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CHARACTERIZATION OF THE ACOUSTIC EMISSION OF RAILWAY NOISE, APPLYING THE CNOSSOS-EU METHOD, BY SOME SPANISH RAILWAY MANAGERS

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ABSTRACT

The adoption of the CNOSSOS-EU as the official method for calculating environmental noise has allowed some railway managers to invest efforts in the acoustic characterization of vehicles and railway infrastructures.
This paper presents the results of some of the projects with this aim, carried out by ADIF AV (National Administrator of Railway Infrastructures of Spain), ETS (Administrator of Railway Infrastructures of the Basque Autonomous Community) and CTB (Administrator of Railway Infrastructures of Bilbao Metro).
In these projects, railway noise emission databases have been defined that contain the input values for the CNOSSOS-EU parameters for the optimal characterization of trains and infrastructures. The characterization is based on the analysis of in-service train passbys campaigns.
ADIF AV has defined a database of 28 types of trains and 6 types of infrastructure, through the analysis of 600 passbys measured at 7 locations. The ETS database contains 4 types of trains and 4 infrastructures (78 measured passbys) and CTB defines 3 types of trains and 1 infrastructure (52 passbys).
The paper presents some of the decisions taken by each institution to better represent the actual measured emissions.

Keywords: *CNOSSOS-EU method, characterization, noise, railway.*

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1. INTRODUCTION

The calculation method CNOSSOS-EU is described in Commission Directive 2015/996, which establishes common methods for assessing noise following Directive 2002/49/EC of the European Parliament and of the Council, as well as with Commission Delegated Directive 2021/1226, which modifies the former [1,2].
Spain has adopted CNOSSOS-EU method as the official evaluation procedure, not only for the elaboration of strategic noise maps and action plans, but also for the quantification of acoustic impacts answering to the Spanish legislation [3,4].
The approval of the CNOSSOS-EU method as the official method for calculating environmental noise has required some railway managers to invest efforts in the acoustic characterization of their railway networks. This characterization takes into account the effect of vehicles, and infrastructure on rolling noise, and singular effects, such as squeal noise, impact noise, or aerodynamic noise, among others.
To calculate the different noise sources CNOSSOS-EU method defines the parameters listed below:

- Train description:
  - Running speed;
  - Vehicle composition by type and number of units;
  - Number of axles of each unit;
  - Wheel roughness, $L_{r,VEH,I}$;
  - Contact filter, $A_{3,I}$;
  - Wheel transfer function, $L_{H,VEH,i}$;
  - Traction noise, $L_{W,0,idling}$;
  - Aerodynamic noise, $L_{W,0,1}$, $L_{W,0,2}$, α_1, α_2.
- Description of the infrastructure:
  - Rail roughness, $L_{r,TR,i}$;
  - Rail transfer function, $L_{H,TR,i}$;

- Additional impact roughness, $L_{R,IMPACT,i}$ and density of joints, nl (number of joints per meter);
- Radius of curvature;
- Transfer function of bridges, $L_{H,bridge,i}$

CNOSSOS-EU method proposes some default input values for these parameters, which are contained in the official method description documents.

In this sense, Tecnalia has collaborated in the acoustic characterization for three different infrastructure managers: ADIF AV, ETS (Euskal Trenbide Sarea), and CTB (Consorcio de Transportes de Bilbao). These projects have carried out a process of characterizing the parameters of the CNOSSOS-EU method that starts from taking measurements in situ and compares measured and calculated noise levels.

The measurement procedure includes monitoring the vertical and lateral acceleration and the sound pressure levels at a distance of 7.5 m from the track and a height of 1.2 and 3.5 m above the ground, recording the signal in time. The results of each measurement campaign have been processed to obtain the value that represents each parameter of the rolling noise sources. The CEN TR 16891: 2016 standard is applied to obtain the combined roughness, the decay rates of the tracks and the transfer functions. Tecnalia has collaborated with TNO to carry out the process described in the standard with the Passby Analysis Software (PBA).

In these projects, railway noise emission databases have been defined that contain the input values for the CNOSSOS-EU parameters to obtain the optimal characterization of trains and infrastructures.

ADIF AV manages a network of 15.519 km and has defined a database of 28 types of trains and 6 types of infrastructure, through the analysis of 600 passbys measured at 7 locations.

The ETS database contains 4 types of trains and 4 infrastructures (78 measured passbys). The network managed by ETS is 200 km in length.

