# THE PROBLEM OF NOISE ON THE ACCESS TO TUNNELS AND ROADS IN TRENCH TO OPEN AIR

Dámaso M. Alegre

**ABSTRACT**

The problem of noise on the access to tunnels and roads in trench to open air is generated by the increase in the noise level, in relation to the noise that would exist if the road were at surface level, due to the reverberant fields created by the multiple reflections that occur in the walls of tunnels and trenches.

The careful study of these problems, allows us to establish some practical recommendations, which should be considered at the time of carrying out the projects of road tunnels and its access trenches. In particular, it is important to highlight the effectiveness of the use of suitable absorbent coatings, as shown by the practical experiences carried out so far in various projects in Europe.

Various types of noise reduction devices can be used, as a solution to the problem. Its effectiveness will depend on the type of material used and the final form of its installation. The regulations of the CEN (European Committee for Standardization) and the CE marking, allows the evaluation of the behavior of the different types of material and their installation.

The problem is analyzed in this presentation, as well as the most recommendable corrective measures and the European Standards regarding the preceptive CE marking that shall be applicable.

**Key words**

Noise, Tunnel access, Open pit trench, Absorbent claddings

## 1 Elevation of the noise level of roads in open pit trench. (Hopper effect).

In open trenches, the roadway is surrounded by acoustically reflective walls, close and parallel, which favor multiple reflections.

These reflections send to the neighbors of the zone, acoustic waves that would not have been received in the event that the vehicles circulated on the surface of a road without reflective walls. The geometric reorientation of certain sound rays towards the neighbors of the exposed area, involves an important elevation of the level of noise that we call "hopper effect" and that can reach up to 5 to 8 dBA. In fact, if we consider the cross section of a road in open pit trench according to Figure 1, we can verify that, despite the screen effect due to the walls, the reflective nature of these causes sound reflections, which we can represent by sources images. Each one will radiate the part of acoustic energy emitted by a source of lower reflection order, not captured by the wall.

**Dámaso M. Alegre**

Head of the Department of Acoustic Engineering. Technical Office FERROVIAL AGROMAN S.A.

Honorary President and Executive Vicepresident of the European Noise Barrier Federation (E.N.B.F.).

President of the Spanish National Association of Manufacturers of Noise Reducing Devices (ANIPAR).

Member of the European Committee for Standardization of noise reduction devices for roads, CEN TC226 WG6.

Member of the European Committee for Standardization of noise reduction devices for railways, CEN TC256 SC1 WG40.

FERROVIAL AGROMAN S.A. C/. Ribera del Loira, 44 – 28044 Madrid (Spain). Phone: +34 618 528 291

