MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Characterisation of wheel/rail roughness and track decay rates on a tram network

Olivier Chiello[1], Adrien Le Bellec, Marie-Agnès Pallas
Univ Lyon, IFSTTAR, CEREMA, UMRAE, F-69675, Lyon

Patricio Munoz, Valérie Janillon
Acoucité, 24 Rue Saint-Michel, 69007 Lyon, France

From the beginning of 2019, the new CNOSSOS-EU method shall be used for strategic noise mapping in application of Directive 2002/49/EC instead of national noise prediction methods. For the railway part, the operators are responsible for providing input data describing the different noise sources characterising the railway system. Concerning the rolling noise, the vehicle and the track have to be distinguished by providing specific transfer functions and wheel/rail roughness spectra. For conventional railways, default values are given in the CNOSSOS-EU method and national operators generally have experimental data at their disposal to evaluate these new input parameters. This is not the case for tram networks, for which very few measurements exist, notably concerning the wheel and rail roughness or the track transfer function. In 2018, Acoucité and IFSTTAR performed an acoustic test campaign on a French tram network in order to propose tram input data from pass-by measurements corresponding to various sites and vehicles. In this paper, the results concerning the direct measurements of wheel/rail roughness and track decay rates (a key parameter for the assessment of the track transfer function) are presented and discussed. The main differences with data corresponding to conventional railways are highlighted.

Keywords: Noise mapping, CNOSSOS-EU method, Light rail, Rolling noise, Tram noise, Wheel/rail roughness, Track decay rate, Tram track
I-INCE Classification of Subject Number: 10

1. INTRODUCTION

The European Directive 2002/49/EC [1] dated 25 June 2002 makes it compulsory for Member States to create noise maps in order to assess the exposure to environmental noise. These maps are made available to the public and allow the implementation of action plans to reduce noise and to estimate the impact of new infrastructures on the noise environment. They take into account noise emissions related to transport and industry. Their implementation is mandatory for urban areas with more than 100000 inhabitants and for major roads, railways and airports. This directive specifies common noise

[1] olivier.chiello@ifsttar.fr

indicators for determining exposure to noise. Pending the adoption of a common assessment method, Member States were allowed to use their national method. For example, in France, the NMPB2008 prediction method has been used [2]. Recently, the common method, called CNOSSOS-EU for "Common Noise Assessment Methods in Europe" [3] has been published in the Official Journal of the European Union on 19 May 2015 to harmonise the production of noise maps among all EU countries. The first noise maps based on this method are expected in 2019.

Concerning the calculation of the propagation of noise in the environment, the changes made by the new CNOSSOS method compared to the French method are not fundamental. This is not the case for the calculation of noise emission terms, particularly those corresponding to rail transport. There are indeed two major changes. On the one hand, the different sources of railway pass-by noise (rolling noise, traction noise and aerodynamic noise) must be distinguished: their respective acoustic powers must be specified in the model. Furthermore, the rolling noise term must be estimated from the specific contributions of the vehicle and the track, themselves calculated from wheel/rail roughness and transfer functions characterising the track and the vehicle "vibro-acoustic efficiency" (see Figure 1). The method gives tabulated values in appendix, corresponding to conventional railway vehicles or tracks. Moreover, major national operators generally have experimental data or advanced models at their disposal to evaluate these new input parameters.

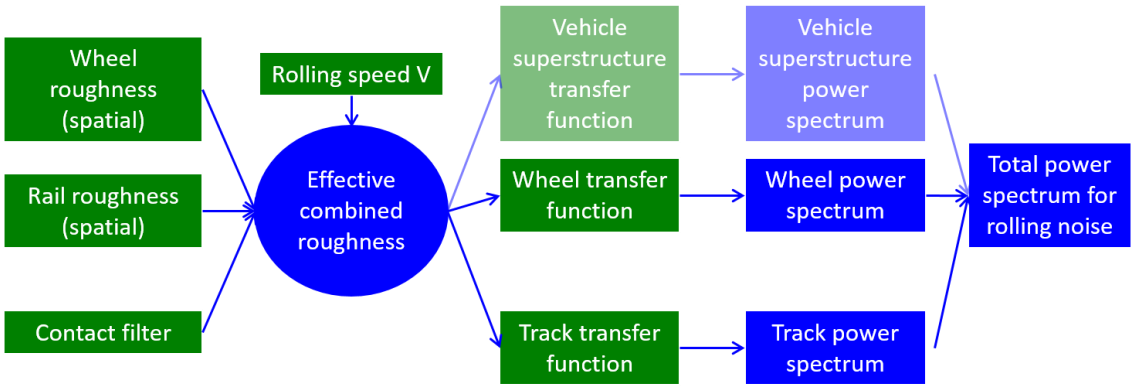

Figure 1: CNOSSOS rolling noise model for rail-bound vehicles (inputs in green, outputs in blue)

