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Road traffic noise sprectra – the need for updates

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In Norway, calculations of indoor traffic noise levels are currently based on normalised traffic noise spectra defined in current Norwegian methodology. These spectra are based on measurement of road traffic noise more than 30 years old. In the meantime, the permissible noise emission levels for vehicles have been strengthened. In addition, there has been a technological development of the vehicles. Power-train noise sources like engine noise and exhaust noise have been considerably reduced, especially for heavy vehicles. This development has been driven more by customer-demand and competition between vehicle manufacturers, rather than by regulations. However, this development has raised concern by the authorities and consultants, that the current spectra no longer were representative for the present vehicle fleet on Norwegian roads. On the request from the Norwegian Public Roads Administration, SINTEF has made a literatures study of recent investigations which included measurement of traffic noise spectra, both on individual vehicle classes and on mixed traffic. In addition, a small measurement program on light and heavy vehicles (pass-by measurements) has been performed. Based on this study and measurement results, a new road traffic noise spectrum for mixed traffic in the speed range 30 to 50 km/h has been proposed. For higher vehicle speeds, no changes have been proposed.

1 Introduction

In Norway, the calculations of indoor road traffic noise levels in dwellings are based on standardised noise spectra defined in Handbook 47, "*Isolering mot utendørs støy. Beregningsmetode og datasamling"* (Eng: Façade insulation against outdoor noise. Calculation methods and data collection). [1]. In this handbook, different traffic noise spectra are given, with regards to road speed classes, to urban or city roads and with or without noise barriers. When calculations according to the Nordic Prediction Method for Road Traffic (NBV96) are made, these spectra can be used. Figure 1 shows the normalised noise spectra for two different situations: C_1 – City 30 km/h and C_2 – City 50 km/h. The spectra represent a mix of light and heavy vehicles. Furthermore, the spectra shall be used both for calculations of equivalent and for maximum sound levels. The spectrum C_2 is identical with C_{tr} as defined in ISO 717-1 and represent urban road traffic. C_1 is based on measurement by SINTEF in streets in Oslo, while C_2 (C_{tr}) is based on measurement in Copenhagen and Gothenburg. All these measurements were made in the 1980-ties. C_{tr} has been adopted from the Nordtest Method NT ACOU 061 (1987). Since these measurements were done more than 30 years ago, the question is if they are representative for the current vehicle fleet. If, for example, there are too high levels for frequencies below 2-300 Hz in the spectra in figure 1, this can lead to an overestimate of the sound insulation needed to meet regulations and unnecessary high costs.

Based on this concern, SINTEF has been asked by the Norwegian Public Roads Administration to evaluate if these spectra need to be revised, to reflect the typical noise spectra from the present vehicle fleet. SINTEF has done this by a literature review and by conducting a small measurement campaign on pass-by noise levels of light and heavy vehicles on trafficked roads. In addition to the literature review, noise spectra used in the prediction methods Nord2000 and EU-CNOSSOS are presented.

This paper presents the main results from the literature review and from the measurements.

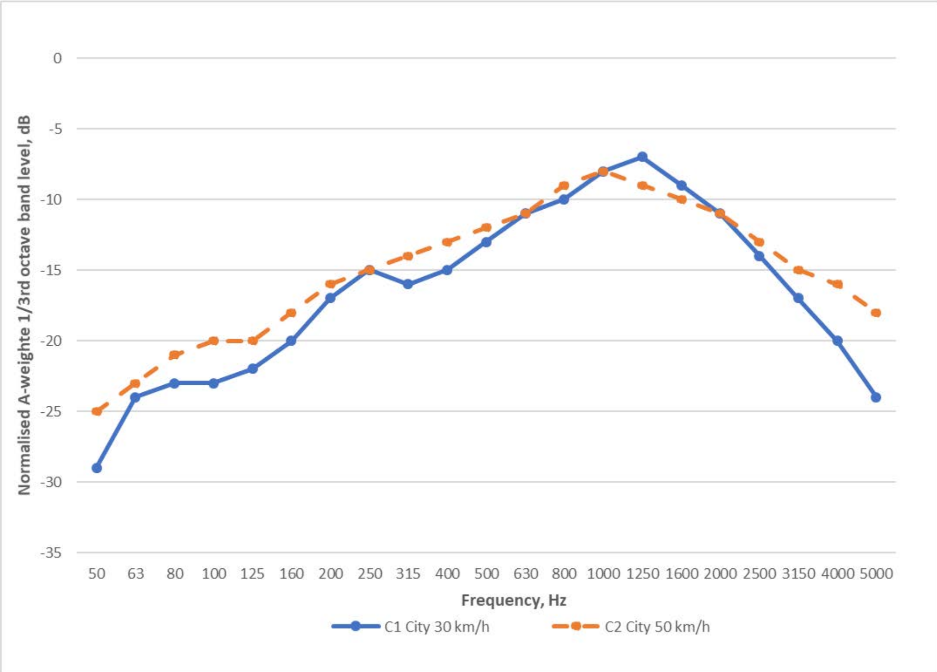

Figure 1: Traffic noise spectra for two traffic situations, from Handbook 47 [1]

2 Literature review

2.1 Selected studies

The main task of the literature review was to look for studies and papers which could present traffic noise spectra from vehicle groups representative for the present vehicle fleet. Therefore, studies made before 2010 were excluded, as they may contain too old vehicles.

