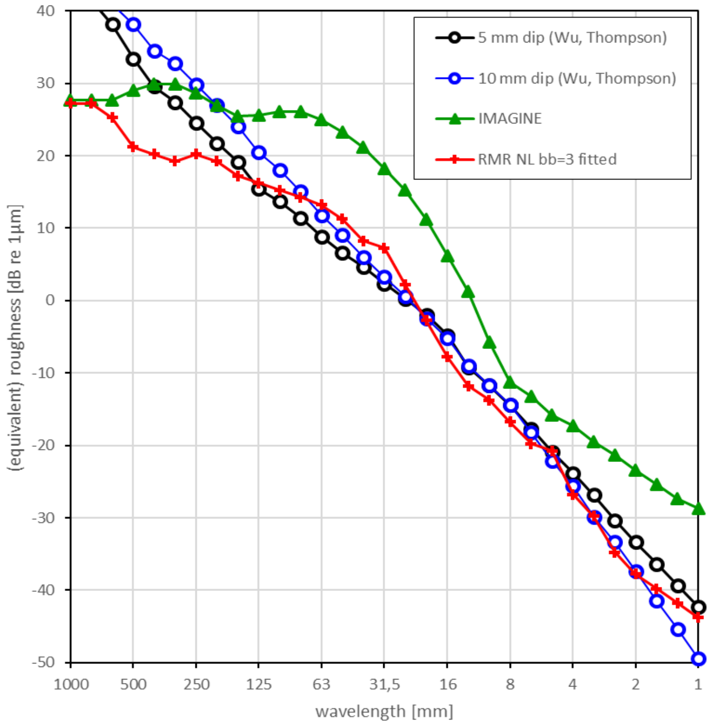


Figure 6 Comparison of impact roughness spectra for 1 joint per 30 m.

2.2.4 Discussion

The modelling results for gaps with 5 and 10 mm depth have the same order of magnitude as the RMR impact roughness.
The relative increase between 125 and 16 mm, seen in the RMR and IMAGINE results, is not visible in the modelling spectra of the 5 and 10 mm dips. It is possible that in this range the RMR impact roughness is contaminated with rail roughness, as the RMR spectrum is based on differential measurements between a site with rail joints and another one without joints. The effect is not large, though.
At wavelengths longer than 250 mm the RMR impact spectrum is much lower than the modelled ones. This part of the spectrum refers to frequencies below 100 Hz (for train speeds that are common on jointed track). In this range, traction noise (if present) may have influenced the accuracy of the differential measurement, but also other explanations, on the side of impact modelling, are possible.

2.2.5 Proposal impact roughness

We propose to replace the IMAGINE default impact roughness spectrum in CNOSSOS by the RMR impact roughness spectrum. The RMR spectrum, normalised to 1 joint per 100 m, is given in Table 4.

Table 4 RMR impact roughness

wavelength	$L_{R,IMPACT,i}$	wavelength	$L_{R,IMPACT,i}$	wavelength	$L_{R,IMPACT,i}$
1000	22	80	9	6,3	-25
800	22	63	8	5	-26
630	20	50	6	4	-32
500	16	40	3	3,15	-35
400	15	31,5	2	2,5	-40
315	14	25	-3	2	-43
250	15	20	-8	1,6	-45
200	14	16	-13	1,25	-47
160	12	12,5	-17	1	-49
125	11	10	-19	0,8	-50
100	10	8	-22		

2.3 Default rail roughness

Rail roughness can vary a lot, depending on many aspects that depend on track usage and maintenance. Also, rail network related factors, such as the average sleeper spacing and the pad stiffness, may influence the rail roughness. Even after rail grinding the resulting roughness will vary because of grinding technique, initial roughness, grinding train speed, and so on. And for metro and tramway systems a 'standard' roughness will differ from high speed systems [7]. For these reasons, it is impossible to provide a suitable reference rail roughness spectrum valid for different networks across Europe.

Still, a computation method like CNOSSOS, that requires rail roughness as input, needs to have a certain default spectrum to start with. We propose to use an improved rail roughness as default spectrum in CNOSSOS. It should replace the present spectrum for 'average network' in CNOSSOS table G-1.