This is not the case for tram networks, for which very few measurements are available, notably concerning the wheel and rail roughness or the transfer functions. With regard to rail roughness, some recent measurements show significant differences with conventional rails [4-6]. Concerning the separation of noise sources and the contributions of track and vehicle to rolling noise, existing models also show that tramways have their own properties [7-10]. There are several reasons for these differences. The most important are that the sound radiation from embedded tram tracks is significantly different from conventional tracks [11-13], the vehicle wheels are smaller and the wheel loads are lower [6]. Consequently, for tram rolling noise modelling, it is clear that the transfer functions defined for conventional railways cannot be used.

In order to propose tram input data, Acoucité and IFSTTAR performed a test campaign on a French tram network. In addition to classic pass-by measurements carried out on various sites and vehicles at different heights, specific measurements of wheel and rail roughness as well as track decay rates were performed. The track decay rate is indeed a key parameter for the assessment of the track transfer function. In this paper, the results concerning these additional measurements are presented and discussed. The main differences with data corresponding to conventional railways are highlighted.

2. DESCRIPTION OF TEST TRACKS AND VEHICLES

Measurements were performed on four sites with different track types and surfacing. Two tracks are equipped with Vignole rail laying on monobloc concrete sleepers and ballast (C and D). One of these two tracks is characterised by the addition of a grassy coating above the ballast layer, outcropping the rail head (C). The other two tracks have grooved rails laying on bi-block sleepers, embedded in a concrete slab (A and B). On one of these two tracks, a grassy coating is also added (A). This last track section is characterised by a slight curve, unlike the three others which are located on straight lines. Table 1 summarises the characteristics of these track sections. Photographs in Figure 2 show the different rail types and surfacing.

Table 1: Characteristics of test track sections

	Rail type	**Track support**	**Surfacing**	**Geometry**
A	Grooved	Bi-block concrete sleepers + concrete slab	Concrete	Slight curve
B	Grooved	Bi-block concrete sleepers + concrete slab	Grass	Straight line
C	Vignole	Monobloc concrete sleepers + ballast	Grass	Straight line
D	Vignole	Monobloc concrete sleepers + ballast	(Ballast)	Straight line