The following studies were included:

- Serbian and Italian studies (2013)
- Swiss study (2015)
- SINTEF study (2015)
- French study (2016)
- Study from Japan (2018)

2.1.1 Serbian and Italian studies (2013)

The data from these studies have been compiled by Mesihovic et al and presented at Inter-noise 2016 [2]. The paper discusses the same concern as in our project; that the C_{tr} spectrum may lead to higher indoor noise levels than based on newer data. In figure 2, the C_{tr} spectrum and the two spectra from measurements in Belgrade (Serbia) and from Italy are compared. Below ca. 500 Hz, the two measured spectra lie clearly below the C_{tr} spectrum. Calculations have been done for some types of wall constructions and using the C_{tr} gives approximately 2,2-2,5 dB **higher** sound levels than using the spectrum from Belgrade.

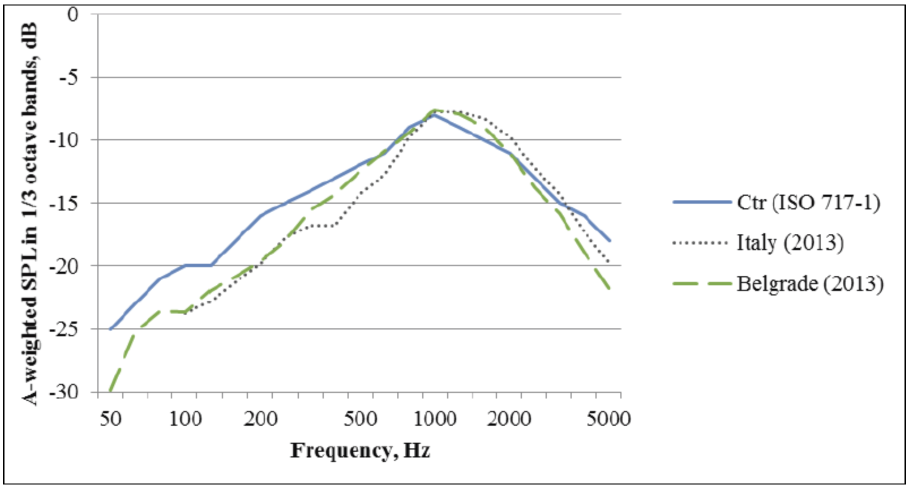

Figure 2: Comparison of C_{tr} spectrum and two measured spectra from Italy and Belgrade [2]

The authors discuss possible reasons for the deviations between the spectra and conclude that there may be a less percentage of heavy trucks in the 2013 data. However, they strongly recommend performing new measurements of traffic noise spectra, to check if these changes in the lower frequency area is a trend based on changes in the noise sources of vehicles.

2.1.2 Swiss study (2015)

The results from this study are presented in a paper by Hammer et al. at ICSV23 in 2016 [3]. On this project, the pass-by noise levels (L_{Amax}) of 22 different passenger cars were measured on a road surface believed to be 5 dB quieter than the reference road surface in CNOSSOS-EU. The test fleet consisted of vehicles with diesel and petrol engines, as well as electric vehicles. The vehicle speeds were 30 and 50 km/h. In figure 3, the average normalised spectrum (30 km/h) from all 22 vehicles are shown, compared to the C_1 and C_2 spectra.