The spectrum is shown Figure 7. It is constructed from three sources of data:

- 100 to 1 mm: (energy) averaged spectrum from the original data of 30 measurement sites in the Netherlands (1996) [8].
- 315 to 100 mm: measurement Dutch network (1999) [9];
- 1000 to 315 mm: data from Grassie (2016) [7].

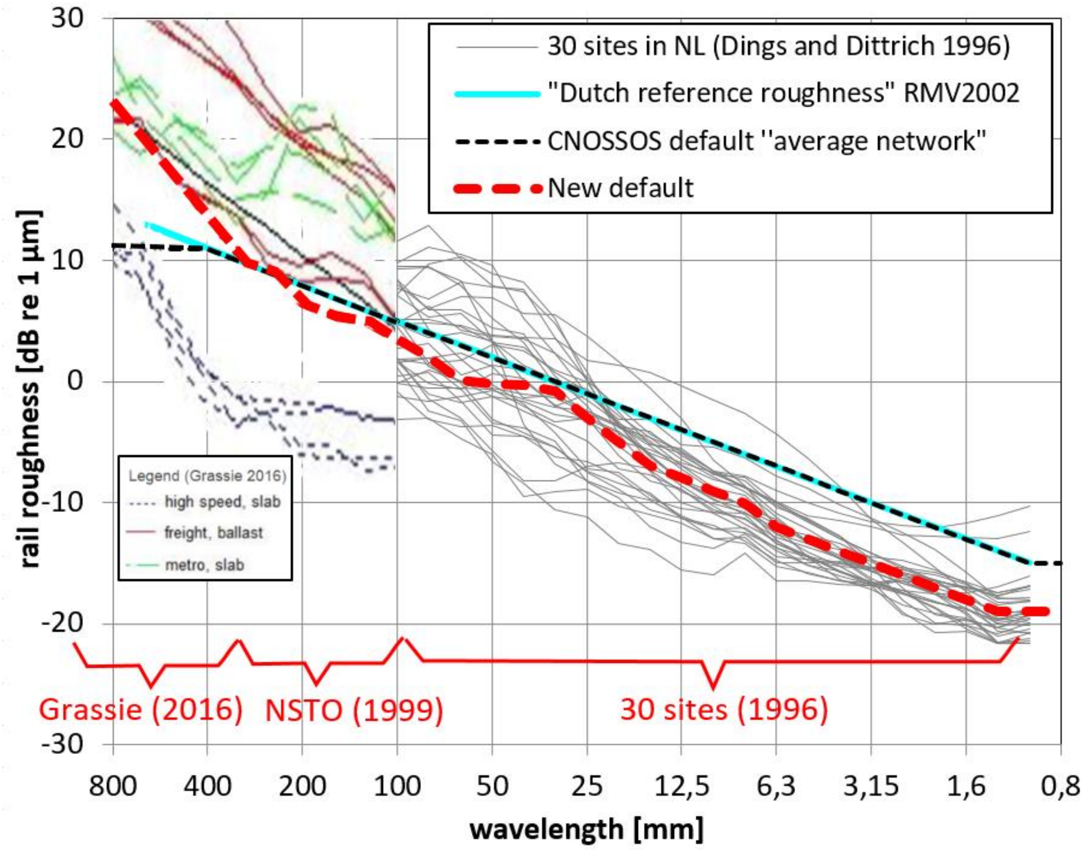


Figure 7 Rail roughness spectra and defaults. The inset to the left, which is copied here from Grassie [7] with permission[8], shows the spread in long wavelength measurement data of metro, high speed and freight tracks.

The figure also shows the present default of CNOSSOS and the Dutch reference roughness. The Dutch reference has been based originally on the average of 30 sites, but it featured a simplified slope of 1 dB per one-third octave, leading to overestimation of the roughness level between 25 and 0,8 mm wavelength.