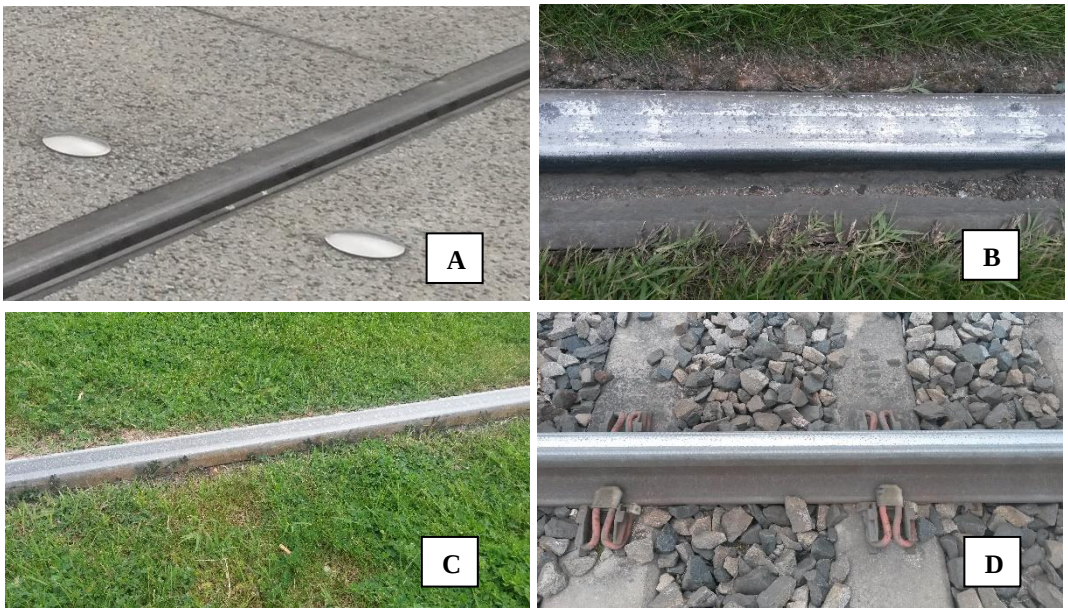

Figure 2: Photos of the tracks

Three types of vehicles regularly run on the network. Two of them are very similar and differ only in the number of units (5 or 7) and bogies (3 or 4 respectively). Both are equipped with disc-braked resilient wheels of diameter 59 cm (new). The third type of vehicle is composed of three units, resting on three bogies in all. It is also equipped with disc-braked resilient wheels but with a diameter of 72 cm (new). Wheel roughness was measured only on three vehicles of the first category but with various mileage since the last reprofiling.

3. RAIL AND WHEEL ROUGHNESS MEASUREMENTS

4.1 Rail roughness

The procedure used for measuring the rail acoustic roughness was in accordance with the standard EN 15610-2009 [14]. The thoroughly validated CAT equipment (for "Corrugation Analysis Trolley") developed by RailMeasurement was used [15]. An accelerometer fixed on the trolley is in contact with the rail. An operator pushes the trolley along the test section. Only one rail is measured at a time, at a speed of approximately 1 m/s and with a sampling distance of 1 mm. The trolley can be configured on a Vignole or grooved rail. The roughness estimation is carried out by post-processing the measured raw vertical profile (after integration of the acceleration signal) according to the standard: removal of localised defects or narrow peaks/spikes, curvature procedure and spectral analysis. Roughness was measured on both rails of each track.

On each rail, the effective width of the running band on the railhead was identified by a visual inspection. It turned out to be rather wide (> 2 cm) and several measurements were made for different lateral positions of the sensor on the rail: 25 and 35 mm for tracks A and D, 25 mm, 30 and 35 mm for tracks B and C (distances from the interior edge of the railhead, see Figure 3).

Figure 3: Identification of the width of the running band on the railhead and measurement with the CAT

Results corresponding to each track section are given in Figure 4: roughness spectra measured on the same rail for various lateral positions, mean roughness for each rail and global mean roughness for both rails (Throughout the paper, roughness means are quadratic averages of individual roughnesses). Default data given in the appendix of the CNOSSOS method for conventional rails are also plotted for comparison: the limit roughness curve prescribed in the standard ISO 3095:2013 [16] for the definition of reference tracks and an average spectrum corresponding to the national Dutch network. The roughness spectra measured on the same rail are very similar with differences generally less than 1 dB per third octave. The differences between the two rails of the same track are greater but often remain below 3 dB except for track B which has significantly higher levels on the left track. On this rail, we note in particular a zone of severe corrugation in the spectrum at wavelengths between 4 and 8 cm. This is probably due to the fact that the track section corresponds to the entrance of a curve. The resulting lateral friction phenomena can indeed lead to wheel/rail wear. The most important point is that the measured roughness levels are much higher than the levels proposed in the CNOSSOS method for conventional rails (sometimes by more than 10 to 15 dB), except

for track D whose average levels are closer to those of the Dutch network (2 to 3 dB difference on average).

