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INCOME EFFECT IN THE RAILWAY GALLERIES

Massimo Coppi[1] and Andrea Venditti[1]

[1]Dipartimento di Fisica Tecnica, Università di Roma "La Sapienza"
Via Eudossiana, 18, 00184, Roma, Italia
massimo.coppi@uniroma1.it

Abstract

A design criterion for a virtual source is presented in this paper that takes into account the increase in acoustic emissions due to the reverberated field that strengthens noise at tunnel entrances.

1. INTRODUCTION

Noise pollution caused by underground railways is particularly felt in open sections close to tunnel entrances. This is due to the fact that acoustic emissions increase near tunnel entrances because of the reverberated field inside the tunnel (income effect); this effect contributes in a substantial way to noise pollution in the surrounding areas. Within reclamation projects, the acoustic impact on open sections close to tunnel entrances must be simulated. In order to characterize the acoustic source it is necessary to consider both direct emissions and the contribution from the reverberated field from inside the gallery. For this reason a simplified method has been introduced based on acoustic and dimensional characteristics of tunnels that allows to take the income effect into account by using an appropriate virtual source. Theoretical results have been confirmed by field measurements.

2. ACOUSTIC SOURCE CHARACTERIZATION

In the classical situation of open sections of railway, noise due to train transit can be approximated by a semi-cylindrical emission from a source having the same geometrical dimensions as the train. When close to tunnel entrances, the total emission consists both of a lateral emission, orthogonal to the railway track, and an axial emission along the track, partly due to the income effect. This effect causes an increase in the strength of the linear source in proximity of the entrances in gallery.

3. ASSESSMENT OF THE POWER LEVEL DUE TO THE INCOME EFFECT

The reverberated acoustic field determines an acoustic intensity J_r on the surfaces that delimit the volume of the tunnel affected by reverberation.

In particular, the part of energy flux directed towards the exterior affects the tunnel entrance.

The reverberated power at the tunnel entrance is equal to:

$$W_r = J_r \cdot S_l \qquad \text{[W]} \qquad (1)$$

Where S_l is the free net entrance cross-section when a train is entering the tunnel. Moreover, the "active" section can be considered to be the entire cross-section of the tunnel since the piston effect due to the presence of possible exiting trains strengthens the reverberating field.

J_r can be determined with a good accuracy with the following:

$$J_r = \frac{4 \cdot 10^{L_W/10} \cdot W_0}{A} \qquad \text{[W/m}^2\text{]} \qquad (2)$$

where:

- L_w is the acoustic power level of the source;
- W_0 is the reference acoustic power = 10^{-12} w;
- A are the equivalent absorption units of the volume of tunnel affected by the reverberation.

The equivalent absorption units (A) can be determined from the characteristics of the reverberating field.

Taking into account the accepted approximations, the Sabine equation can be used to calculate the acoustic intensity of the reverberated field:

$$J_r = \frac{4 \cdot \left(10^{L_W/10} \cdot W_0\right) \cdot T_{60}}{0{,}163 \cdot V} \qquad [\mathrm{W/m^2}] \qquad (3)$$

where:
- V is the volume of the tunnel affected by the reverberation;
- T_{60} is the reverberation time relative to the volume affected by the reverberated field.

The volume of the tunnel affected by the reverberation, which influences the entrance effect, can be determined by finding the distance from the tunnel entrance after which the effects of the free cross-section aren't felt any more. This condition is verified when the lateral surface of the volume affected by the reverberation is much greater than the tunnel cross-section (counted twice since the reverberating volume is bounded by the tunnel lateral surface and by two free cross-sections). This can be expressed as the following:

$$L_i >> D_e / 2 \qquad [\mathrm{m}] \qquad (4)$$

where L_i is the "entrance length" and D_e is the equivalent diameter of the tunnel cross-section.

This condition can occur when:

$$L_i = (8 \div 10) \frac{D_e}{2} \qquad [\mathrm{m}] \qquad (5)$$

Having determined the source acoustic power level L_w and the reverberation time T_{60} measured at the "entrance length" L_i, it is then possible to determine the power level due to the entrance effect with the following relationship:

$$L_{Wr} = 10 \lg_{10} \frac{W_r}{W_0} = 10 \lg_{10} \frac{4 \cdot \left(10^{Lw/10}\right) \cdot T_{60} \cdot S_l}{0{,}163 \cdot V} \qquad [\mathrm{dB}] \qquad (6)$$

4. EXPERIMENTAL VERIFICATION OF THE PROPOSED METHOD

The previously described method has been verified with field measurements on a section of the underground railway system of Rome.