E-mail: alegre.tecpresa@ferrovial.com

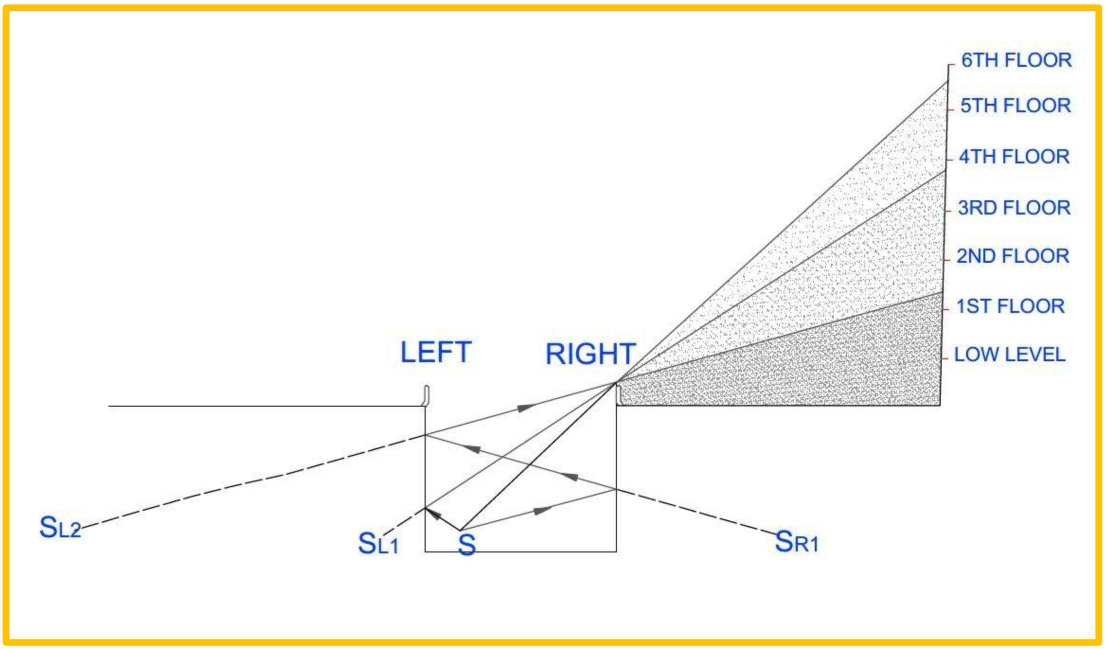



*Fig. 1 Cross section of a road in open pit trench showing the hopper effect*

Thus, according to Figure 2, a vehicle that would originally emit under an angle of 180° if it circulated at surface level, will emit directly to the outside of the trench the $\alpha$ / 180° part, while the left wall will capture the part $\alpha_L$ / 180° and the right wall the part $\alpha_R$ / 180°, where:

$$\alpha_L + \alpha_R = 180° - \alpha$$

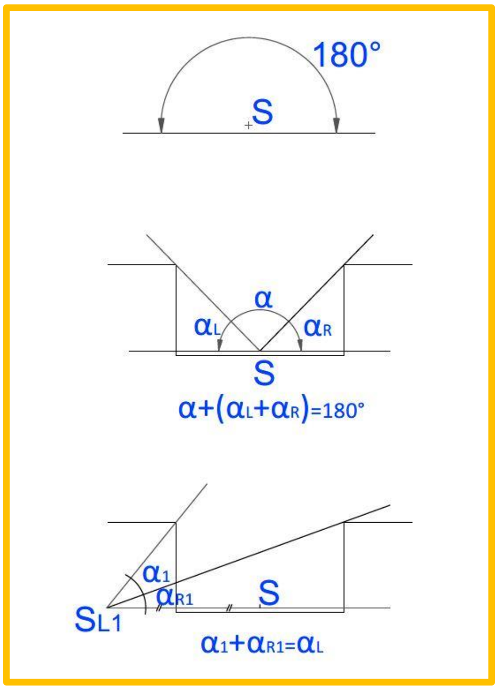



*Fig. 2 Distribution of the sound energy emitted by the source "S" and multiple reflections*

The acoustic energy reflected by the left wall due to the energy part captured by it, from that emitted by the source S, can be assimilated as an image source $S_{L1}$, which in turn, radiates out the part $\alpha_L$ / ($\alpha_1 + \alpha_{R1}$), while the right wall will capture the part $\alpha_{R1}$ / ($\alpha_1 + \alpha_{R1}$), and so on.

Accordingly, to the noise source S, created by the vehicle itself, an infinity of image sources, representing the successive parts of energy captured and reflected by the walls of the trench, will be superimposed.

That is to say, a geometric redistribution of the sound rays takes place, whose immediate effect on the neighbors of the zone, will be an important elevation of the level of noise; aggravated by the fact that, by progressively moving away the image sources from the walls as the order of reflection grows, the screen effect of these walls in front of these sources will be significantly reduced, leaving the neighbors totally unprotected, from the image sources of a certain order.

It should also be noted that, from a sufficiently high order of reflection, the outward emission angle αi, becomes so small that the energy of the higher orders constitutes a reverberated field inside the trench, which is it emits at the midpoint of the opening between the tops of the walls of the same. Figure 3.

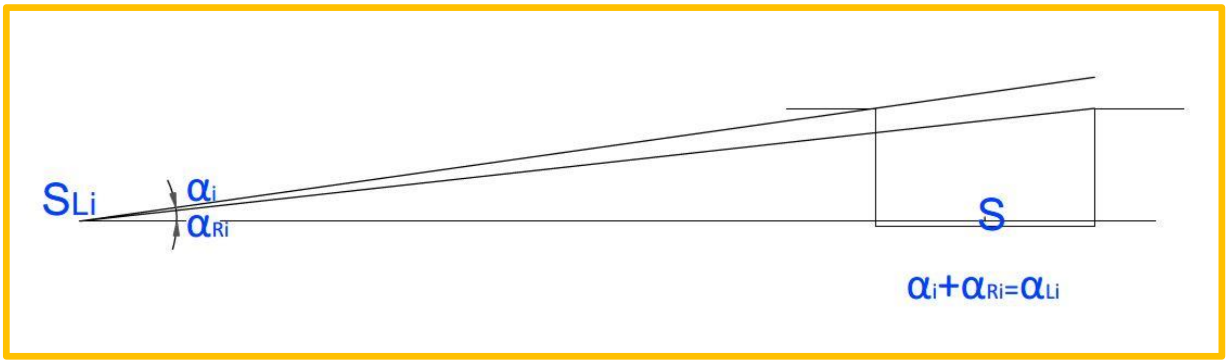



*Fig. 3 Source immage "$S_{Li}$" for the i order of reflection*

As a solution to these problems, we must think about the placement of a highly absorbent acoustic coating on the walls, which allows the reduction of the reflected energy successively to a negligible value, maximizing the shielding effect of the walls of the trench.