CTB manages 49 km and defines 3 types of trains and 1 infrastructure (52 passbys).

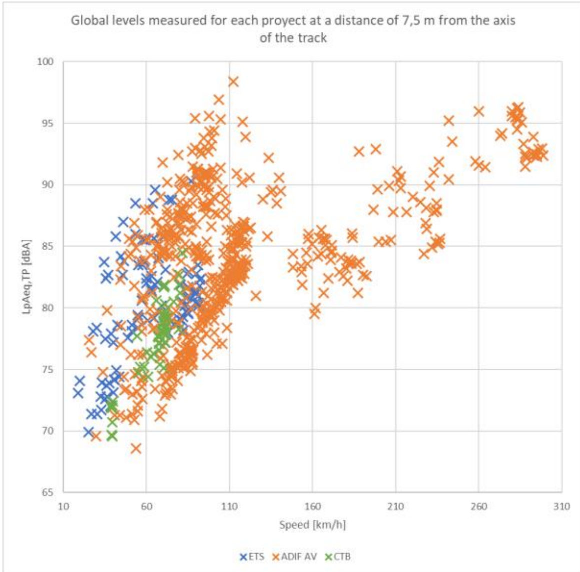

Figure 1. Global level passbyes measured in each project.

Thus, the execution of these projects has allowed the detection of particularities in each railway network, which has led to specific decisions made for the calculation of environmental noise. For example, ETS required the definition of different categories of infrastructure that were initially similar; ADIF created a new category of wheel roughness to represent the emission of a particular type of train and established a limit to apply aerodynamic noise from speeds of 250 km/h; and CTB identified a series of noisier trains for which a new category of wheel roughness was created and a generic presence percentage was established.

In the following section, each of these peculiarities and the decisions taken to represent them correctly in the model are presented in detail. The results obtained with the execution of these projects reflect the importance of acoustically characterizing railway networks and, in this way, representing reality in the model in the best possible way.

2. CHARACTERIZATION DECISIONS

2.1 Definition of different types of infrastructures

ETS has defined a database of 4 types of trains and 4 types of infrastructure, through the analysis of 78 passbys measured at 10 locations.

This railway network has few types of trains, so it has been possible to clearly quantify the effect of different infrastructures that lead to differences in pass-by levels for the same types of trains.

Analyzing the noise levels measured in the different measurement campaigns on potentially different ETS infrastructures and analyzing the details of materials and elements of the infrastructure in each section, it has been decided to carry out a classification that homogenises the infrastructures into 4 groups, three associated with mono-block concrete sleepers and one associated with wooden sleepers.

Figure 2 shows all the rolling noise measurement campaigns, which present a significant dispersion, and the average rolling noise bands that represent each group of infrastructures. It should be noted that the measured trains are equal in terms of acoustic emission.

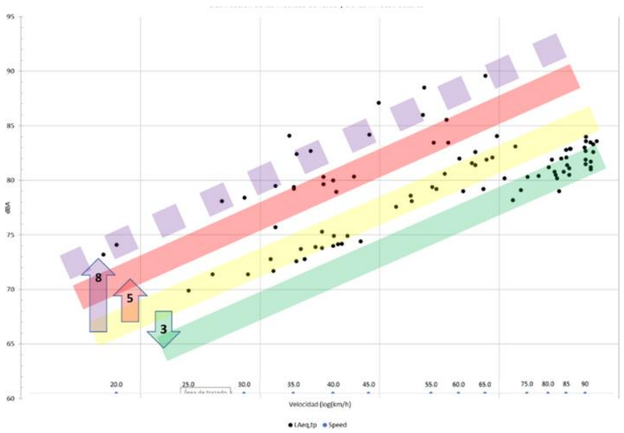

Figure 2. Global noise levels pass-by ($L_{pAeq,TP}$) versus speed and found clusters of data, depending on the infrastructure.

It can be observed in the figure that there are groups of measurements aligned with the natural speed dependence for rolling noise (30*log(speed)), representing four trends. One trend groups low noise levels represented in green, a second trend for medium noise levels represented in yellow, the third trend for high noise levels represented in red, and a fourth trend associated with noise levels generated by infrastructures with wooden sleepers and jointed tracks represented in purple with a dashed line.