In Figure 8 the new default is plotted against a more recent dataset. In this case, it is the well-maintained track near different monitoring stations of ProRail (used to detect wheel flats and excessive axle loads, among others). The device was a 1,2 m fixed direct system, similar to the one used on the 30 sites [8], but this time through post-procressing of subsequent roughness signals also longer wavelengths than 100 mm could be assessed. This comparison clearly shows that these tracks are smoother than the new default. Some corrugation peaks are visible at 30-40

[8] *E-mail from Stuart Grassie, 23 July 2018*

mm, though. At long wavelengths, 200-400 m, the roughness level is quite similar to the new default.

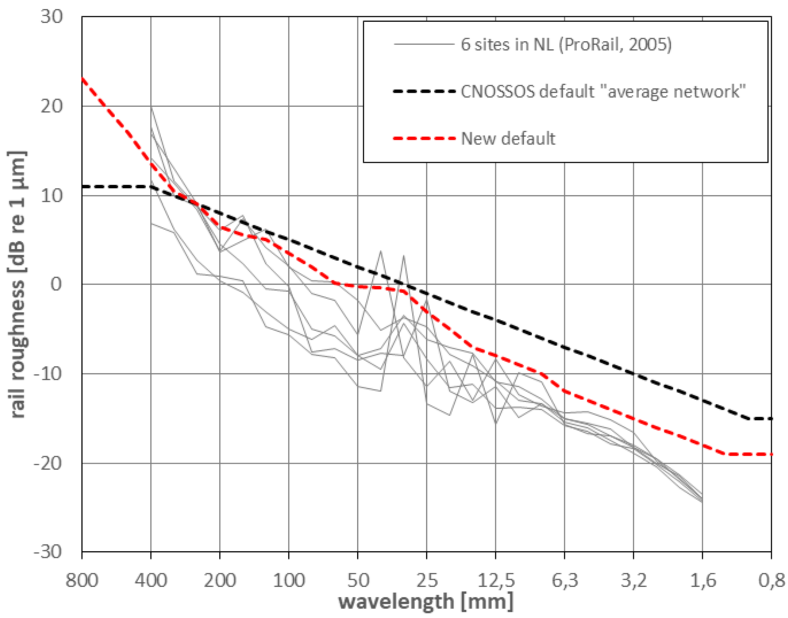


Figure 8 The old and new default roughness compared to a more recent set of measurements in the Netherlands. Source: [3].

The effect of the new default rail roughness needs to be compensated in the wheel roughness, as otherwise it would reduce the rolling noise sound power by about 0,3 dB(A) for trains with cast-iron braked wheels and 1,5 dB(A) for trains with disk braked wheels, as compared to the present default for average network in CNOSSOS.

Table 5 New default: rail roughness average network

wavelength	$L_{r,\mathrm{TR},i}$	wavelength	$L_{r,\mathrm{TR},i}$	wavelength	$L_{r,\mathrm{TR},i}$
1000	25,0	80	2,0	6,3	-12,0
800	23,0	63	0,1	5	-13,0
630	20,0	50	-0,2	4	-14,0
500	17,0	40	-0,3	3,15	-15,0
400	13,5	31,5	-0,8	2,5	-16,0
315	10,5	25	-3,0	2	-17,0
250	9,0	20	-5,0	1,6	-18,0
200	6,5	16	-7,0	1,25	-19,0
160	5,5	12,5	-8,0	1	-19,0

125	5,0	10	-9,0	0,8	-19,0
100	3,5	8	-10,0		

2.4 Compensation for new contact filters and new rail roughness

We propose to compensate the effect of the new contact filters (2-4 dB reduction of rolling noise) and new rail roughness (0,3-1,5 dB reduction of rolling noise) by compensating (i.e. increasing) the wheel roughness default spectra. The other possibility would be to compensate the transfer functions, but these are in the frequency domain while the compensation is required in the wavelength domain. The wheel roughness defaults in CNOSSOS originate from the IMAGINE database, but details about the specific set of data that is used for the defaults in CNOSSOS could not be retrieved[9].

