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ASSESSMENT OF THE REDUCTION OF RAILWAY NOISE ACHIEVED BY THE INSTALLATION OF A LOW-NOISE BARRIER

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ABSTRACT

The objective of the paper is to present a procedure to calculate the effect of a low-noise barrier in the assessment of solutions to abate railway noise. The benefits are quantified both in the exposed area and in the affected population. The calculation can consider the effect of low-noise barriers on one or both sides of the railway line.

The low-noise barrier, in addition, to shielding the acoustic sources referred to as the rail and wheel interaction, located at the low height positions, modifies the acoustic field in the area between the coach and the barrier position. This effect is not well represented by the attenuation factor considered on the propagation formulae that defines the acoustic diffraction, Adiff. This factor only depends on the height of the barrier and the barrier-source and barrier-receiver distance. Therefore, the results of acoustic calculation methods, including CNOSSOS-EU, minimize the effect of a railway low-noise barrier. Based on a project requested by ACUSTRAIN, the document developed by Tecnalia defines how this effect could be simulated based on the formulations of the CNOSSOS-EU method and the capabilities of existing acoustic programs.

Keywords: *noise assessment, low noise barriers, directivity, acoustic software.*

1. INTRODUCTION

The problems associated with the noise generated by railway infrastructures in urban environments are a growing challenge in society that must be tackled specifically, and this has been the case in recent years. The appearance of legislation that has made the problem visible through the establishment of Noise Action Plans to mitigate the acoustic impact produced has led to new solutions to this problem.

After the first years of their implementation, it has been detected that the traditional solutions, high noise barriers, in some cases present significant problems of acceptance, viability and effectiveness in urban environments. The visual impact produced by this type of barrier in these environments, walls of 4 m in front of the windows of the dwellings, implies in some cases a high rejection of this type of measures. In some cases, those solutions are not even viable due to the unavailability of physical space or because they disagree with urban planning regulations.

The main railway noise-generating mechanisms at low speeds are associated with the acoustic emission of the wheel and the rail, located at low heights above the ground. So, specific solutions for low height sources may be effective in reducing railway noise.

To be a real option, these new solutions must be part of the catalogue of solutions available to a designer of railway noise action plans or solutions. However, they are currently not included in existing calculation software.

2. LOW NOISE BARRIERS: PROBLEMS AND NEEDS

A low noise barrier is a low height noise reduction element, less than 1.2m. high, which main objective is to attenuate

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the noise levels generated by the pass-by of railways and/or trams in urban environments.

In order for the low noise barrier to work correctly, it must be located in the track environment. This implies occupying space in the ballast area, complying with the limitations set by the particularized gauge for the section where the solution is proposed. The application gauge is for the implementation of obstacles with a height of 1 m.

This means that infrastructure managers must first address and solve non-acoustic problems in the implementation project, such as those associated with risks, maintenance, the existence of obstacles or services in the location environment of the low-noise barrier, etc. Likewise, the project manager needs the product to be approved or authorised for its infrastructure and, if possible, certified in a similar way to an acoustic barrier.

Once these steps have been covered, it is necessary to carry out an acoustic study, that is, to estimate the reduction in noise levels that the installation of the low noise barrier will achieve concerning the initial situation, in the same way, that the effectiveness of a traditional acoustic barrier is quantified.

The ACUSTRAIN company has designed and manufactures a low-noise barrier product. The results obtained in the first real implementations of the product have been very encouraging. The level reductions, quantified in measurement campaigns, are greater than 9 dB in the protected environment, therefore comparable with the attenuations offered by traditional acoustic barriers [1].

Its behaviour depends on the acoustic properties of the materials used and its location concerning the noise source, like any barrier. But in the case of the low-noise barrier solution, its location is critical, since only if it can be located close to the source it will be able to modify the acoustic field and the directivity of the acoustic emission.

ACUSTRAIN requested the support of TECNALIA so that the low-noise barrier solution could be integrated into an acoustic study that considers all possible noise reduction solutions. The objective pursued is that the effectiveness of the low-noise barriers can be calculated in a standard calculation software and that the calculation is based on the CNOSSOS-EU method.