The most common situation is represented by the yellow trend and this type of infrastructure has been defined as *Medium-noise infrastructure. In order to apply CNOSSOS-EU method, the* characterization to be selected to represent this trend corresponds to the default input value for the Rail transfer function, $L_{H,TR,I}$, named *Mono-block sleeper on medium stiffness rail pad* and default input value for Rail roughness, $L_{r,TR,i}$, named as *ISO 3095:2013*.

Compared to this infrastructure type (yellow trend), noise levels are 3 dB lower for low-noise infrastructure, 5 dB higher for high-noise infrastructure, and 8 dB higher for the wooden sleeper infrastructure with jointed tracks.

The CNOSSOS-EU method parameters associated with the infrastructure are the rail transfer function and rail roughness. In addition, there are other rail parameters associated with singular effects, such as impact noise (joint density parameter, nl) or squeal noise.

The low noise infrastructure can be represented with the default input values for Mono-block on a hard rail pad.

However, high noise infrastructure and wooden sleeper cannot be correctly represented with any default input value proposed in the CNOSSOS-EU method. Even so, in these cases, ETS decided not to create new particular rail transfer functions. Instead, the emission levels were forcibly increased to represent the measured values, applying the effect of impact noise, although the presence of this type of noise is not real in the case of high noise infrastructure.

As a conclusion, based on the existing infrastructures in the ETS lines and the results obtained in the measurement campaigns, four types of track infrastructure have been defined according to their noise generation.

Table 1. Assignment of CNOSSOS parameters to the different types of ETS infrastructure.

Type of infrastructure	Rail roughness	Rail transfer function	Impact noise
Low-noise infrastructure	ISO 3095:2013	Mono-block on hard rail pad	-
Medium-noise infrastructure	ISO 3095:2013	Mono-block sleeper on medium stiffness rail pad	-
High-noise infrastructure	ISO 3095:2013	Mono-block sleeper on medium stiffness rail pad	$n_l = 0{,}01$
High-noise wooden infrastructure	ISO 3095:2013	Wooden sleepers	$n_l = 0{,}03$

Therefore, in this case, the characterization process, accompanied by measurements, has allowed us to identify these 4 types of acoustic emission trends that depend on the infrastructure on which the train runs.

Since the relationship between these trends and physical characteristics of the infrastructure is known, results can be extrapolated, and the acoustical modelling of the whole network has been realized.

2.2 Characterization of the acoustic emission of a special train (double-decker train)

ADIF AV has defined a database of 28 types of trains and 6 types of infrastructure, through the analysis of 600 pass-by measured at 7 locations.
The S-450 type train is considered a special vehicle due to its acoustic emission since the application of the interim method. This train is a double-decker train and cast iron brakes.
Figure 3 shows noise levels generated by different types of trains running in ADIF AV conventional network. The noise levels generated by the S-450 train are much higher than the rest of the passenger trains, reaching levels close to those produced by freight trains.

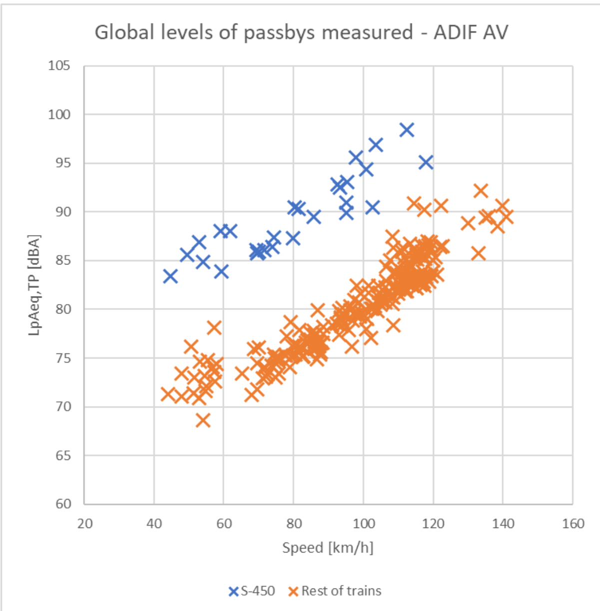

Figure 3. Global noise levels pass-by ($L_{pAeq,TP}$) measured by ADIF AV.

Looking at the previous figure, it can be observed that the difference between the noise levels generated by the S-450 train, with cast iron brakes, and the rest of the passenger trains in the conventional network, with disc brakes, is approximately 10 dB. In the characterization project, the wheel roughness of some S-450 units was directly measured in the mechanic workshop managed by RENFE.
According to these results (see Figure 4), it can be appreciated that the wheel roughness of the S-450 train is very high, even exceeding the default input values proposed by CNOSSOS-EU for wheel roughness associated with cast iron brakes.