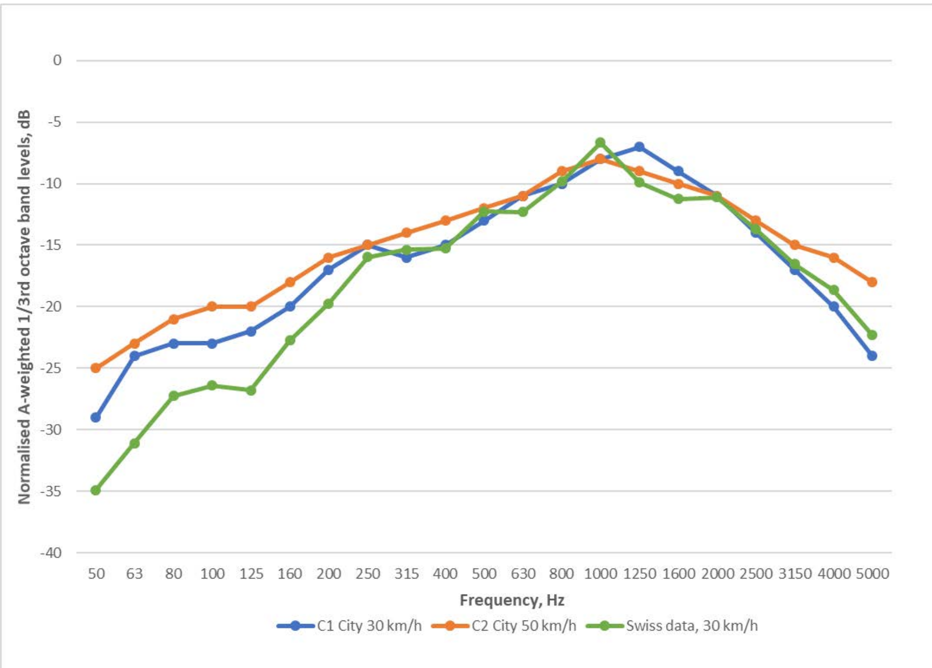

Figure 3: Average 1/3rd octave band spectrum from measurements of 22 vehicles (30 km/h) in Switzerland compared with the C_a and C_2 spectra [3]

The measurements indicates up to 5 dB lower levels below 200-250 Hz, compared to the standardized spectra. Among the 22 passenger cars, there were 2 pure electric vehicles (VW e-Golf and BMW i3). In figure 4, the spectra from the 2 electric vehicles are compared with the spectra for a VW Golf with petrol engines (right) and for a VW Golf with diesel engine (right). Driving condition is moderate acceleration from 30 km/h (left) and constant speed (right).

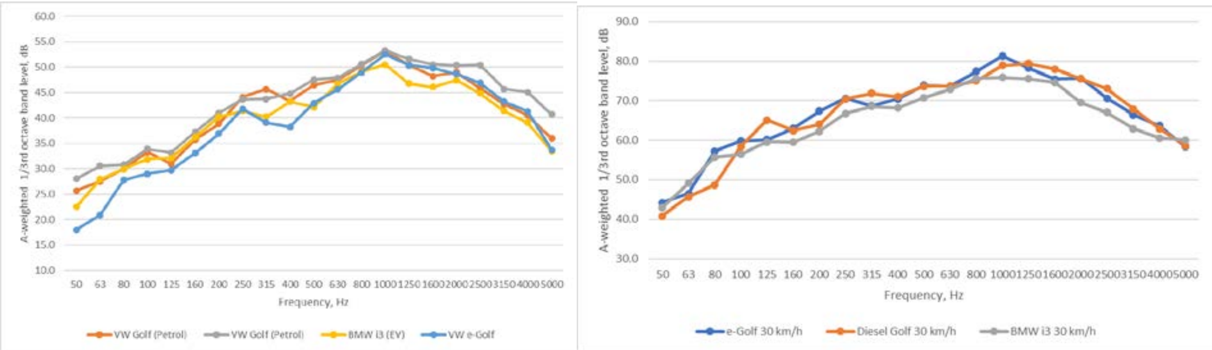

Figure 4: Comparison of noise spectra of electric vehicles and vehicles with petrol/diesel engines. Moderate acceleration from 30 km/h (left) and constant speed 30 km/h (right) [3]

Based on these few samples, there seems to be no major differences in the shape of the spectra between EVs and vehicles with internal combustion engines (ICE). However, more investigations on such comparison between EVs and ICE are recommended.

2.1.3 SINTEF study (2015)

In the Norwegian research project, MOVE, SINTEF tested out a microphone array to find out if it was feasible to measure the pass-by noise levels of individual vehicles in a traffic stream [4,5]. More than 8000 individual noise levels of passenger cars and around 1000 heavy vehicles were measured on a trafficked road with speed limit of 70 km/h. Besides the pass-by noise level and the noise spectrum, the vehicle speed and environmental conditions (temperature, wind speed, wind direction, road surface humidity) were also measured for each individual pass-by.

In figure 5, the normalised spectra for passenger cars within the speed range 40-69 km/h, and for 2 classes of heavy-duty vehicles (HDV- 2 axles and 3 or more axles) in the speed range 50-69 km/h are shown, compared to the C_1 and C_2 spectra.

No speed or temperature corrections are applied to these data.