3. ESTIMATION OF THE EFFECT OF LOW-NOISE BARRIER APPLYING CNOSSOS-EU METHOD

First of all, it is necessary to understand how CNOSSOS-EU defines the source of railway noise. The location of the different types of noise characterized (rolling, traction and aerodynamics), the directivity of the sources and the behaviour of the different elements that affect the acoustic propagation (track infrastructure, ground absorption, diffraction, reflection and properties of vertical elements) [2].In summary, the development of a calculation methodology that allows calculating the effect of a low-noise barrier must consider the following aspects of CNOSSOS-EU: (1) The noise source is located in the centre of the track at two heights (0.5 m and 4 m) with different acoustic powers that depend on the speed; (2) Both sources have a sound power [3] which has horizontal and vertical directivity LW,0,dir and makes the propagation of the linear source look like a dipole. Fig. 1 shows a cross-section with the above-mentioned effect.

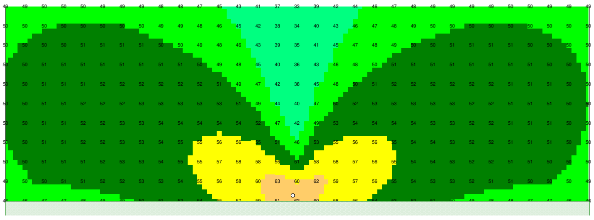


Figure 1. CNOSSOS-EU directivity on propagation

(3) The absorption of the ground at the track infrastructure area is considered differently than in other areas; (4) There is a retrodiffraction property associated with effects between acoustic barriers and rolling stock. This effect is calculated considering that the source is located at 0.5 m above the ground and the effect on the modification of the acoustic power depends on the number of reflections that occur with the barrier. Therefore, this property cannot represent the effect of a 1.2 m height barrier.

The low-noise barrier is located in the lower area of the fairing panel of the rolling stock. A reverberant acoustic field is produced in the area under the body of the train, where the wheels and bogies are. Another effect of the low noise barrier is that the source of noise is forced to only emit through a reduced space: an opening of less than 0.5m. between the body of the train and the barrier at its upper point. Each of these aspects has been taken into account in the development of a technical procedure to calculating the acoustic effect of the low noise barrier.

4. ACOUSTIC CHARACTERIZATION

4.1 Analysis of alternative approaches

In order to address the problems exposed, different approaches were analyzed to ensure that the setting composed of the railway line and the low noise barrier

behaves acoustically as it has been characterized in experimental campaigns and simulations carried out with BEM/FEM models. The following lines of work were considered: (1) equivalent higher height barriers, (2) modifications of emission acoustic power, (3) change of location of the emitting source. However, these approaches present associated problems, both to the representativeness of the acoustic behaviour at different heights and to the impossibility of having differentiated emissions on both sides of the railway. In addition, in all cases, they represent a too complex application of acoustic software for technicians who develop railway noise maps and action plans.
Finally, it was established the following requirements for the calculation procedure: keeping the location of the lower source at 0.5m. above the ground, considering the directional behaviour of the source according to CNOSSOS-EU and the ability to combine different solutions of low noise barriers and traditional barriers.
The approach adopted is to create a CNOSSOS-EU industrial linear acoustic source to represent the emission of the section where the acoustic low-noise barrier is placed. The acoustic power of the line source is equal to that of the railway line according to CNOSSOS-EU. The directivity of the lower source of CNOSSOS-EU (0.5 m) is defined in 3D, incorporating the effect that the low noise barrier produces in the acoustic field. In this way, the noise levels expected in vertical and horizontal propagation due to the insertion of the low noise barrier are obtained.
To define this technical procedure two steps must be taken. First, verify that a linear acoustic source can incorporate the directivity defined by CNOSSOS-EU with sufficient precision. Secondly, define the modified directivities produced by the insertion of the low noise barrier. These directivities must consider the different configurations that can be considered when planning the installation of a low noise barrier.

4.2 CNOSSOS-EU directivity and additional correction

The directivity of the railway source defined in CNOSSOS-EU has been generated in 3D format so that the noise levels obtained with the industrial source and this directivity behave in an analogous way to the source of railway CNOSSOS-EU method. This directivity ensures that the conversion from the railway CNOSSOS-EU source to the industrial CNOSSOS-EU linear source (Fig. 2) is correctly assigned in power, spectrum, alignment of the axis and directivity.