2.4.1 Compensation to match original CNOSSOS default rolling noise

From the set of contact filters $A_{3,i}$ we choose only the ones applicable to trains (not trams): 50kN|920mm and 100kN|920mm[10]. This is because the default wheel roughness in CNOSSOS (cast-iron, disk and composite) is primarily meant for train systems. The new wheel roughness $L^{new}{}_{r,VEH,I}$ is calculated as follows (the present defaults of CNOSSOS have the suffix 'old', the newly proposed ones 'new'):

$$L^{new}{}_{r,VEH,i} = (L^{old}{}_{R,TOT,i} - A^{new}{}_{3,i}) \ominus L^{new}{}_{r,TR,i} \quad ,$$

where

$$L^{old}{}_{R,TOT,i} = (L^{old}{}_{r,TR,i} \oplus L^{old}{}_{r,VEH,i}) + A^{old}{}_{3,i} \quad .$$

The symbols ⊕ and ⊖ represent energy summation and subtraction, respectively. These expressions are evaluated for the 50kN|920mm and 100kN|920mm filters separately. Finally, the new default wheel roughness is calculated by averaging the results that are obtained for both contact filters. The old and new spectra are shown in Figure 9.

Appendix 2 gives a comparison of the rolling noise calculated with CNOSSOS for the old and new defaults. It is demonstrated that the rolling noise spectra are similar in a wide frequency range for various train speeds.

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[9] *Communication by e-mail with Rick Jones (29 August) and Paul van der Stap (30 August 2018)*

[10] *annotation: wheel load | wheel diameter*

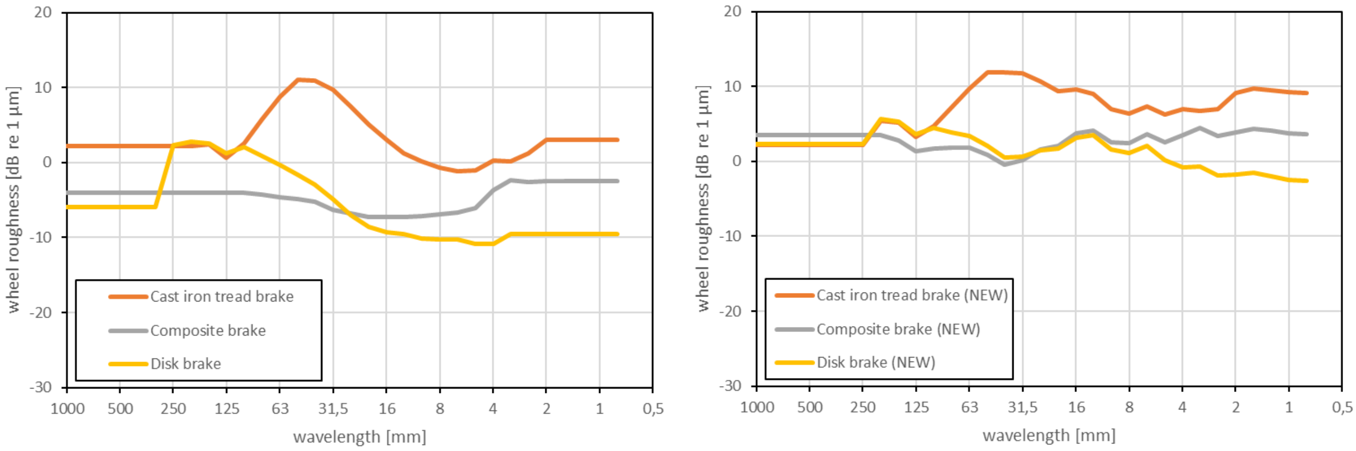

Figure 9 The present defaults (left graph) and the new defaults (right graph) for wheel roughness.

2.4.2 Conclusion

The proposed modification of the contact filters and default rail roughness would lead to a reduction of the computed rolling noise level, if nothing else changes. As there is no reason to assume that resulting rolling noise emission would need to be changed, we propose to compensate the wheel roughness defaults in such a way that the effect of the modifications of the contact filters and rail roughness is neutralised.