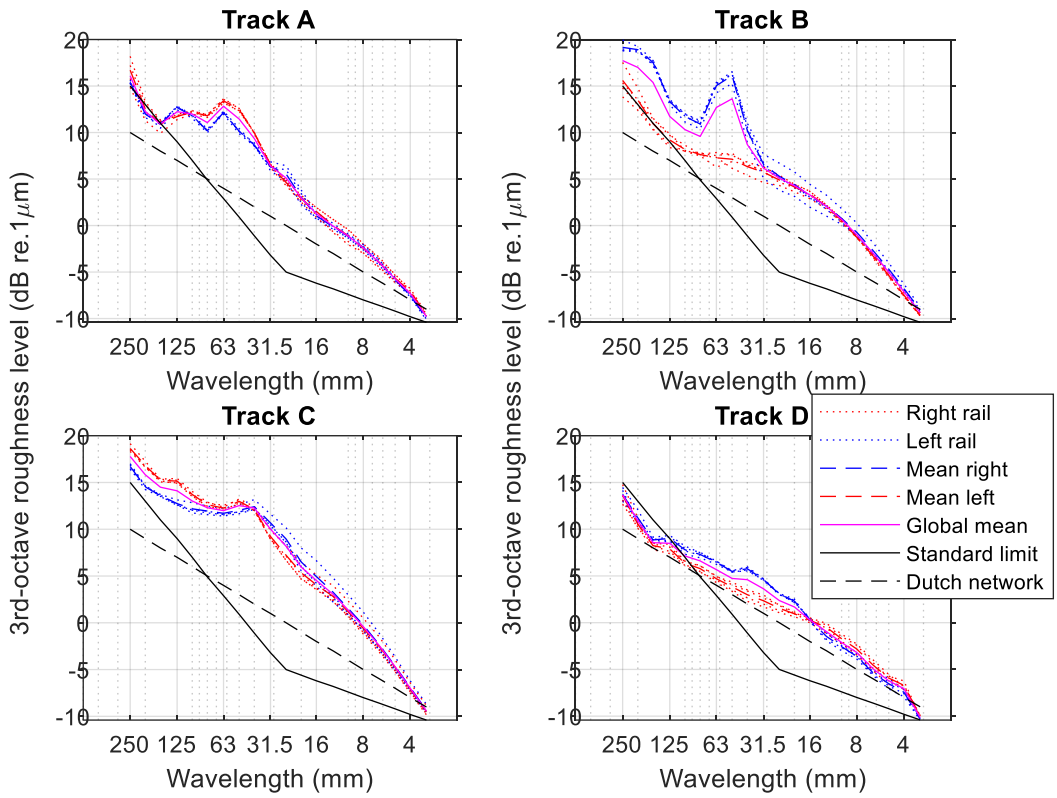

Figure 4: Rail roughness spectra measured on test tracks

4.2 Wheel roughness

Wheel roughness measurements were carried out in the workshop on a free wheel, with an axle raised a few millimetres above the rail. A magnetic-based measuring system (TriTops device developed by RailMeasurement) was installed on the rail near the wheel to be measured (see Figure 5). Three displacement sensors and an incremental encoder wheel were in contact with the wheel. The three sensors were positioned on the contact area of the wheel tread. The measurement was achieved by turning the axle by hand over a few turns (5 or 6 in this case).

Figure 5: Wheel roughness measurement system

Results corresponding to a wheel of each vehicle are given in Figure 6 : roughness spectra measured on the same wheel for various lateral positions (the three displacements sensors of the measuring device) and mean roughness for each vehicle. Default data given in the appendix of the CNOSSOS method for a conventional disc-braked wheel are also plotted for comparison. A significant dispersion is observed with regard to the lateral position on the wheel (i.e. between the three sensors of the system) with differences of up to 3-4 dB per third. The differences between the roughness measured on the different vehicles are also significant, but no correlation could be established between the roughness spectra and the mileage since the last reprofiling. Finally, the comparison with the roughness spectrum proposed in the CNOSSOS method for a disc-braked wheel shows that tram wheels generally have higher roughness levels, particularly at the shortest wavelengths (< 31.5 mm) for which differences of up to 10 dB are observed in some third octaves.