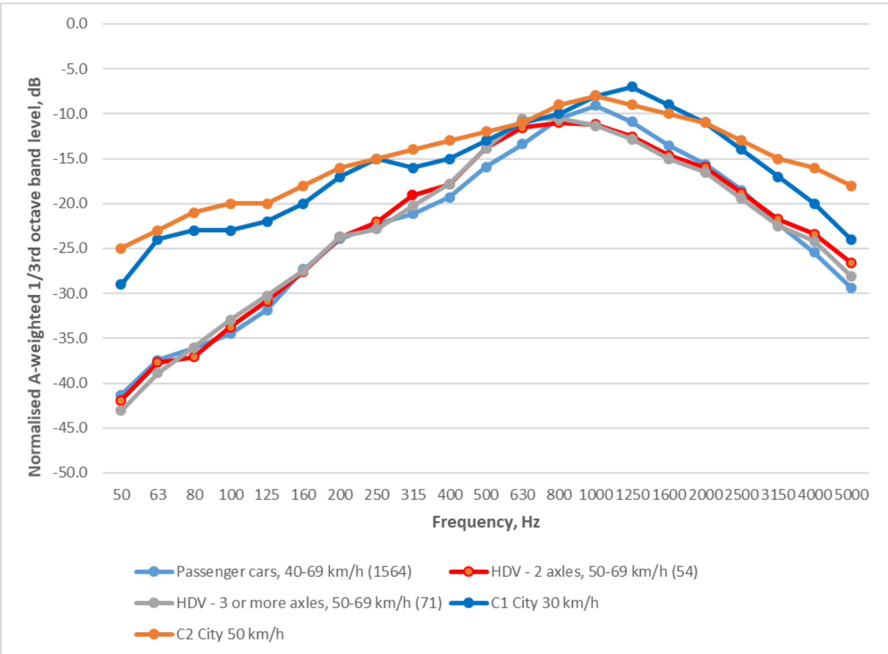

Figure 5: Normalised A-weighed 1/3rd octave band spectra for passenger cars and heavy-duty vehicles, measured by SINTEF in 2015 [4,5]. Number of vehicles in parenthesis

These results show no principal differences in the shape of the spectra for passenger cars and heavy-duty vehicles. At frequencies below 315-400 Hz, the measured spectra is significant lower than the reference spectra and below 100 Hz, the measured levels are more than 10 dB lower.

2.1.4 French study (2016)

In 2016, the French research institute, IFSSTAR, measured pass-by levels of heavy trucks according to the SPB standard ISO 11819-1 on two different locations [6]. On both locations, the road surfaces were of dense asphalt concrete types. The main objective was to compare the results with similar measurements made in 2004, to investigate if there has been a change in the speed index (relationship between noise level and vehicle speed) within this time frame.

From these measurements, SINTEF has received frequency spectra from the measurements in 2016, separately for vehicles with 2, 3 or 5 axles [6]. In figure 6, the normalised noise spectra for these 3 HDV classes are shown and compared with the C_1 and C_2 spectra.

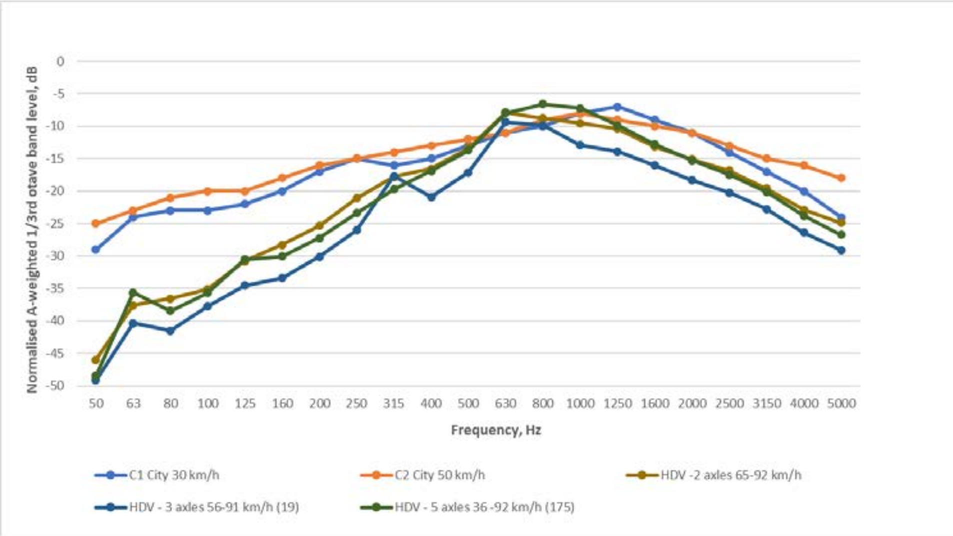

Figure 6: Comparison of normalised noise spectra for 3 classes of heavy-duty vehicles from a French study in 2016, compared to the C_1 and C_2 spectra [6]

These results show the same trend as for the measurements by SINTEF in 2015, where the noise levels below 250 – 315 Hz are significantly lower than the standardized spectra in Handbook 47, even if the vehicle speeds in the French study are higher than given for the reference spectra.

2.1.5 Study from Japan (2018)

The Acoustical Society of Japan (ASJ) has published a new version of the Road Traffic Noise Prediction Model (ASJ RTN-Model 2018). As a basis for this new version, the noise spectra for a mix of traffic on different pavements have been measured, to update the reference spectra in the model. The results for these measurements were presented at ICA2019 in Aachen [7]. In the ASJ RTN-model, the reference noise levels from the different vehicle categories are based on the sound power levels. However, the shape of the spectra is comparable to spectra based on L_{Amax}-levels. In figure 7, the average normalised spectrum in the ASJ RTN-model at 80 km/h on a dense graded asphalt is compared with the C_1 and C_2 spectra. Again, there are significant lower levels in the Japanese data for frequencies below 315 Hz.