## 2 The elevation of the level of noise in the accesses to the mouths of the tunnels. (Tunnel effect).

The most peculiar aspects that define the acoustic impact due to the tunnels are:

The persistence of noise while a vehicle remains inside the tunnel. This phenomenon is particularly troublesome during the night in some tunnels, since it would suffice, for example, a small continuous traffic of vehicles separated from each other at an interdistance equal to the length of the tunnel, to have the impression of a continuous noise with only some vehicles.

The noise emitted by the mouths of the tunnel, when a large amount of traffic circulates in its interior, is constituted by the energy accumulation of the noise induced by each vehicle considered in isolation.

When a vehicle enters a tunnel, a part of the sound energy emitted by it spreads directly to the outside through the mouth of the tunnel ($\alpha_d$) and another part creates a reverberated field due to the infinity of reflections on the walls, floor and roof of the tunnel ($\alpha_r$), see Figure 4. The order of reflection is such, that the sound field can be considered as a diffuse field (that is, all directions of reflection will be equiprobable), propagating to the ends of the tunnel.

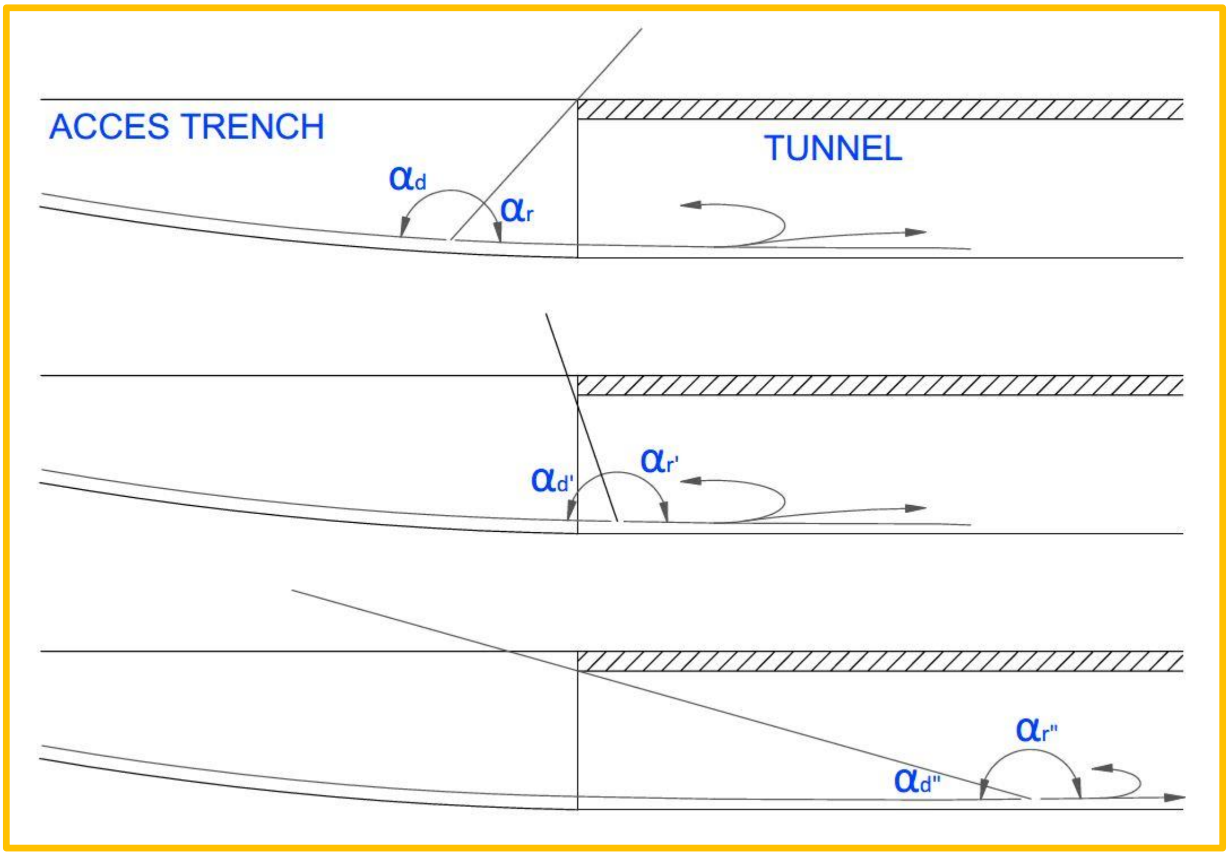



*Fig. 4 Distribution of the sound energy emitted by one vehicle when it comes into a tunnel*