2.5 Pad stiffness

2.5.1 Introduction

The pad stiffness value that is relevant for acoustics needs to refer to the *dynamic stiffness* (at small strains). Its value can be quite different from static stiffness over large strains, which is relevant for track engineering. Chapter 3.8 from Thompson's book gives a thorough treatment on pad stiffness for noise prediction [2].

The relevant frequency range for the dynamic stiffness is 100-5000 Hz. When measuring the dynamic stiffness of a rail pad in a laboratory set-up, a pre-load within the range 20-60 kN needs to be applied to it.

It would be helpful to know the value of the pad stiffness belonging to the classification 'soft', 'medium' and 'hard' in table G-3 of CNOSSOS.
The source of these track transfer functions is the IMAGINE project (2004-2006) [4]. Modifications to the tabulated functions were necessary in CNOSSOS, probably due to the different definition of the transfer function in IMAGINE. Unfortunately, the pad stiffness values are not listed in IMAGINE, and neither are most of the other settings in the TWINS model that produced these transfer functions.

Elsewhere in the CNOSSOS document, in table 2.3.b, another classification is given for the pad stiffness: ‘soft’, ‘medium’ and ‘stiff’. This classification contains certain stiffness ranges in MN/m. It probably originates from the STAIRRS project (2000-2002). It is unlikely that it these ranges for the (‘acoustic’) stiffness correspond to the classification in table G-3, as they are from a different source, with a different goal.

2.5.2 Conclusion

In the CNOSSOS text it is proposed to use the term ‘dynamic stiffness’ when introduced first, and to use the classification Soft-Medium-Hard.

3 Validation

The proposed modifications to the contact filters and rail roughness has been validated in Appendix 2 of this paper.
The effect of the proposed modification to the impact noise spectrum has been verified by comparing the new empirical spectrum with theoretical spectra.

4 Conclusion

Based on the discussion and arguments given in this paper, a new text proposal for the Directive is given in Appendix 1.

All roughness wavelength ranges of the new data are now given from 2000 mm to 0,8 mm. This is because the original range (1000 mm - 0,8 mm) is not sufficient for calculations up to 300 km/h of vehicle speed. Also, some one-third octave band centre frequencies in the tables needed to be changed to standard values: 125 mm, 12,5 mm, 3,15 mm.

Note that the lay-out in Appendix 1 is based on the Corrigendum lay-out of 18 January 2018, which differs from the 2015/996 publication of the Directive.

5 Literature

[1] Commission directive 2015/996 of 19 May 2015, establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council.
[2] Railway Noise and Vibration, David Thompson, Elsevier, 2009
[3] CNOSSOS railverkeer, Bronkentallen en adviezen voor implementatie van rekenmethode CNOSSOS voor railverkeer in Nederland, Edwin Verheijen, dBvision report RIM006-03-06ev, 14 december 2017
[4] IMAGINE railway noise source model, default source data and measurement protocol, Michael Dittrich, IMA6TR-060720-TNO01, 20 July 2006.

[5] An assessment of the effectiveness of noise reduction systems on Dublin's light rail system (Luas), Stephen Byrne, paper 224 of Euronoise, Crete, 2018
[6] T. X. Wu, D. J. Thompson, *On the impact noise generation due to a wheel passing over rail joints*, ISVR, 2001. The manuscript version can be downloaded freely from the server of ISVR. An article with the same title is published in the Journal of Sound and Vibration 267 (2003) pp. 485–496.
[7] Routine measurement of long wavelength irregularities from vehicle-based equipment", in "Noise and vibration mitigation for rail transport systems", David Anderson et al (eds), Notes on Numerical Fluid Mechanics and Multidisciplinary Design, 2018, vol 139, pp333-342 (also Proceedings of 12th International Workshop on Railway Noise, Terrigal, NSW, Australia, 13-15 September 2016)
[8] Dings, Dittrich, Roughness on Dutch Railway Wheels and Rails, JS&V 193(1):103-112, 1996
[9] Harmonoise WP1.2, Deliverable 12 part 1, Definition of track influence: roughness in rolling noise, HAR12TR-020813-AEA10, Annemarie van Beek *et al*. (AEAT), July 2003
[10] E. Verheijen, M.S. Roovers, J.W. van den Brink, Statistical analysis of railway noise: trackside monitoring of individual trains, Paper S5.1 van de Proceedings van de International Workshop on Railway Noise and Vibrations, München, September 2007

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Appendix 1 Modifications for CNOSSOS

Original text fragments are in black, new text is in blue.