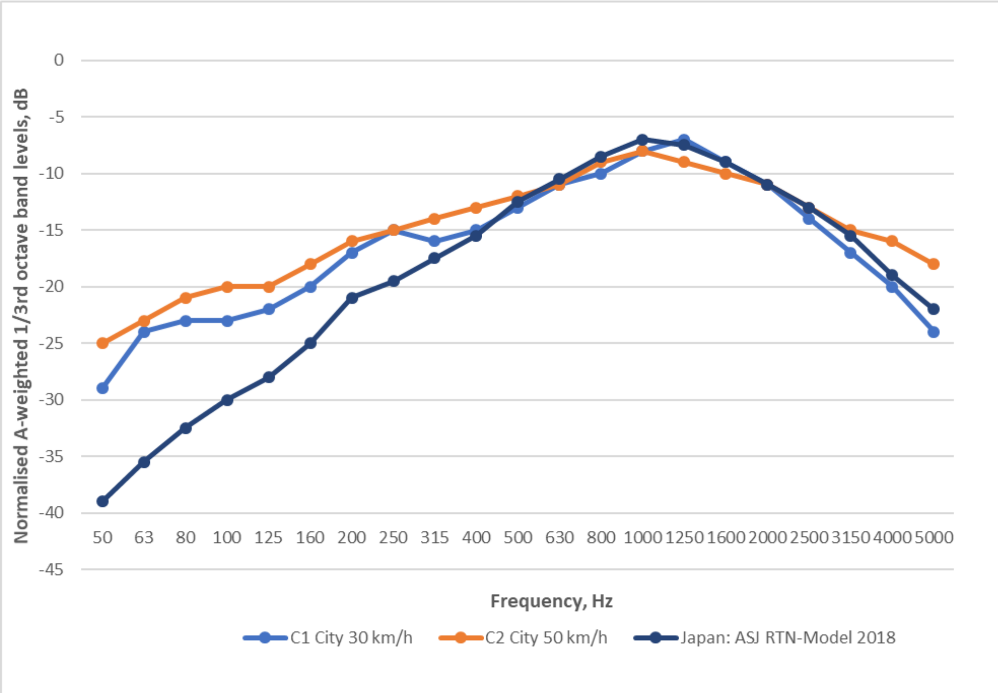

Figure 7: Normalised traffic noise spectrum in the ASJ-RTN-Model (Japan), for mixed traffic at 80 km/h, compared to the C_1 and C_2 spectra [7]

3 SINTEF measurements (2019)

To update the knowledge of noise spectra for different vehicle classes representative for Norwegian roads, a small measurement program was initiated in the autumn of 2019.

At two different locations, the pass-by noise levels (SEL - Sound Exposure Levels) of approximately 100 light vehicles and 50 heavy-duty vehicles were measured along with the vehicle speed. The light vehicles included passenger cars and vans, while the heavy-duty vehicles included trucks and buses with 2 or more axles. The measurements were made with an air temperature in the area of 12-14 °C. No correction of temperature influence has been made. The speed variation was in the range of 34 to 67 km/h.

In figure 8, the normalised spectra for light and heavy-duty vehicles from these measurements are shown together with the reference spectra for C_1 and C_2.

