Sound radiation from railway tunnel openings

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Introduction

In the vicinity of railway tunnel openings people often complain about increased noise levels or a modified sound character compared to free field lines. Whereas for road traffic tunnels [1] it is standard to make the segment close to the opening from absorbing material railway tunnels are usually built without any absorber. To learn more about the emission of railway tunnels, the Swiss Agency for the Environment, Forests and Landscape (SAEFL) initiated a research project. A working group consisting of EMPA and B+S Ingenieur AG is now developing a recipe to calculate the amplifying effect of railway tunnel openings. In addition it is investigated what's the effect of a certain amount of absorption in the region of the tunnel opening. The problem is tackled by theoretical investigations on sound propagation in tunnels and by measurements. The measurements presented here were performed in a scale model and additionally in real situations.

Scale model experiments

In a 1:16 scale model three different tunnel cross sections (double lane with 68 m^2 rectangular, double lane with 66 m^2 circular and single lane with 43 m^2 circular cross section) were investigated. The frequency range in the scale experiments reached from 4 to 32 kHz, corresponding to 250...2'000 Hz. The loudspeaker was built in a model railway from wood. The passage of the train was approximated by a series of discrete source positions. For each source position the impulse response to the receiver microphone was measured. In the impulse response the extra air absorption in the model frequency range was compensated for.

A total of eight receiver points were chosen according to figure 1 and table 1. Note that all dimensions in the text are understood in real life scale.

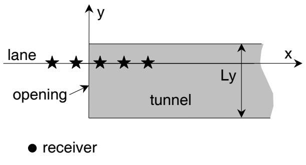

Figure 1: Situation of tunnel and receiver geometry with the coordinate system used. L_y denotes the width of the tunnel, the tunnel opening is at $x = 0$.

Figure 2 shows exemplary results for receiver point 2.

point nr.	x [m]	y [m]	height [m]
1	0	-10	3.5
2	-10	-10	3.5
3	-20	-10	3.5
4	-40	-10	3.5
5	0	-20	3.5
6	-10	-20	3.5
7	-20	-20	3.5
8	-40	-20	3.5

Table 1: Coordinates of receiver points.

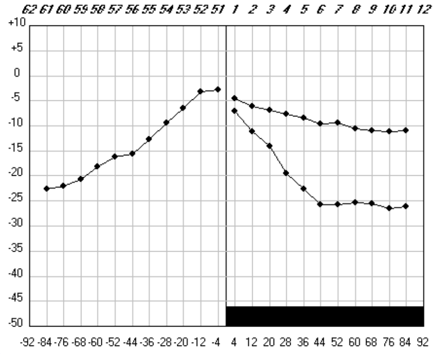

Figure 2: Sound pressure level (ordinate) at receiver no. 2 ($x = -10$ m, $y = -10$ m) as a function of source position along the x- axis (abscissa) for the double lane tunnel with circular cross section. The upper curve in the tunnel section ($\rightarrow x > 0$) denotes the case without absorption, the lower curve is for 30 m absorption along the circumference without the ground surface.

The immission levels from each source position were then summed up to an energy of the event. E_{free} denotes the energy for the section where the train was outside the tunnel. E_{total} stands for the energy of the complete pass-by including the portion coming from the tunnel. As the tunnel in the scale model experiments had a length of only 100 m the level distance functions (figure 2) were extrapolated to 200 m for integration. Table 2 gives the ratios $\frac{E_{\text{total}}}{E_{\text{free}}}$ for all situations investigated. There is good agreement between the scale model experiments without absorption and data of measurements at real tunnels reported by Bartl [2].