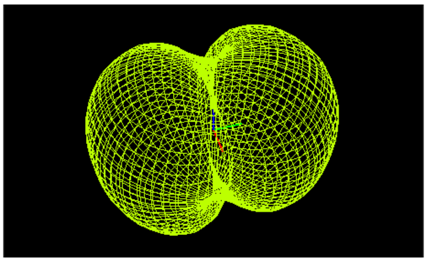
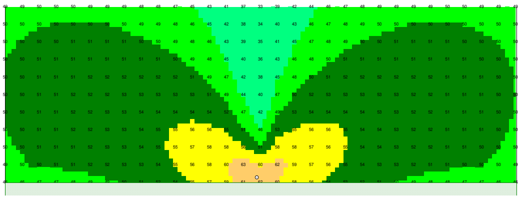
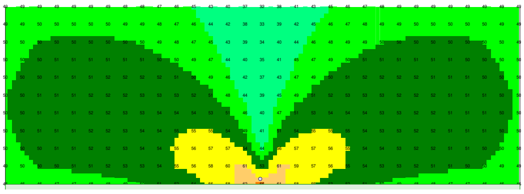


Figure 2. CNOSSOS-EU directivity for linear source

Tests have been carried out with different configurations of sources and spectrum and at different angles of the railway line axis. The results obtained are in a dispersion range of less than 1 dB, as shown in the Fig. 3.



Railway CNOSSOS-EU Implementation



Industrial CNOSSOS-EU+Directivity Implementation

Figure 3. Propagation of railway and industrial sources

4.3 Correction of ground effect by railway CNOSSOS-EU vs linear CNOSSOS-EU source

One of the aspects found when adjusting the emission of the source is the acoustic effect of the ground. The CNOSSOS-EU railway source assumes that the ground under the track is absorbent (ballasted track system). Therefore, in the space occupied by the track platform, the industrial CNOSSOS-EU source must create a zone with an absorbent ground (same absorption as CNOSSOS).

4.4 Different effects based on the location of low noise barriers.

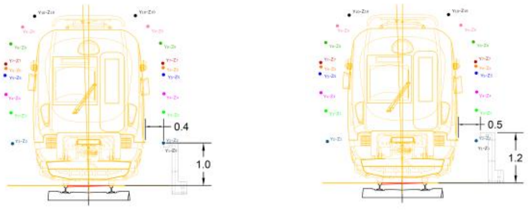
It has been already mentioned that the insertion of the low noise barriers modifies the acoustic field around the railway source. This has been contrasted with acoustic field simulations carried out with BEM/FEM models. However, the real effect of the low noise barrier is critically dependent on the distance between the upper diffraction edge and the train body. This distance can vary in real situations and simulating all possible cases can require too much effort.

Therefore, BEM/FEM simulations have helped in the design process, but the characterization of the acoustic effect has been defined considering the insertion loss data measured in real low noise barrier installation projects. These are the projects carried out by two railway infrastructure managers, Euskal Trenbide Sarea (ETS) and Bizkaia Transport Consortium (CTB).

In these projects, different configurations of low noise barriers have been characterized, and the directivity has been analyzed to replicate the "insertion loss" obtained in an array of control points in the area of influence of the low noise barrier. In this way, a modification of the directivity of the CNOSSOS-EU railway source has been proposed.

From the analysis carried out, directivities have been defined for different cases: 1) standard performance for straight sections or for curves with R> 500 m; 2) optimal performance in the inner part of curves R<500 m; and 3) performance for the outer part of curves R<500 m.

It may also happen that the low noise barrier cannot be positioned at the optimum distance from the railway line. In the studies carried out, it has been determined that the low noise barrier can continue to behave as such in a displaced situation. This situation has been defined as horizontally displaced 100 mm horizontally and 200 mm in height. Fig.4 shows this configuration. A directivity associated with this case has been also defined.