On page 14, in Table [2.3.b], fourth column, third row:

for: Represents an indication of the 'acoustic' stiffness

read: Represents an indication of the dynamic stiffness

On page 14, in Table [2.3.b], Fourth column, sixth row:

for: H
Stiff
(800-1 000 MN/m)

read: H
Hard
(800-1 000 MN/m)

Appendix G to the Annex shall have the following modifications:

Table G-1

Coefficients $L_{r,TR,i}$ and $L_{r,VEH,i}$ for rail and wheel roughness

$L_{r,VEH,i}$			
Wavelength	Brake type		
	c	k	n
	Cast-iron tread brake	Composite brake	Disk brake
2 000 mm	2,2	3,5	2,3
1 600 mm	2,2	3,5	2,3
1 250 mm	2,2	3,5	2,3
1 000 mm	2,2	3,5	2,3
800 mm	2,2	3,5	2,3
630 mm	2,2	3,5	2,3
500 mm	2,2	3,5	2,3
400 mm	2,2	3,5	2,3
315 mm	2,2	3,5	2,3
250 mm	2,2	3,5	2,3
200 mm	5,4	3,5	5,7
160 mm	5,2	2,8	5,3
125 mm	3,3	1,4	3,7
100 mm	4,7	1,7	4,4

80 mm	7,2	1,9	3,9
63 mm	9,8	1,9	3,4
50 mm	11,9	0,8	2,1
40 mm	11,9	-0,5	0,6
31,5 mm	11,8	0,2	0,7
25 mm	10,7	1,6	1,5
20 mm	9,4	2,1	1,7
16 mm	9,6	3,7	3,2
12,5 mm	9,1	4,1	3,5
10 mm	7,0	2,5	1,6
8 mm	6,4	2,4	1,1
6,3 mm	7,3	3,6	2,0
5 mm	6,3	2,6	0,2
4 mm	6,9	3,5	-0,8
3,15 mm	6,8	4,5	-0,6
2,5 mm	7,0	3,4	-1,8
2 mm	9,2	3,9	-1,7
1,6 mm	9,7	4,4	-1,4
1,25 mm	9,5	4,1	-2,0
1 mm	9,3	3,8	-2,4
0,8 mm	9,1	3,7	-2,6

$L_{r,TR,i}$		
Wavelength	Rail roughness	
	E	M
	EN ISO 3095:2013 (Well maintained and very smooth)	Average network (Normally maintained smooth)
2 000 mm	17,1	35,0
1 600 mm	17,1	31,0
1 250 mm	17,1	28,0
1 000 mm	17,1	25,0
800 mm	17,1	23,0
630 mm	17,1	20,0
500 mm	17,1	17,0
400 mm	17,1	13,5
315 mm	15,0	10,5
250 mm	13,0	9,0

200 mm	11,0	6,5
160 mm	9,0	5,5
125 mm	7,0	5,0
100 mm	4,9	3,5
80 mm	2,9	2,0
63 mm	0,9	0,1
50 mm	−1,1	-0,2
40 mm	−3,2	-0,3
31,5 mm	−5,0	-0,8
25 mm	−5,6	-3,0
20 mm	−6,2	-5,0
16 mm	−6,8	-7,0
12,5 mm	−7,4	-8,0
10 mm	−8,0	-9,0
8 mm	−8,6	-10,0
6,3 mm	−9,2	-12,0
5 mm	−9,8	-13,0
4 mm	−10,4	-14,0
3,15 mm	−11,0	-15,0
2,5 mm	−11,6	-16,0
2 mm	−12,2	-17,0
1,6 mm	−12,8	-18,0
1,25 mm	−13,4	-19,0
1 mm	−14,0	-19,0
0,8 mm	−14,0	-19,0