If we stand at one end of the tunnel and observe the progress of a vehicle inside, we will see that as the vehicle advances in the tunnel the field directly radiated by it, outwards decreases, while the reverberated field increases. The superposition of both is such that they produce a quasi-persistence of the noise level emitted by the mouth of the tunnel. In Figure 5, the pass-by noise signature of a vehicle's passage in front of a hypothetical observer, located at the mouth of the tunnel, are compared within different cases, revealing the significant increase in noise level induced by the tunnel. In practice, increases of the noise levels will usually be produced at the entrances to the tunnels, which can reach 7 to 10 dBA.

Since this effect, known as "tunnel effect", is conditioned by the free mean travel of the sound waves inside the tunnel, it will be all the more significant, and therefore annoying, the narrower the tunnel.

As in the case of open pit trench constructions, the use of materials with a high acoustic absorption coefficient will reduce the importance of multiple reflections. The treatment should be the best possible at the access points to the tunnel (where the noise issued to residents will be predominant). Thus, for example, for tunnels with four lanes of circulation in both directions, the acoustic treatment of the first 50 to 70 meters will be necessary, and may even be sufficient.

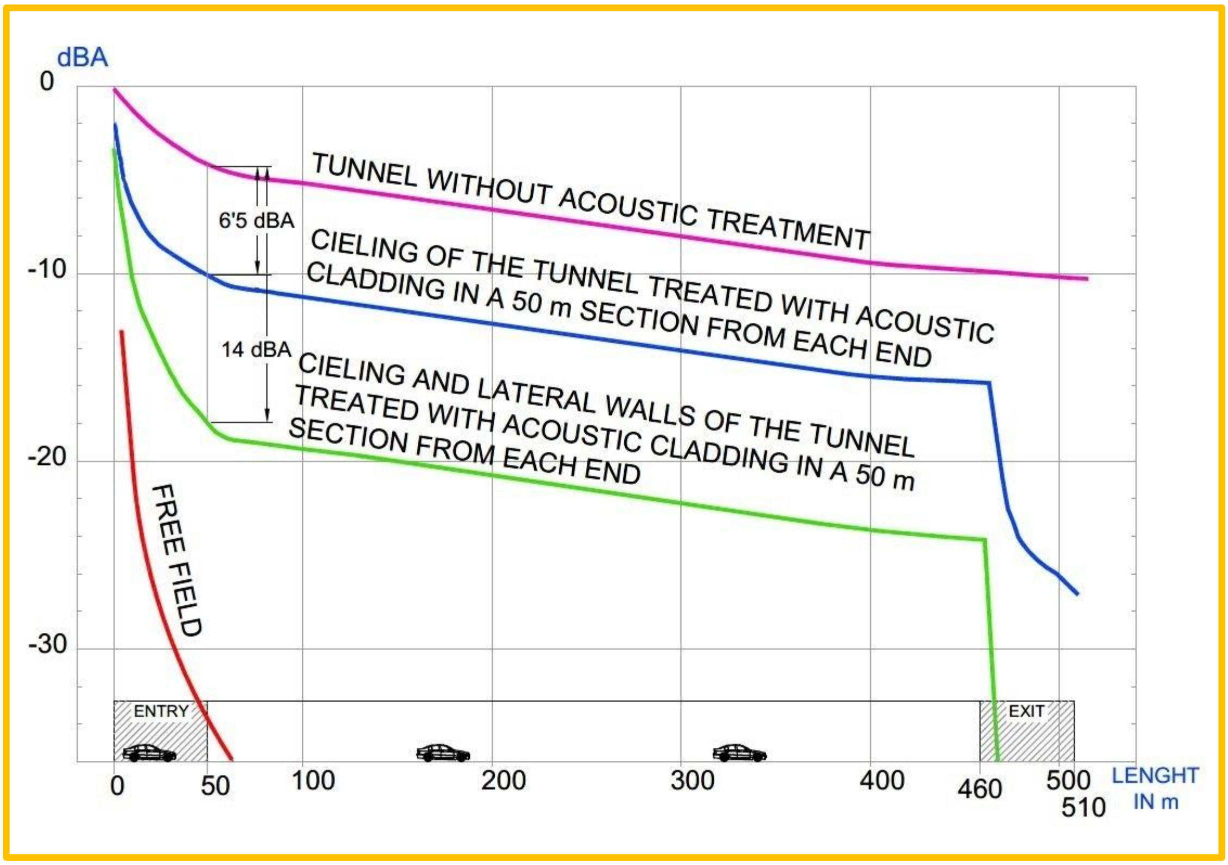



*Fig. 5 Theoretical pass-by noise signature of a vehicle's passage in front of a hypothetical observer, located at the mouth of the tunnel, in different cases*

In effect, when a vehicle circulates beyond the treated area, this section will act as a muffler on the noise issued by the reverberant field created by the vehicle into the tunnel.