Optimal location Displaced location

Figure 4. Low noise barrier operating positions

4.5 Acoustic effect in curves with small radius (< 500 m)

The behaviour of the low noise barrier in curved sections is different in the inner and outer parts. The difference is due to the contribution of the railway line sections far from the barrier. In the outer part, since the low noise barrier is further away from the source, its effect is negligible.

Therefore, the efficiency in the outer part is lower than that in the inner part. Fig. 5 shows this effect, by marking the section of low noise barrier that is acting as a barrier.

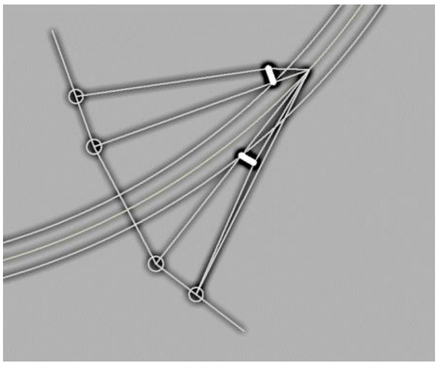


Figure 5. Effect of efficiency on curves

An intermediate situation occurs in straight sections or curves with a radius greater than 500 m.

These situations suggest that the attenuations expected by the insertion of the low noise barrier vary. The procedure considers three criteria to define the acoustic directivity to represent the effect of the low noise barrier:

- Straight line or Inner part of a curve / Outer part of a curve
- Optimal location referred to the track / Displaced location: horizontally displaced 100 mm horizontally and 200 mm in height.
- Low noise barrier at one side of the lines / Low noise barrier at both sides.

5. TECHNICAL INSTRUCTION

The objective of the instruction is to be able to consider in an acoustic study, carried out with standard software, the low noise barrier as a potential abatement solution for railway noise.

The process to simulate the effect of low noise barrier must follow these steps:

1. The simulation must be carried splitting the railway line in each axis, representing each direction of circulation. Each track emits in both directions and the low noise barriers protect, in principle, only one of the directions. The solution for each track must estimate the effect of whether both sides of the track are protected or only one of them.

2. Those sections of track with low noise barrier will be simulated differently from the rest of the railway line. A

CNOSSOS-EU industrial source is created with the same geometry as the railway source.
3. The acoustic emission of the industrial linear source is equal to the existing railway source, as defined by CNOSSOS-EU. Only the lower railway source is considered, having verified that the higher source at speeds below 160 km/h does not contribute.
4. The effect of the low noise barrier is incorporated by applying a 3D directivity to the emission power defined in the previous step.
5. The 3D directivity must be selected from a database of directivities that is defined by:

- Straight line or Inner part of a curve / Outer part of a curve
- Optimal location referred to the track / Displaced location: horizontally displaced 100 mm and 200 mm in height
- Low noise barrier at one side of the lines / Low noise barrier at both sides.

The process of simulating the effect of the low noise barrier requires similar technical knowledge as for a standard simulation.
The procedure is shown in Fig. 6 and described below.

5.1 Confirm the feasibility of the optimal location

The low noise barrier is an acoustic solution that is different from a barrier, but its correct acoustic performance requires that it is located at a certain distance from the track.
Therefore, it should be verified with the infrastructure manager that there is space available, parallel and close to the track, to locate the low noise barrier.
The railway infrastructure manager must give the gauge for obstacles at that particular section. The gauge depends on several factors: the dynamic characteristics of the track platform, the radius of curvature, the superelevation, and the rolling stock. Once this gauge is known, the low noise barrier must be placed with the following criteria:

- If the gauge allows a distance below 450 mm, the location is the closest point defined by the gauge at a height of 1m from the head of the nearest track.
- If the gauge marks a distance between 450 and 550 mm, the location should assure that the highest part of the low noise barrier is at height of 1.2 m from the head of the nearest track.

Otherwise, if the gauge indicates that the location must be further than 550 mm, the low noise barrier will not act as such, and this instruction could not be applied. Its acoustic behavior would be that of a traditional acoustic barrier and its effectiveness would be estimated with a traditional calculation.