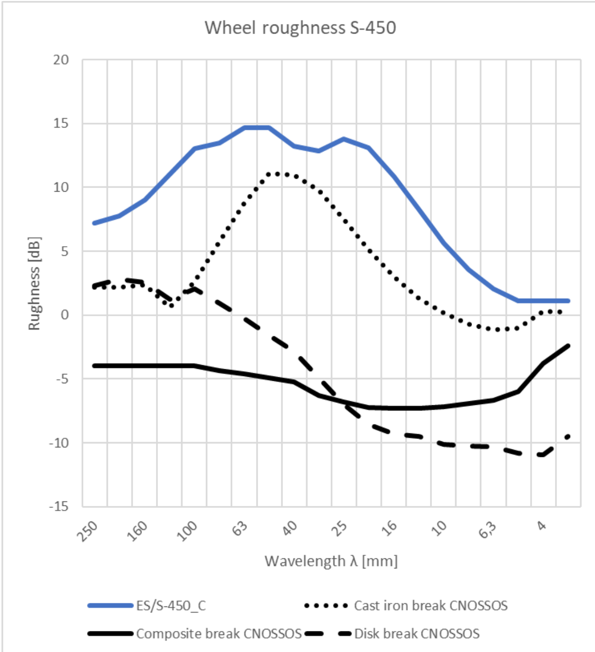

Figure 4. Wheel roughness categories.

Obviously, by applying the default input values presented in the method, an emission as high as the one generated by this train cannot be obtained. Table 2 shows a comparison of measured and calculated noise levels for three pass-by at different speeds. The calculated levels are obtained by applying the default CNOSSOS-EU input values for wheel roughness, named the cast iron brake. This default input value produces the highest emission levels. Differences are presented in terms of *measured level – calculated level*, so positive differences imply that the method underestimates.

Table 2. Comparison between measured and calculated levels applying the default input values for wheel roughness, named cast iron brake.

Speed [km/h]	Measured level [dBA]	Calculated level "Cast iron break" CNOSSOS category	Difference
59	83,9	73,3	10,6
70	85,8	75	10,8
103	90,5	79,4	11,1

The difference between the calculated and measured levels is very high, around 10 dB.
This led to the decision to create a specific category of wheel roughness to represent the acoustic emission of the S-450 train. The base for the roughness spectrum was the average of the direct wheel roughness measurements.
As a summary of the validation of this decision, Table 3 shows a comparison of measured and calculated noise levels for three pass-by at different speeds. This time the calculation has applied the new S-450 wheel roughness category. The differences are presented in terms of *measured level – calculated level*, so negative differences imply that the method overestimates.

Table 3. Comparison between measured and calculated levels with specific S-450 wheel roughness category.

Speed [km/h]	Measured level [dBA]	Calculated level new category	Difference
59	83,9	85,4	-1,5
70	85,8	87,6	-1,8
103	90,5	92,4	-1,9

The new values for wheel roughness to represent the acoustic emission of this type of train were adopted by ADIF AV.

2.3 Characterization of the acoustic emission of a noisier train type and definition of a percentage of their presence.

CTB has defined a database of 3 types of trains and 1 infrastructure, through the analysis of 52 passbys measured at one representative location.
In the case of the acoustic characterization made by CTB, the noise levels measured during the campaigns resulted in the identification of some pass-by of the same type of train with higher noise levels, which deviated from the general trend (Figure 4). The trains causing these high noise levels were identified by their registration number and it was confirmed that particular units were causing higher noise levels in all of their pass.by. So, the differences in terms of noise were attributed to the train itself and not to the infrastructure or any other specific effect.