It is interesting to highlight the convenience of acoustically treating also the walls of the tunnel access trenches, since in addition to its performance as a silencer against noise issued by the tunnel, due to the vehicles that circulate inside it, can act effectively on the noise emitted by the vehicles that are in the section of access to the tunnel and that could be amplified by it.

Although we had been referring in the preceding paragraphs to the problem for road tunnels, the same happens in the case of railway tunnels.

## 3 Typical solutions of absorbent claddings in open pit trenches and tunnels access

When implementing solutions for the problem of noise elevation in trenches and access to tunnels by installing highly absorbent claddings, we can select various types of materials and to foresee their installation, in order to improve their capacity as acoustic absorbent, facilitating the arrangement of the different elements of the tunnel installations, such as lighting, variable signaling, etc. at the same time that an adequate aesthetic finishing of the interior surfaces of the walls is achieved.

It is worth taking into consideration several aspects:

- In general, the claddings formed by metal perforated sheet panels with rock wool or glass fiber as an absorbent material have the advantage of their reduced weight, which greatly facilitates their installation and allows the registration of the back part, being able to take advantage of the space between panels and wall, to arrange the different conduits, wiring and lighting equipment of the tunnel. Figure 6.

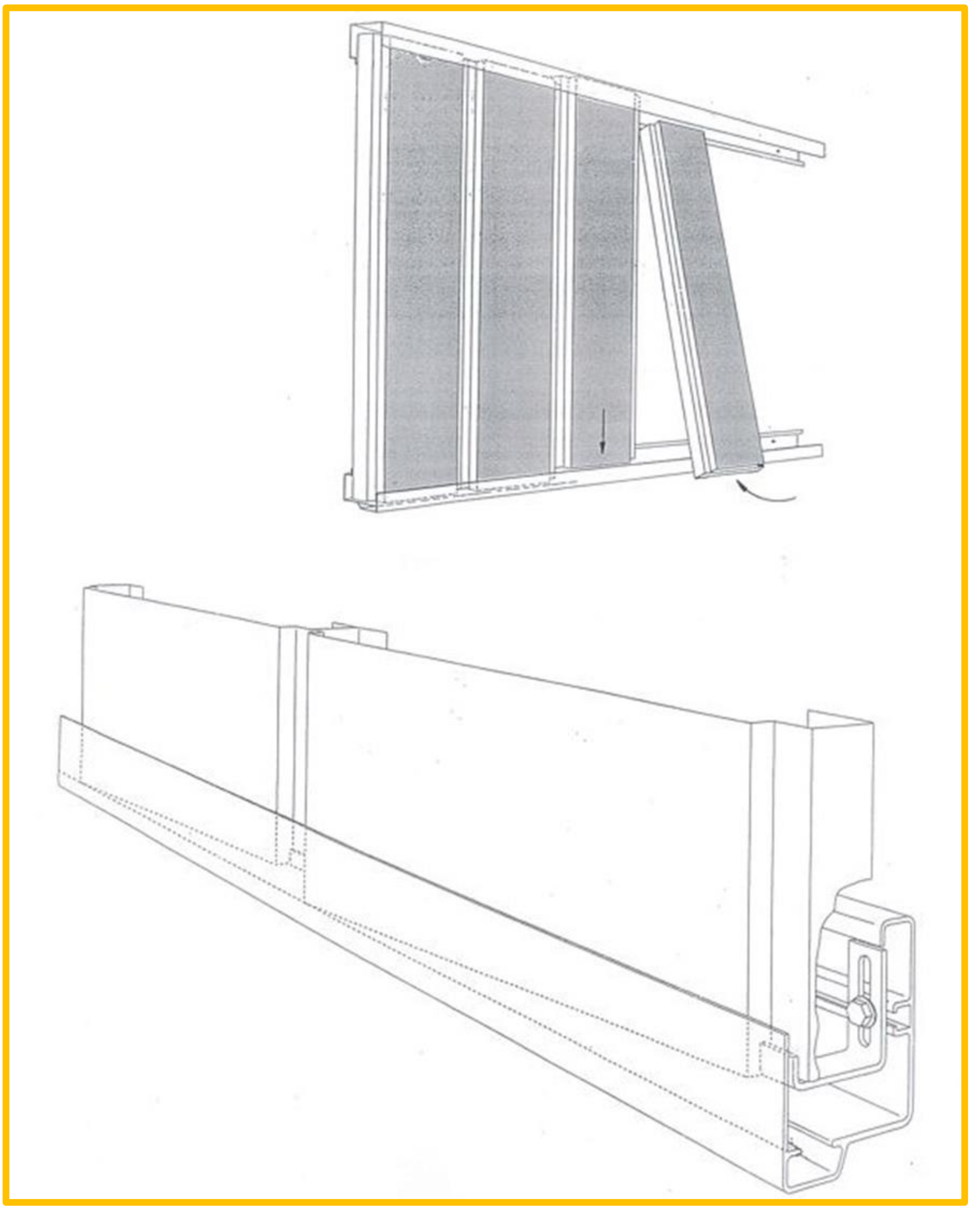


*Fig. 6 Details of the installation of absorbent claddings with lightweight panels*

- For the same type of cladding, its acoustic absorbent behavior will be better the more we separate the acoustic panels from the walls, increasing their absorption capacity in the low frequencies of the sound spectrum. Figure 7.

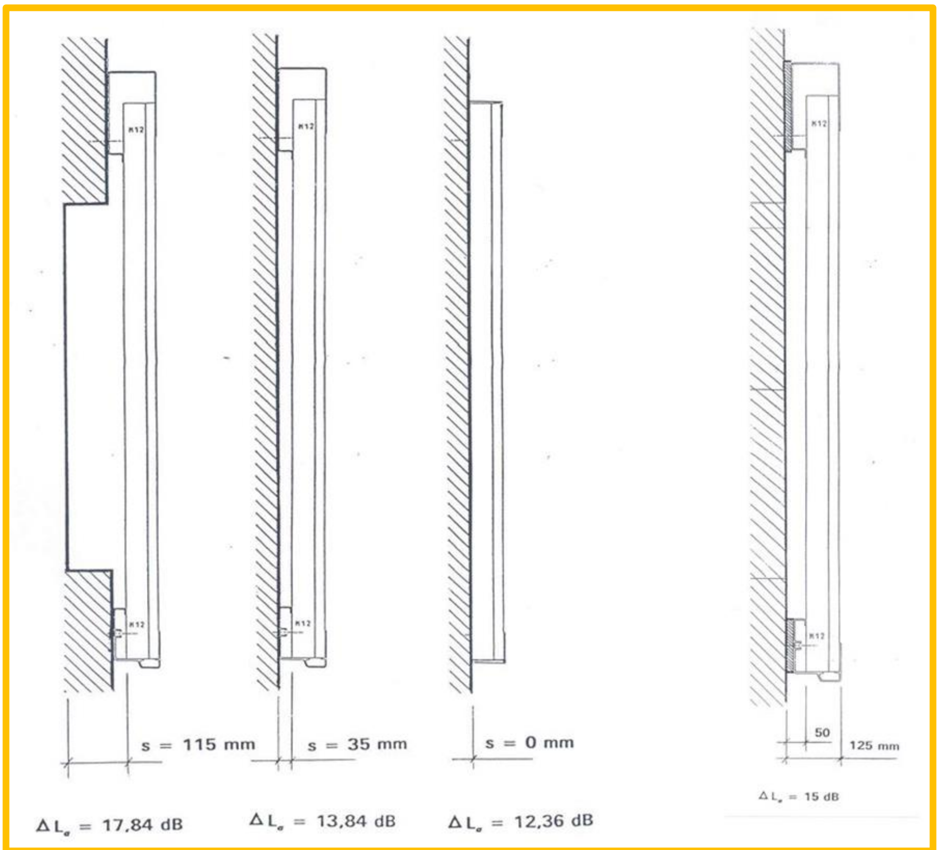



*Fig. 7 Variation of the acoustic absorption coefficient, depending on the separation between panels and walls.*

The types of cladding most frequently used are:

- Metal sheet panels with mineral wool. They are the most versatile and easiest to install. They have a very high acoustic absorption coefficient, $12 \leq DL\alpha \leq 18$ dBA. Figure 8.