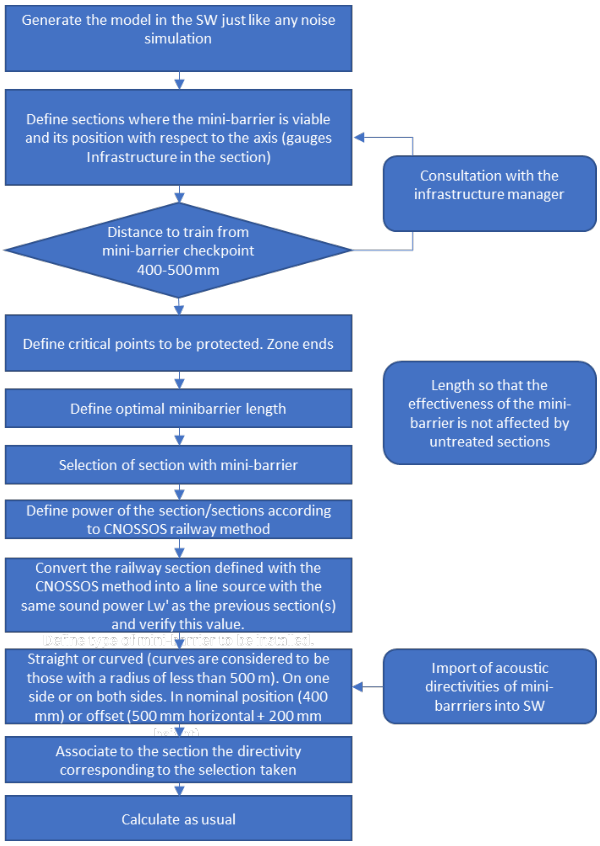


Figure 6. Work process scheme

5.2 Define the optimal length

The length of the low noise barrier should be the length at which the contribution of non-protected sections does not affect the sound level at the points protected by the solution. Fig. 7 describes this concept.

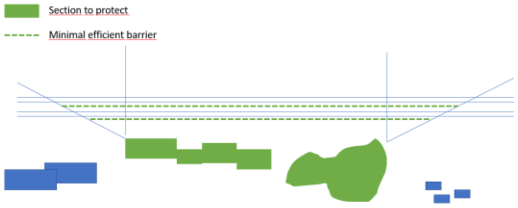


Figure 7. Determination of optimal length

5.3 Definition of the acoustic source

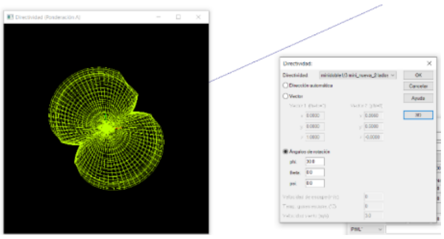
Once the area has been analysed, the possible location of the low noise barrier (optimal or displaced) is defined. In addition, it is identified if the section has a curve of radius <500 m. Finally, it is decided if the low noise barrier is positioned on one or both sides of the railway line.

Based on the location options, the applicable 3D directivity of the database is identified in each section.

According to the possible location options in each section, homogeneous sections will be defined in the railway acoustic model. Proceeding as follows

- Apply railway CNOSSOS-EU to obtain the acoustic emission spectrum of the railway source at the section of track where will be placed the low noise barrier. These emission values are defined by the $L_{w'}$ spectrum (power level per meter) for the different periods.
- In the section where the low noise barrier is going to be placed, replace the railway source with an industrial linear source. The CNOSSOS-EU railway section can be directly converted to a CNOSSOS-EU linear source and thus preserve the relevant section information. The source is placed 0.5 m above the calculation axis, on the ground.
- Define the acoustic power of the linear source equal to the emission values ($L_{w'}$ spectrum) previously calculated by railway CNOSSOS-EU.

If you want to verify that the section behaves correctly, you can assign the CNOSSOS-EU railway directivity, with the necessary alignment (Fig. 8) of the directivity to the section and compare results between the new industrial source and the railway source.