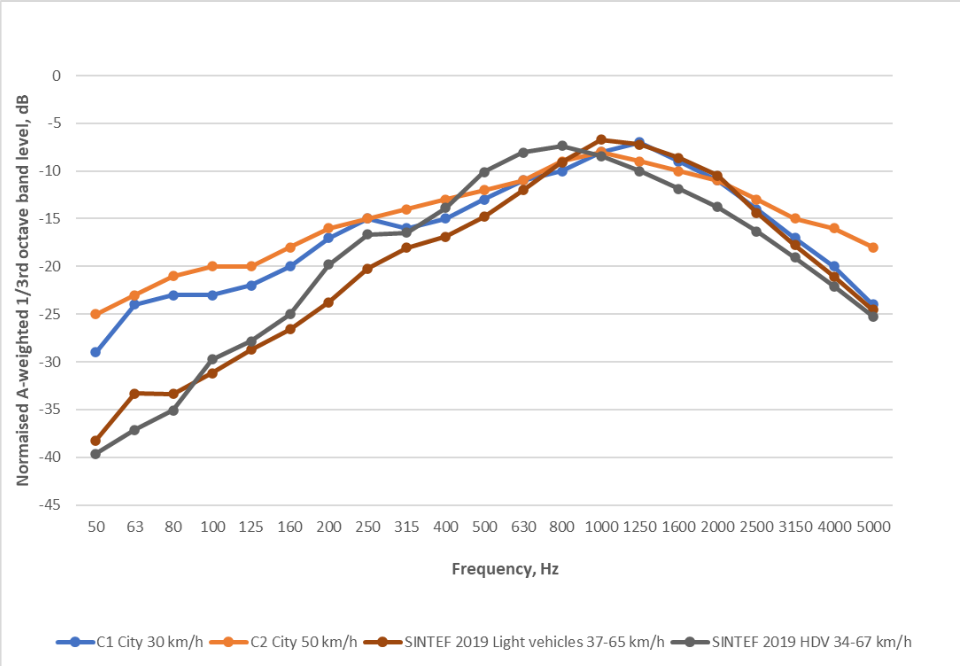

Figure 8: Normalised 1/3rd octave band noise spectra from SINTEF measurements on light and heavy-duty vehicles in 2019, compared to the reference spectra C_1 and C_2

Compared to the reference spectra from Handbook 47, the present vehicle fleet seems to have significant lower noise levels at frequencies below ca. 200 Hz. The measurements from 2019 is quite similar to the results from the SINTEF study in 2015, even if the measurements in 2019 were made on significantly fewer vehicles.

4 CNOSSOS-EU and Nord2000

In new traffic noise calculations models, the source models do include noise spectra. Example of such models are CNOSSOS-EU and Nord2000. However, the spectra in these models are related to the sound power levels for the source, and not the spectra for the road-side sound pressure levels, as presented in this paper. The differences in these two kinds of spectra can be related to the influence of the propagation of the sound field from the source to the receiver. However, for our purpose, we assume that these differences are rather small, and could be neglected in our comparison of spectra.

The Nord2000 method was developed in the period 2000 to 2006 and the aim was to have a calculation method representing Nordic conditions. This method has later been a basis for the development of methods like Harmonoise and CNOSSOS-EU. The model has a separate source for the tyre/road noise contribution (low positioned noise source) and for the power-train related sources.

In figure 9, spectra are shown for 3 speed classes (30, 50 and 80 km/h) in combination with 2 values for traffic mixes; one with 20 % heavy vehicles, 20 % medium heavy and 60 % light vehicles, and one with 100 % light vehicles. The first mix represent a road with a high number of heavy vehicles. The spectra are related to a reference road surface type of SMA0/16.

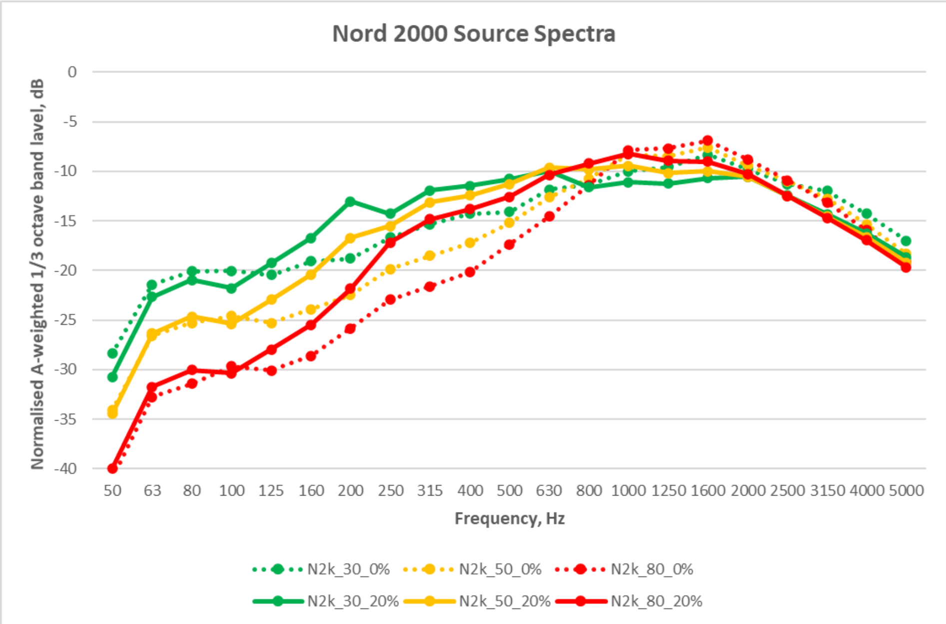

Figure 9: Nord2000 – Normalised traffic noise spectra for different speed classes and traffic mix

Figure 10 shows the equivalent spectra in the CNOSSOS-EU model, using the same speed classes and traffic mix as for Nord2000. Note that the source model in CNOSSOS-EU is only using 1/1 octave band levels. The spectra in figure 10 represent levels on a standard dense European road surface and at a reference temperature of + 20 °C. The shown spectra include some additional work and correction of errors in the model, made by the Dutch road authorities.

Both figures show that these calculations models have somewhat higher levels in the low frequency area, than our measurements and literature review indicate. This may be an argument to also promote a revision of the source models in these two calculation models.