The source power level L_W was calculated as shown in (6) by carrying out SEL measurements on the section at a distance of 5m from the railway.

From the number of train transits, it was possible to determine the equivalent continuous level at a distance of 5 m from the tunnel axis. Having supposed a semi-cylindrical emission and a virtual source on the rail tracks axis, the entrance effect power level L_w was calculated.

The calculation of the "entrance distance" (4) was calculated experimentally by measuring the reverberation times at increasing distances from the tunnel entrance (5m steps). As it can be seen from fig.1, the reverberation time depends on the tunnel opening up to a certain distance, after which it stabilizes itself. Such distance is defined as the "entrance length".

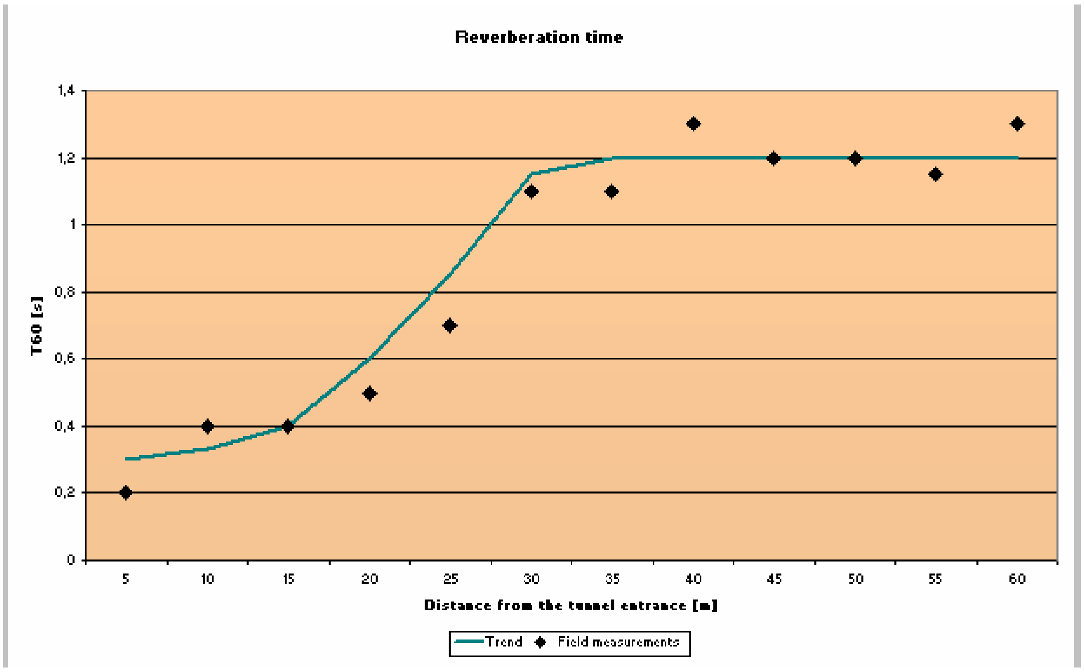

Figure 1 – Reverberation time as a function of the distance from the tunnel entrance.

As can be seen, the experimental "entrance length" is equal to 40 m, very close to the estimated value with equation (5), considering an equivalent diameter De = 7,8 m.

Considering a source power level L_w equal to 94 dBA, a reverberation time T_{60} = 1,2 s, an entrance length L_i= 40 m (the volume affected by reverberation is thus equal to 1.200 m^3) and assuming the free cross-section to be equal to the entire entrance cross-section (piston effect), the entrance effect power level is equal to 92,5 dBA.

The entrance effect was simulated by considering a plane source at the entrance having a cross-section equal to the tunnel cross-section and a power level equal to 92,5 dBA.

Using this power level in a simulation software (Sound Plan), the levels were calculated at a distance of 20 m from the railway axis, along the axis. The results were then experimentally verified. The experimental measurements showed a slight overestimate of the proposed method of 0,5 - 1 dB, being the experimental measurements equal to 70 dBA while the simulation results were 71 dBA.

5. CONCLUSIONS

The proposed method for evaluating the income effect, notwithstanding the theoretical simplifications, was proven by field measurements to be sufficiently accurate.

This method can be readily used for noise pollution forecasts together with simulation software that accepts as inputs the acoustic power levels of the linear source which represents a generic train travelling on a railway track.

6. REFERENCES

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