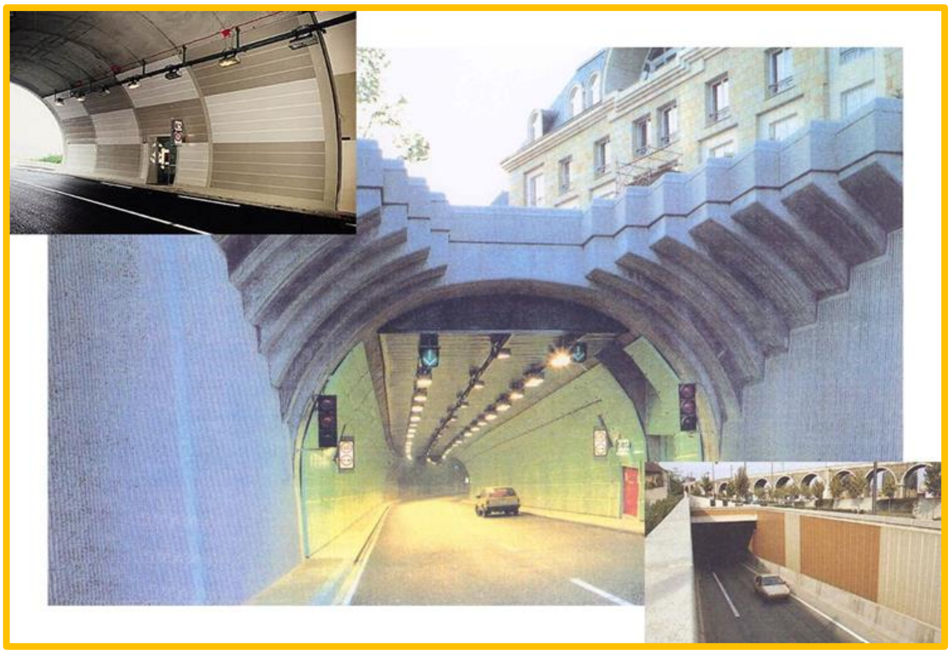


*Fig. 8 Absorbent claddings with metal panels*

- Glass fiber reinforced concrete, GRC panels, with mineral wool. They are heavier and somewhat more difficult to handle than the previous ones. They also have a high acoustic absorption coefficient, 8 ≤ DLα ≤ 15 dBA. Figure 9.

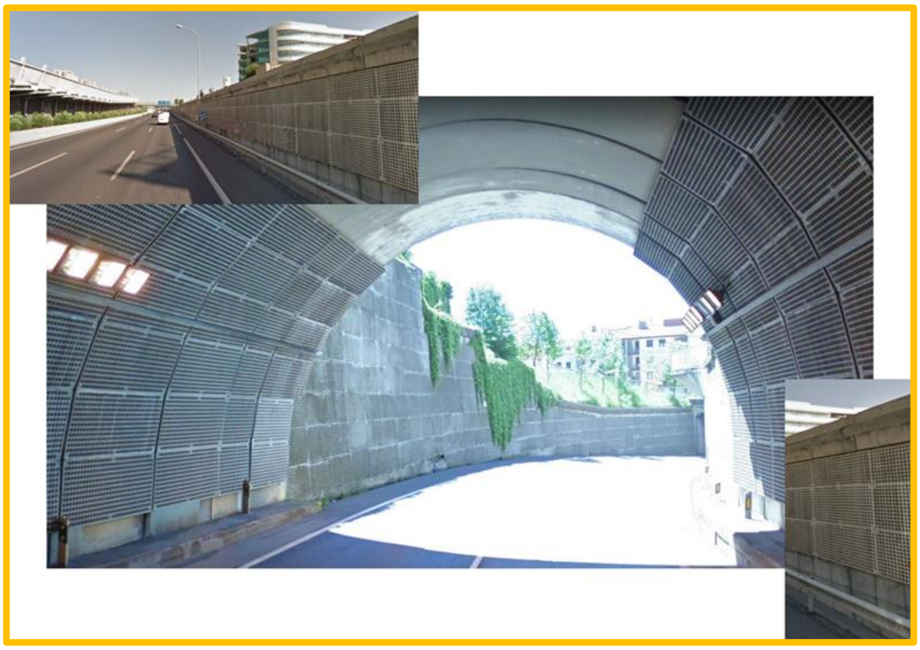


*Fig. 9 Absorbent claddings with GRC panels*

- Porous concrete panels. They are very heavy and much harder to handle than the previous ones. They have a low acoustic absorption coefficient, 3 ≤ DLα ≤ 5 dBA. Figure 10.

*Fig. 10 Absorbent claddings with porous concrete panels*

- PVC recycled panels, with mineral wool. Like metal panels, they are easier to install. They have the disadvantage that their use is restricted to roads and railways open pit trenches that do not have fire resistance requirements as severe as in tunnels. They also have a high acoustic absorption coefficient, $12 \leq DL\alpha \leq 17$ dBA. Figure 11.

*Fig. 11 Absorbent claddings with recycled PVC panels*

- Wood panels with fiberglass. They are also easy to install. It is necessary to pay attention because they have the disadvantage that their use is restricted to roads and railways open pit trenches that do not have special fire resistance requirements. They also have a high acoustic absorption coefficient, $12 \leq DL\alpha \leq 17$ dBA. Figure 12.