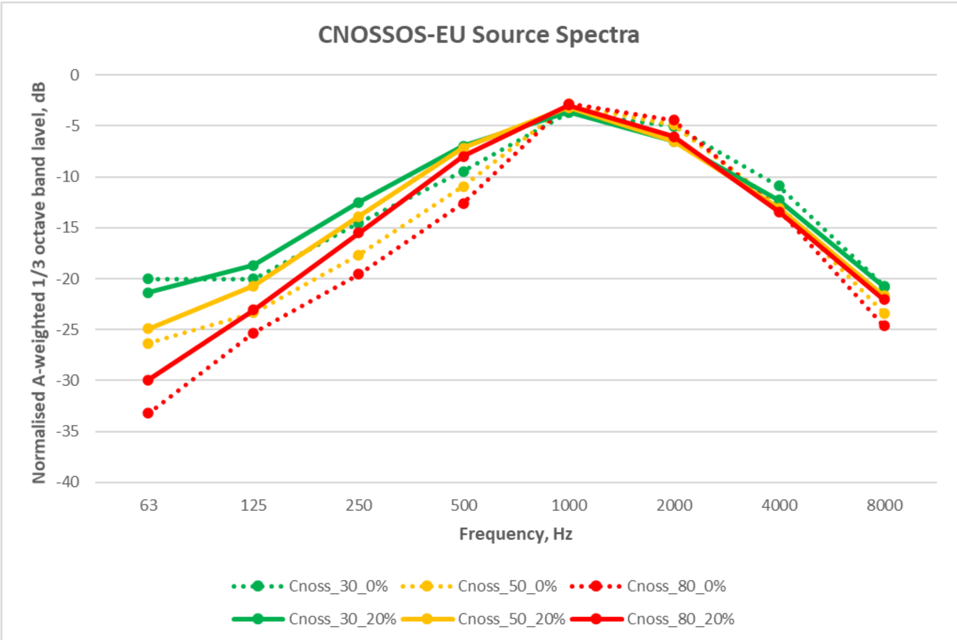

Figure 10: CNOSSOS-EU – Normalised traffic noise spectra for different speed classes and traffic mix

5 Comparison of all spectra

In figure 11, all frequency spectra from the above studies are compared with the reference spectra in Handbook 47.

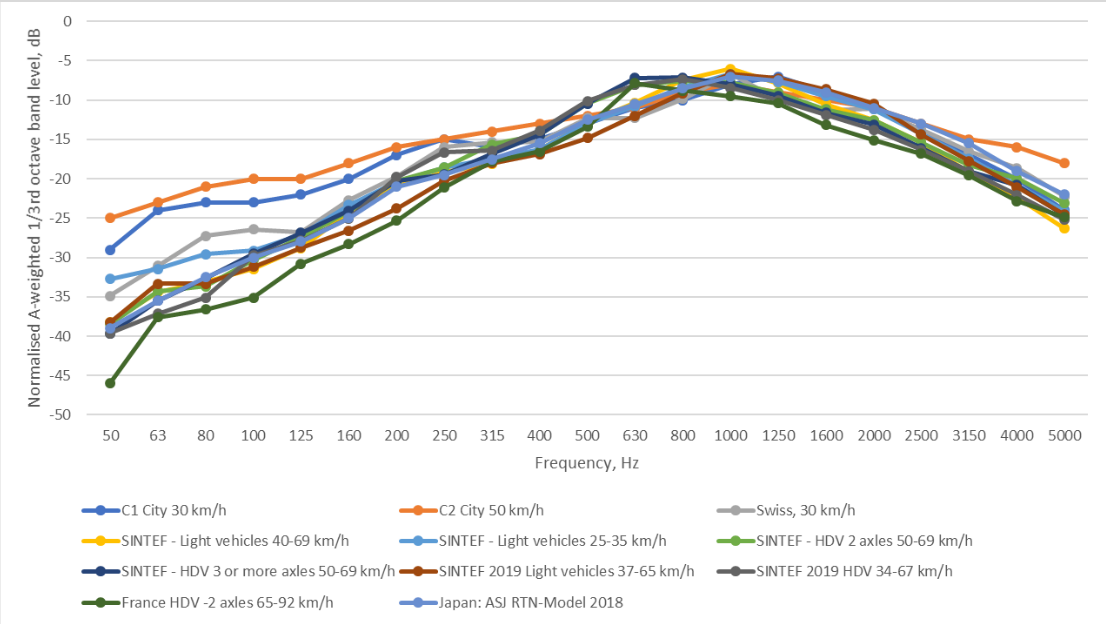

Figure 11: Collection of noise spectra from the literature study and from noise measurements in 2019, compared to the reference spectra C_1 and C_2

The figure shows that the newer data from pass-by levels of vehicles, especially in the lower speed range (30-50 km/h) have significant lower sound levels than given by the reference spectra C_1 and C_2 in Handbook 47.