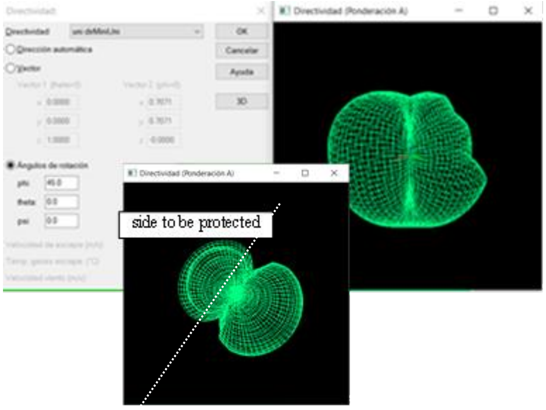


phi 30.0
theta 0.0
psi 0.0

Figure 8. Alignment of directivity to the axle

Once it has been verified that the alignment of the directivity is correct, the directivity of the corresponding low noise barrier is assigned to the section, checking that the alignment of the axis has not been modified.

The directivity (dipole-shaped) must be oriented by modifying the phi angle, as seen in Fig. 9, at the angle that maintains the section with the vertical. The narrowest area marks the angle to which it should be aligned. When the low noise barrier is only located on one side, it must be assured that the side with less directivity is on the side to be protected.



phi 45.0
theta 0.0
psi 0.0

Figure 9. Verification of the side to be protected

Once the noise sources are in the acoustic model, in sections without low noise barriers and in sections with low noise barriers, the procedure to calculate noise maps is the usual one, being able to calculate maps and levels in receivers at facades of buildings.

Results can be verified by calculating noise levels in cross-sections to ensure that the low noise barrier attenuates the correct side of the track (Fig. 10).

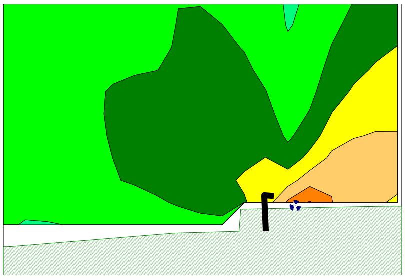


Figure 10. Cross-section with mini-barrier effect

6. EXAMPLES OF RESULTS. CONTRAST WITH REALITY

In the area where the low noise barrier was installed for the first time, the location is called OPTIMA, that is, 1.2m. from the nearest rail and 1m. high (corresponding to a distance to the train body of the order of 400 mm).

The results obtained from the application of this instruction are adjusted to the levels measured in this situation obtaining improvements of the order of 10 dB. See Fig. 11 and 12.

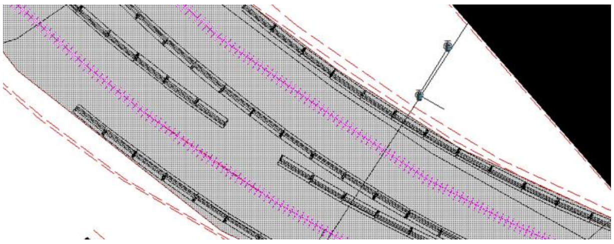


Figure 11. Configuration of measurements to characterize insertion loss

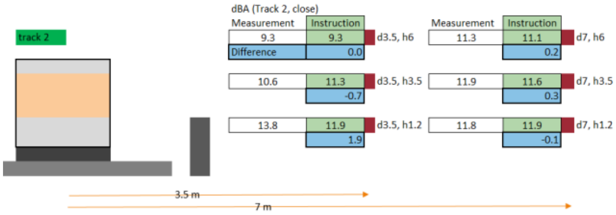
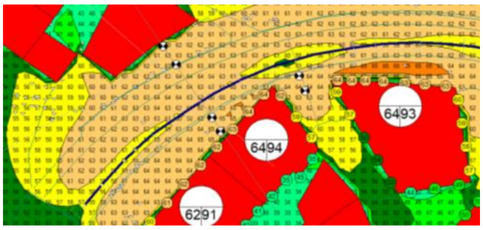
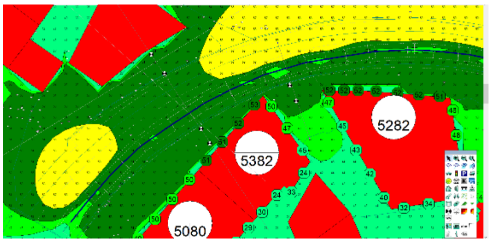


Figure 12. Comparison of insertion loss value between measurements and simulations