*Fig. 12 Absorbent claddings with wood panels*

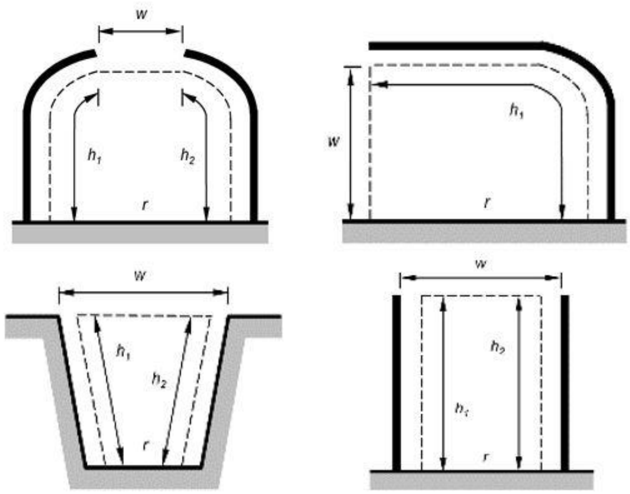
## 4 CEN Standards and regulations applicable to absorbent claddings for open trenches and access to tunnels

Absorbent claddings for transport infrastructures like tunnels and open pit trenches, are noise reducing devices, NRD, that fall within the scope of application of the Construction Products Regulation of the European Union, in the case of roads, and in the Community Directive of Interoperability, in the case of railways.

This means that, in the case of roads in tunnel or open pit trench, in order to install an acoustic absorbent cladding, it must have the mandatory CE marking, according to the harmonized standard CEN EN 14388.

The assessment of the acoustic behavior of the materials, must have been carried out according to the provisions of the auxiliary standards EN 1793-1, EN 1793-2 and EN 1793-3 of the CEN, concerning the acoustic behavior in diffuse field, Figure 13. The new CEN standards EN 1793-5 and EN 1793-6 regarding the use in direct field conditions, do not apply to this case.

**The EN 1793-1 and EN 1793-2 standards are only applicable in tunnels and in cases where it is true that:**




$$e = w + h_1 + h_2$$

$$w / e \leq 0,25$$

*Fig. 13 Definition of diffuse field conditions*

The mechanical behavior of the elements of the absorbent claddings, shall be evaluated in accordance with the appropriate sections resulting from the application of the auxiliary standards CEN, EN 1794-1 and EN 1794-2, as well as their behavior against fire, according to EN 1794-3 and other applicable rules, as the case may be.

Special attention should be paid when the distance between the heavy vehicles that circulate and the absorbent claddings are very small, in order to avoid fatigue failure of the anchor systems of the cladding, due to the dynamic forces generated by the passage of the vehicles.

Other aspects such as long-term behavior (EN 14389-1 and EN 14389-2) should be taken into consideration to evaluate the suitability of the type of coating to be installed in each case.

In the case of railways, the CE marking of acoustic claddings is not required, but their suitability should be assessed by applying the CEN, EN 16272-1, EN 16272-2 and EN 16272-

3-1 standards for the acoustic behavior in diffuse field and the standards EN 16727-1, EN 16727-2-1, EN 16727-2-2 and EN 16727-3 for the mechanical behavior.

## 5 Conclusions and practical recommendations

Both the tunnel effect and the hopper effect of the open pit trenches are the result of the multiple reflections of the sound waves on the existing reflecting walls and cause a significant increase in the noise level.

This increase in noise and consequently the inconvenience for the neighbors of the affected area can be effectively reduced by the use of high quality acoustic absorbent materials on the walls. (The efficacy obtained in practice varies from 3 to 8 dBA).

The effectiveness of the treatment in tunnels grows logarithmically with the tunnel length coated with absorbent. However, for equal acoustically treated surface, it will always be much more efficient to treat the roof and walls of the tunnel than the ceiling only, even if this means a longer treated tunnel length.

The cross section of a tunnel is a critical element in terms of the acoustic impact induced by it, being able to affirm that, if no type of acoustic treatment has been foreseen, a tunnel of large section will be much less noisy and annoying, than a tunnel of small section. However, the use of a good acoustic absorber will make it possible to obtain, for a small treated tunnel length, a similar efficiency whatever the section of the tunnel, but at a much lower cost in the case of tunnels with a small section.

Therefore, in each case, a proper commitment must be sought to obtain, if not the optimum, a high value of the effectiveness/cost ratio.

The double function, acoustics and aesthetics of these coatings can significantly reduce the budgetary increase that would correspond to the acoustic treatment (savings in formwork, finishes, etc.).

All these recommendations should be taken into account when projecting this type of transport infrastructures or remodeling of existing ones.

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