Table G-2

Coefficients $A_{3,i}$ for the contact filter

	$A_{3,i}$				
Wavelength	Wheel load 50 kN - wheel diameter 360 mm	Wheel load 50 kN - wheel diameter 680 mm	Wheel load 50 kN - wheel diameter 920 mm	Wheel load 25 kN - wheel diameter 920 mm	Wheel load 100 kN - wheel diameter 920 mm
2 000 mm	0,0	0,0	0,0	0,0	0,0
1 600 mm	0,0	0,0	0,0	0,0	0,0
1 250 mm	0,0	0,0	0,0	0,0	0,0
1 000 mm	0,0	0,0	0,0	0,0	0,0

800 mm	0,0	0,0	0,0	0,0	0,0
630 mm	0,0	0,0	0,0	0,0	0,0
500 mm	0,0	0,0	0,0	0,0	0,0
400 mm	0,0	0,0	0,0	0,0	0,0
315 mm	0,0	0,0	0,0	0,0	0,0
250 mm	0,0	0,0	0,0	0,0	0,0
200 mm	0,0	0,0	0,0	0,0	0,0
160 mm	0,0	0,0	0,0	0,0	-0,1
125 mm	0,0	0,0	-0,1	0,0	-0,2
100 mm	0,0	-0,1	-0,1	0,0	-0,3
80 mm	-0,1	-0,2	-0,3	-0,1	-0,6
63 mm	-0,2	-0,3	-0,6	-0,3	-1,0
50 mm	-0,3	-0,7	-1,1	-0,5	-1,8
40 mm	-0,6	-1,2	-1,3	-1,1	-3,2
31,5 mm	-1,0	-2,0	-3,5	-1,8	-5,4
25 mm	-1,8	-4,1	-5,3	-3,3	-8,7
20 mm	-3,2	-6,0	-8,0	-5,3	-12,2
16 mm	-5,4	-9,2	-12,0	-7,9	-16,7
12,5 mm	-8,7	-13,8	-16,8	-12,8	-17,7
10 mm	-12,2	-17,2	-17,7	-16,8	-17,8
8 mm	-16,7	-17,7	-18,0	-17,7	-20,7
6,3 mm	-17,7	-18,6	-21,5	-18,2	-22,1
5 mm	-17,8	-21,5	-21,8	-20,5	-22,8
4 mm	-20,7	-22,3	-22,8	-22,0	-24,0
3,15 mm	-22,1	-23,1	-24,0	-22,8	-24,5
2,5 mm	-22,8	-24,4	-24,5	-24,2	-24,7
2 mm	-24,0	-24,5	-25,0	-24,5	-27,0
1,6 mm	-24,5	-25,0	-27,3	-25,0	-27,8
1,25 mm	-24,7	-28,0	-28,1	-27,4	-28,6
1 mm	-27,0	-28,8	-28,9	-28,2	-29,4
0,8 mm	-27,8	-29,6	-29,7	-29,0	-30,2

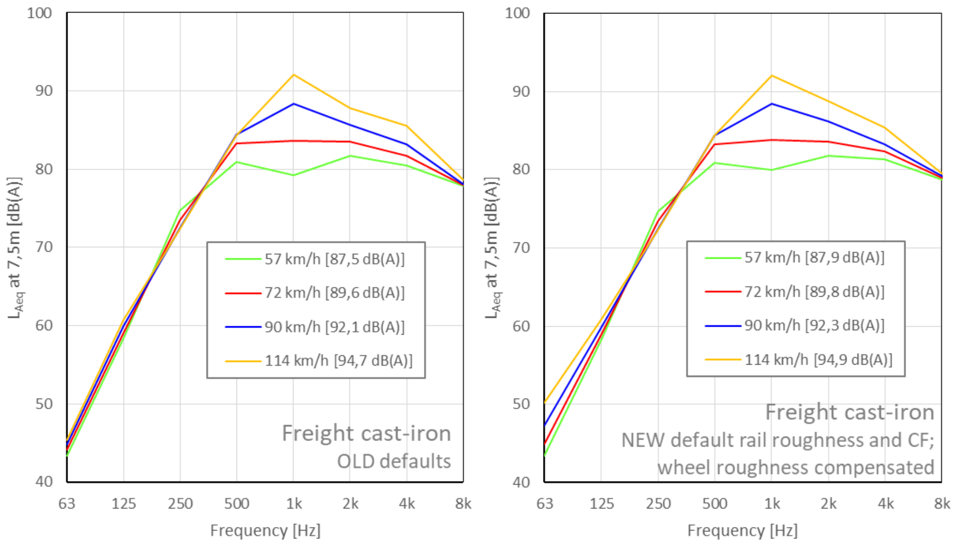
Table G-3 can be left unaltered.