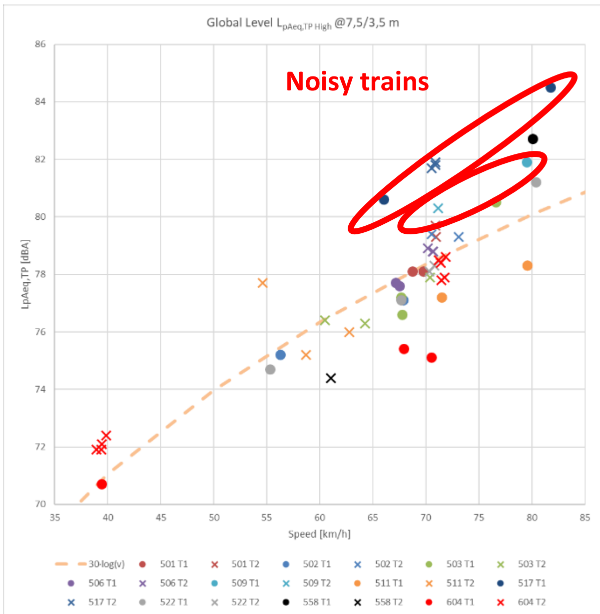

Figure 5. Global noise levels passby ($L_{pAeq,TP}$) measured by CTB.

From this, it was concluded that there were some units whose wheels were in worse condition and were probably at the end of their maintenance cycle, causing higher rolling noise levels in their contact with the rail. This type of train was called a "noisy train". Pending the analysis and improvement of the rolling stock maintenance strategy to avoid units in these conditions, a particular type of acoustic train was created that only differed from the other type of train in the values for the roughness parameter of the wheels.
The "Normal Train" was characterized by a disc wheel roughness, while the "Noisy Train" was characterized by the same category but added 4 dB to the entire roughness spectrum ("Disc +4dB" category). The values for the rest of the parameters are the same for both trends.
As a summary of the analysis carried out to validate this decision, Table 4 shows a comparison of some measured train pass-by and the levels calculated using the CNOSSOS method. The differences obtained between the measured and calculated levels are considered as *Measured Level - Calculated Level*, so negative differences indicate that the calculation method overestimates the noise.

Table 4. Comparison between calculated and simulated levels for different types of trains (CTB).

Speed [km/h]	Type of train	Measured level	Calculated level	Difference
68	S-500	74,9	76,0	-1,1
68	S-500	75,4	76,0	-0,6
68	S-500	74,4	76,0	-1,6
80	S-500	76,1	77,9	-1,8
70	S-500	75,9	76,3	-0,4
56	S-500	73	74,0	-1,0
67	S-500	75,5	75,9	-0,4
68	S-500	75	76,0	-1,0
72	S-500	75	76,5	-1,5
80	Noisy train	80,5	80,3	0,2
82	Noisy train	82,3	80,5	1,8
80	Noisy train	79,7	80,2	-0,5
66	Noisy train	78,4	78,1	0,3

For CTB it has been important to carry out this acoustic characterization, since two different noise trends have been detected in trains of the same type. Therefore, if this study had not been carried out, the emissions could be underestimated or overestimated, as was the case previously.
To extrapolate the conclusions to the noise calculation models, CTB estimated that the presence of “noisy trains” on the network is 13.5%, compared to the total number of circulations. This percentage was obtained from the presence of noisy trains in the measurement campaigns carried out.

2.4 Definition of the limit of application of aerodynamic noise

ADIF AV also made some decisions to consider aerodynamic noise. The CNOSSOS-EU method indicates that the contribution of this type of noise it can be applied from a speed of 200 km/h.
The project carried out by ADIF AV also analysed this effect considering different types of trains. For it, two measurement campaigns have been carried out on high-speed lines, measuring train pass-bys at high and medium speeds. Table 5 shows some of the results of the comparison, at global levels, of measured and calculated results applying CNOSSOS-EU, with and without the contribution of aerodynamic noise. The difference is expressed as *Measured level – Calculated level*, which means that negative values imply that the calculation overestimates the levels.

Table 5. Differences between measured and calculated level with and without aerodynamic effect (ADIF AV).

Tipe of train	S-130	S-104	S-104	S-130	S-100	S-100
Speed [km/h]	193	221	234	250	260	284
WITHOUT AERODYNAMIC NOISE EFECT						
Diference [dB]	0,2	-0,8	-0,4	4,5	4,5	4
WITH AERODYNAMIC NOISE EFECT (v>200 km/h)						
Diference [dB]		-3,7	-3,3	-0,1	0,3	-0,9

It is observed that when the method calculates noise levels applying the aerodynamic noise effect at speeds lower than 250 km/h, the method overestimates the measure level by more than 3 dB.
From this speed up, measured and calculated levels agree quite well with the application of the aerodynamic noise effect.
Therefore, results obtained in the measurement campaigns show that the contribution of aerodynamics is better represented by applying it when the speed is equal to or greater than 250 km/h and not at lower speeds.