6 Conclusions and proposal for revised spectrum

This investigation has partly been based on a literature review on recent international presentations of traffic noise spectra based on measurement campaigns, and partly on spectra from pass-by noise measurements by SINTEF in 2015 and 2019. In both these last two projects, there is a high consistency between the traffic noise spectra for light and heavy vehicles.

The current spectra in Handbook 47 overestimate the in-door noise levels in the lower frequency range (below 315 Hz). This can lead to unnecessary higher costs for sound insulation of dwellings to meet national regulation for in-door noise levels.

The comparison of the spectra from Handbook 47 with new data from literature and from measurements, clearly show the need to establish a revised spectrum.

The following criteria has been set for a revised 1/3rd octave band spectrum:

- The revised spectrum shall combine both categories of light and heavy vehicles
- The spectrum shall be valid for typically urban speeds in the area 30-50 km/h
- The revision of the spectrum is only made for 1/3rd octave bands from 50 to 315 Hz.

Table 1 gives the A-weighted values in dB for the new spectrum and in figure 12, the new spectrum is compared to the average spectrum for C_1 and C_2, and C_3 (motorway, 90 km/h) in Handbook 47.

Table 1: Proposed new A-weighted traffic noise spectrum for vehicle speeds, 30-50 km/h

Frequency, Hz	50	63	80	100	125	160	200	250	315	400	500	630	800
Sound level, dB	-38	-34	-33	-30	-28	-25	-21	-19	-17	-14	-13	-11	-10

Frequency, Hz	1000	1250	1600	2000	2500	3150	4000	5000
Sound level, dB	-8	-8	-10	-11	-14	-16	-18	-21

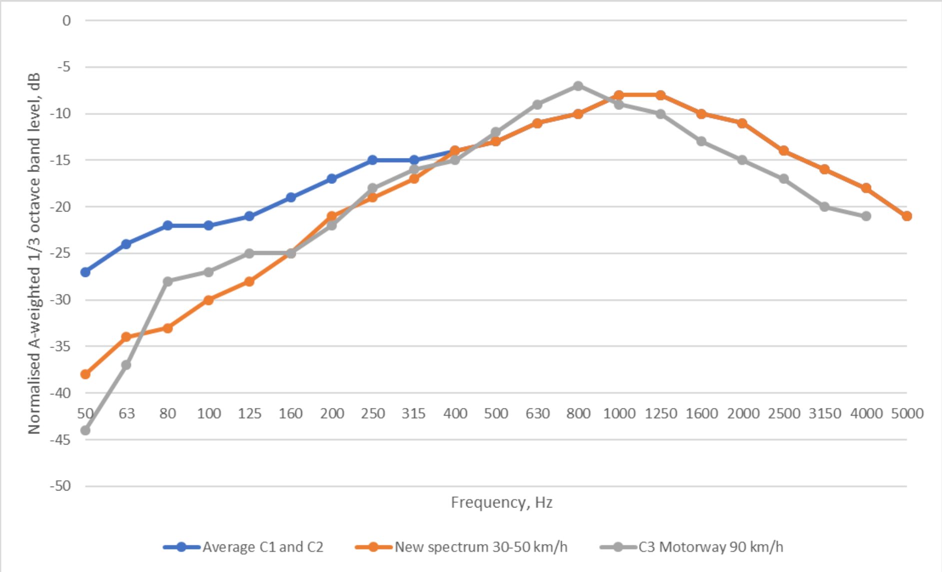

Figure 12: Comparison of existing spectrum in Handbook 47 (average of C_1+ C_2, C_3) and proposed new spectrum for a speed range 30-50 km/h

For speeds higher than 50 km/h, we assume that the present spectrum C_3 is still valid. However, as figure 12 shows, the new spectrum is quite similar to the C_3 spectrum in Handbook 47 in the lower frequency range. Therefore, the revised spectrum may also be used for higher speeds than 50 km/h. However, some more investigations on the spectra at higher vehicle speed is recommended.

In cases where there is a noise barrier or other screening means, this will influence the calculated in-door sound levels. In Handbook 47, there are reference noise spectra for such cases (C_4, C_5 and C_6). For these spectra, a fixed sound insulation value is assumed. It is not realistic to evaluate all variations of different types of noise spectra, which can be related to different traffic situations. However, in this project we have proposed a single revised spectrum to be used in cases where noise screening is involved, and this is shown in Table 2.

Table 2. Proposed new A-weighted traffic noise spectrum for cases with screening, 30-50 km/h.

Frequency, Hz	50	63	80	100	125	160	200	250	315	400	500	630	800
Sound level, dB	-30	-27	-26	-24	-23	-20	-17	-15	-14	-12	-12	-11	-11

Frequency, Hz	1000	1250	1600	2000	2500	3150	4000	5000
Sound level, dB	-9	-10	-13	-15	-19	-22	-25	-29

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