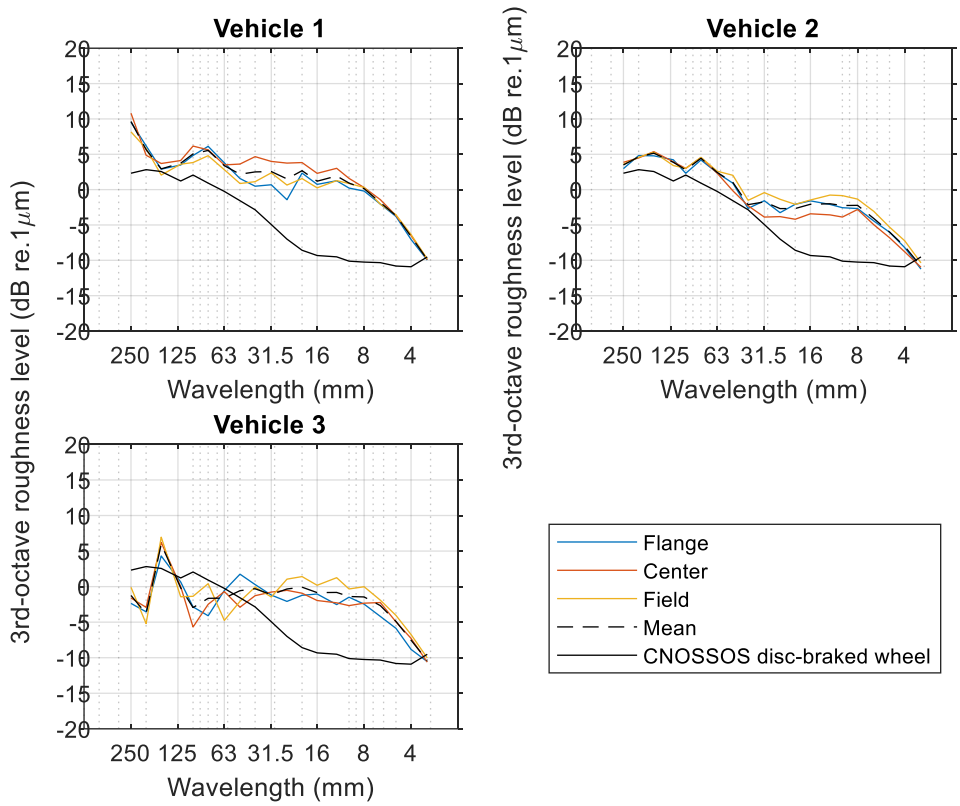

Figure 6 : Wheel roughness spectra measured on test vehicles

4.3 Influence of the track and the vehicle on the combined roughness

In order to evaluate the contributions of the wheels and the rail to the total combined roughness, mean rail roughness spectra corresponding to each track are plotted in Figure 7 and compared with the wheel roughness spectrum averaged over the three vehicles. In addition to the graduation of the abscissa in terms of wavelength, a frequency scale has been added at the top of the figure. The frequency (f) - wavelength (λ) correspondence is performed by the relationship $f = V/\lambda$, for a speed of 45 km/h which is representative of the vehicle speed on the test track sections. It can be seen that all over the first part of the spectrum (above 25 mm wavelength or below about 500 Hz at 45 km/h) the contribution of the track to the combined roughness is predominant. In this range, the track will thus have a significant influence (up to 7-8 dB) on pass-by noise levels via the rail roughness. In the second part of the spectrum (below 25 mm wavelength

or above about 500 Hz at 45 km/h), wheel and rail roughness have the same order of magnitude. Thus, both the track and the vehicle contribute to the combined roughness. However, the differences between the roughness levels of the different tracks are less important in this range and all rail roughnesses will therefore play a similar role in the pass-by noise.

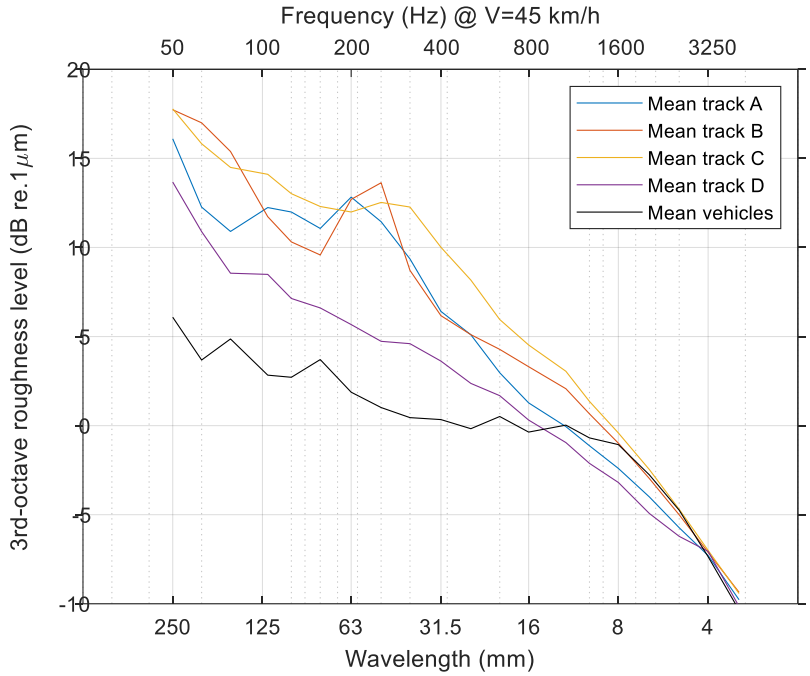

Figure 7: Comparison of wheel and rail roughness spectra as a function of wavelength and frequency