3. ADIF AV INSTRUCTION GUIDE FOR THE APPLICATION OF THE CNOSSOS – EU METHOD

ADIF AV has published a Guide for the application of CNOSSOS-EU [5] with the purpose of offering the necessary information for the use of the method in the calculation of railway noise in ADIF and ADIF AV infrastructures, through a series of instructions that aim to facilitate its practical implementation for the preparation of any acoustic study that requires modelling.
The guide establishes instructions on the definition of input values for each parameter defined in the method: speed (with a procedure to define the sections close to stations), meteorological conditions, impact, aerodynamic, squeal noise, structural noise in metallic bridges and parameters associated with trains and infrastructure.
The type of noise most studied has been rolling noise and, as a consequence of its characterization, the guide includes tables with the values to be used to represent the noise produced by trains and infrastructures. In addition, ADIF AV has made available to acoustic software developers a library with databases that collect the acoustic characterization of all types of trains that run on the ADIF and ADIF AV lines. It defines the composition of each

train, its number of axles and the link to the spectra of each parameter defined by CNOSSOS-EU for the calculation of its acoustic emission.

Finally, the Guide also includes a general description of the method, a list of all the data needed to calculate railway noise, some recommendations for the use of acoustic software and a procedure to calculate Lmax values caused by railway noise.
The Guide can be downloaded at https://www.adif.es/gestion-de-contaminacion-acustica.

4. OPEN ISSUES

The acoustic characterization carried out so far in these projects can be improved with additional studies. The work carried out on them focuses mainly on the most relevant type of noise: rolling, traction and aerodynamic.
However, a better characterization of some type of trains is needed, and freight trains are always a challenge since there is a great uncertainty and variability in their composition regarding the type of wagons.
Another great challenge to face is how to include in the acoustic characterization the effect of maintenance activities and strategies on the infrastructure and rolling stock.
Some assumptions have been made in these projects, based on few measured data, to define input values to characterize other effects, such as squeal noise, and with respect to impact noise. And the results can be improved considering measured data from more types of switches and junctions.
However, one of the most important open issues is the acoustic characterization of noise caused when trains run at low speeds, close to station and potentially in an urban area with residential or sensitive buildings.

5. CONCLUSIONS

The process carried out to characterize railway noise to obtain input values for the application of CNOSSOS-EU method can improve in the understanding of the concepts of railway noise generation.
The process includes the analysis of data measured during, its interpretation and the need for criteria to extrapolate the conclusions obtained to non-measured situations, both trains, running speeds, infrastructure types.
This process carried out by infrastructure managers makes it easier for them to make decisions and define strategies to improve accuracy of the diagnosis, and most importantly, to be able in the future to define, plan and consider benefits of potential abatement measures linked to the design or the maintenance of key elements of the source contribution: trains and infrastructures.

6. ACKNOWLEDGMENTS

Tecnalia recognizes the initiative of ADIF AV (National Administrator of Railway Infrastructures of Spain), ETS (Administrator of Railway Infrastructures of the Basque Autonomous Community) and CTB (Administrator of Railway Infrastructures of Bilbao Metro) to lead the railway acoustic characterization projects.
In the three projects, the collaboration of the train operators has been highly valuable: RENFE, Euskotren and Metro Bilbao.
Finally, thanks also to the expertise of TNO and AVIngenieros. TNO has contributed to the projects with the application of PBA procedures to obtain parameter values from the measured levels, and AVIngenieros has developed the direct rail and wheel roughness.

7. REFERENCES

[1] 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
[2] Commission Delegated Directive (EU) 2021/1226 of 21 December 2020 amending, for the purposes of adapting to scientific and technical progress, Annex II to Directive 2002/49/EC of the European Parliament and of the Council as regards common noise assessment methods
[3] Real Decreto 1513/2005, de 16 de diciembre, por el que se desarrolla la Ley 37/2003, de 17 de noviembre, del Ruido, en lo referente a la evaluación y gestión del ruido ambiental.
[4] Orden PCI/1319/2018, de 7 de diciembre, por la que se modifica el Anexo II del Real Decreto 1513/2005, de 16 de diciembre, por el que se desarrolla la Ley 37/2003, de 17 de noviembre, del ruido, en lo referente a la evaluación del ruido ambiental.
[5] ADIF AV. Guía para la aplicación del método CNOSSOS-EU en la modelización del ruido producido por las circulaciones ferroviarias en las infraestructuras de ADIF y ADIF AV. 2022.