A plausible approach to model the sound energy coming from the tunnel is to assume an incoherent area source in the tunnel opening. For distances above about one third of the opening diameter a $-20\log(d)$ point source law can be expected. To investigate this assumption the tunnel energy portions at the receivers were normalized for 1 m values and plotted as a function of angle relative to the tunnel axis (figure 3).

point nr.	TQ01	TQ01-a	TQ02	TQ02-a	TQ03	TQ03-a
1	3.9	0.6	1.1	0.1	4.2	0.4
2	3.8	0.9	2.3	0.3	3.6	0.8
3	1.3	0.4	0.9	0.2	1.3	0.4
4	0.8	0.2	0.5	0.1	0.8	0.3
5	0.6	0.1	0.4	0.0	0.6	0.1
6	3.1	0.7	1.7	0.1	3.2	0.6
7	2.1	0.4	1.3	0.2	2.3	0.4
8	0.9	0.2	0.7	0.1	1.0	0.2

Table 2: Tunnel effect as the energy of total pass-by events relative to the portion coming from the free field section alone in dB(A) for a typical train noise spectrum. TQ01: double lane tunnel with circular cross section, TQ02: single lane tunnel with circular cross section, TQ03: double lane tunnel with rectangular cross section, -a: absorption along the circumference from the opening to a depth of 30 m.

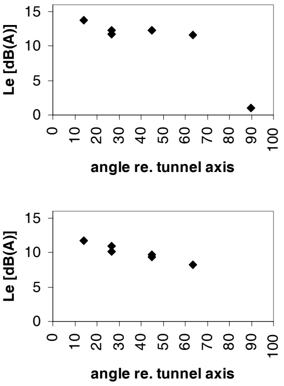

Figure 3: Energy levels of a virtual point source in the middle of the tunnel opening, resulting in the measured receiver energies, plotted as a function of the angle re. tunnel axis. Top: double lane tunnel with circular cross section, bottom: single lane tunnel with circular cross section, both tunnels without absorption. The abscissa is scaled relative to the $-\infty$ to $+\infty$ pass-by energy outside the tunnel at 1 m distance.

From table 2 and figure 3 the following conclusions for the tunnel effect $\frac{E_{\text{total}}}{E_{\text{free}}}$ can be drawn:

- the tunnel effect is largest for receiver points close to the tunnel and reaches up to 4 dB(A)
- both double lane tunnels show similar results in comparison to the single lane tunnel which gives a smaller tunnel effect
- 30 m absorption in the tunnel close to the opening is very efficient as the tunnel effects are reduced to values less than 1 dB in all cases
- for the double lane tunnels there is only a small directivity up to angles of 70°. This finding agrees well with data found at road tunnels by Tachibana [3]. The single lane tunnel shows a more pronounced directivity with a maximum in the direction of the tunnel axis

Real life measurements

A crucial point in the scale model experiments is the question of damping in the tunnel. The surfaces in the model tunnel were made from laminated wood to guarantee low absorption up to high frequencies. The surface of modern real tunnels is usually acoustically hard as well. To validate the scale model experiments a series of measurements at real tunnels were performed. The main attribute that was focused on was the damping per 100 m in the level time (-position) history of a train passage. The measurement positions were chosen according to the geometry of receiver point 2 in the scale model experiments (see table 1).

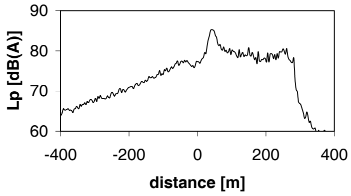

Figure 4: Exemplary real life measurement at a double lane tunnel. The figure shows the sound pressure level as a function of train position (negative values on the abscissa correspond to positions in the tunnel).

Figure 5 shows preliminary results of measured tunnel damping at two different locations. The mean value results in 4.5 dB which compares well with the mean damping in the scale model experiments.

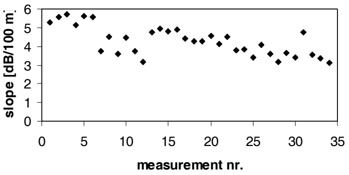

Figure 5: Measured damping in real tunnels in dB/100 m.

Conclusions

The presented investigations led to a large set of measurement data both from scale model experiments and real life situations. The next step will consist of theoretical investigations of the sound field in a rectangular duct and an estimation of the sound radiation from the opening. Preliminary results seem to promise, that a relation between the damping in the tunnel and the directivity of the radiation can be established. The parameters of the theoretical model will then be adapted to coincide with the measurement data. Finally a recipe will be given to calculate the immission at an arbitrary receiver point for a point source inside the tunnel.

References

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