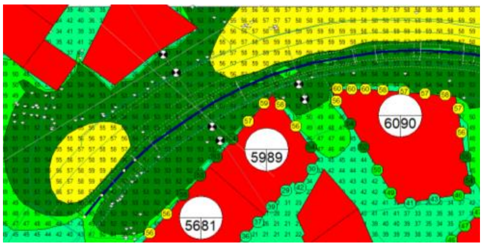
Different low noise barrier configurations have been tested. The STANDARD configuration represents a more conservative effect where the reductions achieved were of the order of 8 dB. There is still another setting, called MINIMUM. The data comes from a real case, where the barrier had been moved away from the axis by 10%. This solution provides a reduction of the order of 6 dB. In one of the actual installation projects it has been possible to analyze different combinations, with a low noise barrier on both sides, only on one side, and even considering the gaps left in the final installation. This complex case contributes to testing the correct behaviour of the instruction.
Fig. 13 shows the simulation of the acoustic effect in the area where the low noise barrier was tested, comparing noise levels with and without the solution, and the effect of the low noise barrier in the OPTIMA position (real situation measured in the simulated environment) and with the barrier in the MINIMA configuration (configuration obtained from a real installation environment with the barrier moved).



WITHOUT LOW NOISE BARRIER



LOW NOISE BARRIER AT OPTIMA LOCATION



LOW NOISE BARRIER AT MINIMUM LOCATION

Figure 13. Noise map and building exposure without and with low noise barriers at different locations

7. APPLICATION IN ACOUSTIC SOFTWARE

It has been verified that the main noise calculation software can implement the procedure. Thus, they generate a linear source with the same acoustic power in spectrum. In addition, they can associate a 3D directivity oriented to the circulation axis. Of the analyzes carried out with CADNA [4], IMMI [5], SOUNDPLAN [6], all of them allow the import of directivity formats such as clf [7], xhn [8] or text formats, in addition to allowing the generation of their own directivity.
This instruction is applicable in different environments, and different technicians have been able to apply it.

8. FUTURE RESEARCH LINES

From the installations made so far and from preliminary analysis of locations of low noise barriers in new situations, some lines of improvement have been detected.

In relation to the improvement of the instructions, it is needed to collect or to share more "insertion loss" data representing different location options for the low noise barrier. This would allow a better adjustment of the database of directivity both in a straight line and in curves.

It is an open question if there can be a procedure to calculate the effect of low noise barriers valid for any specific design of the solution. It would be needed an independent technical discussion to establish the acoustic characteristics of the solutions to be used as input data.

On the other hand, considering some of the measurements carried out, it has been verified that the fairing panels of the rolling stock can modify the railway CNOSSOS-EU directivity. This means that the potential efficiency of the low noise barriers when the rolling stock has very low fairing panels increases significantly. If the characteristic of the train is relevant, the assessment of the effectiveness of the low noise barriers would require a detailed study taking into account the directivity of different type of trains.

Finally, the market requests the development of new elements in the area between tracks, which would allow reducing the noise levels of remote tracks in combination with the on side low noise barriers. All these developments must be accompanied by the corresponding directivities depending on the possibilities of their location and the type of track and rolling stock.

ACUSTRAIN together with Tecnalia are working on these lines of improvement to push the access to the market of this type of acoustic abatement measures as the low noise barriers, as a necessary product for the problem of urban noise.

9. CONCLUSIONS

As a result of this research, it has been possible to write a technical instruction that allows the elaboration of acoustic studies of solutions that incorporate low noise barriers as another element to achieve noise reduction in railway environments. It is quite simple instruction, without the need for additional developments by acoustic software and compatible with different software.

A solution that is open to new low noise barrier elements and new situations resulting from actual implementation.

A solution that allows consultants to work with different scenarios of the location of low noise barriers.

10. ACKNOWLEDGMENTS

We would like to thank the many people who have allowed us to study this line of work, both ACUSTRAIN, which has entrusted Tecnalia with this development, and the infrastructure managers of Euskal Trenbide Sarea (ETS) and Bizkaia Transport Consortium (CTB), who have relied on the low noise barriers and have carried out the first installations on their infrastructures, allowing their performance to be verified, as well as our colleagues at TECNALIA, without whom this work would not have been possible.

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