Table G-4
Coefficients $L_{R,\mathrm{IMPACT},i}$ for impact noise

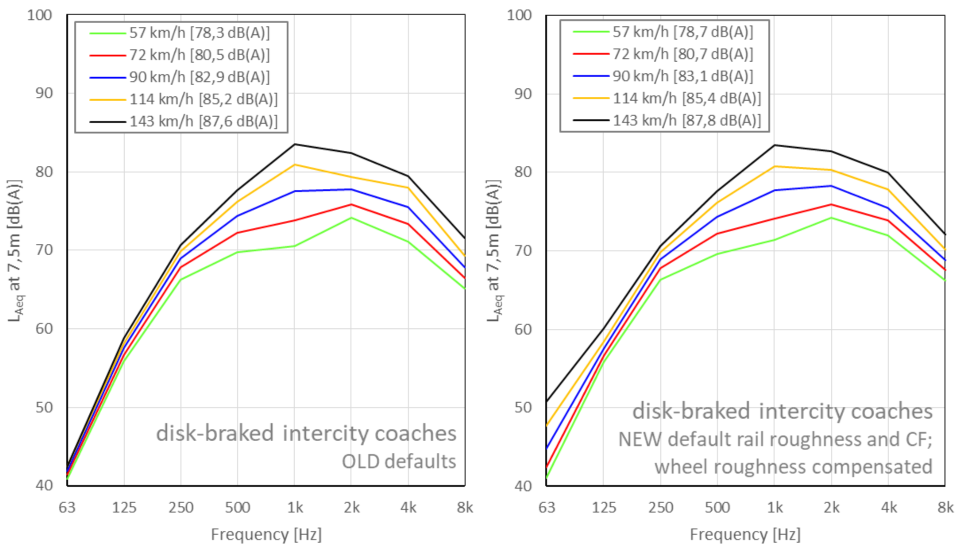
$L_{R,IMPACT,i}$	
Wavelength	Single switch/joint/crossing/100 m
2 000 mm	22,0
1 600 mm	22,0
1 250 mm	22,0
1 000 mm	22,0
800 mm	22,0
630 mm	20,0
500 mm	16,0
400 mm	15,0
315 mm	14,0
250 mm	15,0
200 mm	14,0
160 mm	12,0
125 mm	11,0
100 mm	10,0
80 mm	9,0
63 mm	8,0
50 mm	6,0
40 mm	3,0
31,5 mm	2,0
25 mm	-3,0
20 mm	-8,0
16 mm	-13,0
12,5 mm	-17,0
10 mm	-19,0
8 mm	-22,0
6,3 mm	-25,0
5 mm	-26,0
4 mm	-32,0
3,15 mm	-35,0
2,5 mm	-40,0
2 mm	-43,0
1,6 mm	-45,0
1,25 mm	-47,0
1 mm	-49,0
0,8 mm	-50,0

Appendix 2 Comparing present and new default parameters

The effect of the present and new defaults is calculated in CNOSSOS. The calculation is a simulation of the pass-by noise for a receiver position at 7,5 m from the track. On the left, the rolling noise is shown for the present defaults (‘old’). On the right, the rolling noise for the defaults proposed in this paper are shown (‘new’). The new wheel roughness defaults have been optimised in such a way that the effect on the calculated rolling noise is negligible.



Freight with cast-iron blocks



Passenger train with disk brakes