4. TRACK DECAY RATE MEASUREMENTS

The last part of the campaign concerns the characterisation of the dynamic behaviour of the track. Indeed, as indicated above, in order to validate and adjust the calculation of the track vibro-acoustic transfer functions, it is necessary to characterise the specificities of tram tracks with embedded rails which may have a very different behaviour from conventional railways. The track decay rate (TDR), which reflects the attenuation of waves along the rails from the excitation, is the key indicator to characterise this behaviour. The method for direct measurement of the TDR is defined in the standard EN 15461+A1:2011. The procedure was applied on track B (specific tramway track: grooved rail on sleepers embedded in a concrete slab) and track D (rather conventional track: Vignole rail on concrete sleepers and ballast). On track D, the vertical and lateral decay rates were measured, whereas on track B, only the vertical decay rate was measured.

Figure 8: Accelerometer fixed on the embedded rail with first impact location marks for the measurement of the vertical decay rate according to EN 15461 (track B)

The measured decay rates are given in Figure 9 and compared with the limit vertical and lateral curves prescribed in the standard ISO 3095:2013 [16] for the definition of reference tracks. The TDR curves measured of track D display classic shapes. Vertically, three peaks are identified around 500, 1250 and 5000 Hz due respectively to the resonance of the rail on the pad, the periodicity of the sleepers (pinned-pinned frequency) and the deformation modes of the rail section (in particular the rail foot). Lateral peaks are also visible with significantly lower frequencies (125, 630 and 3150 Hz). Finally, we note that the two TDRs of track D remain higher than the standard gauge for most frequency bands. The vertical TDR measured on track B is completely different from that measured on track D. Three peaks can also be identified but with frequencies much lower than those of track D. In particular, a minimum of less than 2 dB/m is observed in the curve at a frequency of 630 Hz, which is quite unusual on conventional tracks. It should also be noted that at this frequency, the measured TDR is lower than the standard limit curve, which implies a possible high contribution of the rail to the pass-by noise emitted (to be qualified according to the rail radiation factor at this frequency).

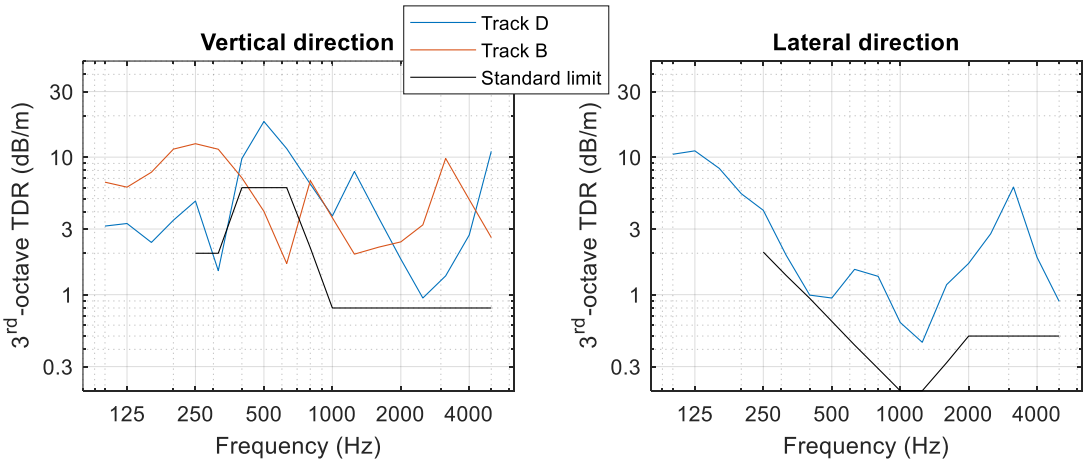

Figure 9: Track Decay Rates (TDR) measured on test tracks D and B

4. CONCLUSIONS

In order to identify input parameters for CNOSSOS noise emission models specific to trams, measurements of acoustic roughness and vibration decay rates were performed on various tracks and vehicles of a tramway network. It appears that the characteristics measured are very different from those corresponding to conventional railways. In particular, wheel and rail roughness levels are higher in all wavelength bands, with differences that may exceed 10 dB. In the high-wavelength (or low-frequency) range, rail roughness levels are much higher than wheel roughness levels and the track has a significant influence (up to 7-8 dB) on the combined roughness. The comparison of measured decay rates also shows that tram-specific transfer functions must be proposed, particularly for the tracks with embedded rail. The identification of appropriate vibro-acoustic transfer functions for trams based on these measurements and pass-by acoustic measurements is the next step of this project.

5. ACKNOWLEDGEMENTS

This work was supported by the LabEx CeLyA of Université of Lyon, operated by the French National Research Agency (ANR-10-LABX-0060/ANR-11-IDEX-0007). This support is greatly appreciated.

The authors are grateful to SYTRAL and Keolys for their support in the measurement campaign.

6. REFERENCES

1. Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise - Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise, (2002). http://data.europa.eu/eli/dir/2002/49/oj/eng.
2. Association française de normalisation (AFNOR), "*NF S31-133: Acoustique - Bruit dans l'environnement - Calcul des niveaux sonores*", (2011).
3. Commission Directive (EU) 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 (Text with EEA relevance), (2015). http://data.europa.eu/eli/dir/2015/996/oj/eng.
4. S.L. Grassie, "*Rail irregularities, corrugation and acoustic roughness: characteristics, significance and effects of reprofiling*", Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. (2012). doi:10.1177/0954409712443492.
5. L. Chiacchiari, G. Loprencipe, "*Measurement methods and analysis tools for rail irregularities: a case study for urban tram track*", J. Mod. Transport. 23 (2015) 137–147. doi:10.1007/s40534-015-0070-6.
6. L. Chiacchiari, D.J. Thompson, G. Squicciarini, E. Ntotsios, G. Loprencipe, "*Rail roughness and rolling noise in tramways*", J. Phys.: Conf. Ser. 744 (2016) 012147. doi:10.1088/1742-6596/744/1/012147.
7. Y.K. Wijnia, "*Noise emission from trams*", Journal of Sound and Vibration. 120 (1988) 281–286. doi:10.1016/0022-460X(88)90436-1.
8. J. Mandula, B. Salaiová, M. Koval'aková, "*Prediction of noise from trams*", Applied Acoustics. 63 (2002) 373–389. doi:10.1016/S0003-682X(01)00047-0.
9. M.-A. Pallas, J. Lelong, R. Chatagnon, "*Characterisation of tram noise emission and contribution of the noise sources*", Applied Acoustics. 72 (2011) 437–450. doi:10.1016/j.apacoust.2011.01.008.
10. E. Panulinová, "*Input Data for Tram Noise Analysis*", Procedia Engineering. 190 (2017) 371–376. doi:10.1016/j.proeng.2017.05.351.
11. S. Van lier, "*The vibro-acoustic modelling of slab track with embedded rails*", Journal of Sound and Vibration. 231 (2000) 805–817. doi:10.1006/jsvi.1999.2564.
12. C.-M. Nilsson, C.J.C. Jones, D.J. Thompson, J. Ryue, "*A waveguide finite element and boundary element approach to calculating the sound radiated by railway and tram rails*", Journal of Sound and Vibration. 321 (2009) 813–836. doi:10.1016/j.jsv.2008.10.027.
13. Y. Zhao, X. Li, Q. Lv, H. Jiao, X. Xiao, X. Jin, "*Measuring, modelling and optimising an embedded rail track*", Applied Acoustics. 116 (2017) 70–81. doi:10.1016/j.apacoust.2016.07.021.

14. European Committee for Standardization (CEN), "*EN 15610:2009 - Railway applications - Noise emission - Rail roughness measurement related to rolling noise generation*", (2009).
15. S.L. Grassie, "*Rail corrugation: advances in measurement, understanding and treatment*", Wear. 258 (2005) 1224–1234. doi:10.1016/j.wear.2004.03.066.
15. International Standard Organisation, "*NF EN ISO 3095:2013 Acoustics - Railway applications - Measurement of noise emitted by railbound vehicles*", (2013).