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NOISE FROM ROAD TUNNEL OPENINGS - AN ENGINEERING APPROACH

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1. INTRODUCTION

Tunnels and cut- and cover solutions are increasingly being used to remove traffic noise from residential areas or other noise-sensitive zones. There is a need for an engineering method for predicting noise from tunnel openings. This paper will give a simple theory for predicting noise from tunnel openings and a way to determine the parameters required as input to the model.

2. THE MODEL

Some basic assumptions must be made in all prediction models. This model makes the following assumptions:

- The tunnel may be considered as a uniform circular tube
- The sound power radiated from the tunnel openings is equal to the sound power generated inside the tunnel multiplied by a reduction factor
- The reduction factor is equal to the integral (over the length of the tunnel) of a logarithmic decay function.

This may be summed up in the following equation (eq. 1):

Equation 1

$$P = P_0 \cdot \int_0^L e^{-\frac{4 \cdot \alpha \cdot x}{d}} dx$$

where
The whole integral term is the reduction factor
P is the sound power radiated from the tunnel openings
P_0 is the sound power generated on an equal stretch of open road
α is a parameter which we may call the tunnel absorption coefficient
d is the diameter of a circle with the same cross-section as the tunnel
L is the length of the tunnel
and the x-axis is parallell to the tunnel axis
In equation 1, P_0 is the sound power generated inside the tunnel. The value of P_0 (in dBA, octave or 1/3-octave bands) should be calculated from locally accepted prediction methods. The other parameters are the geometry of the tunnel and α. A possible approach is to use the values for α that this paper gives.
Equation 1 can be simplified to:

Equation 2

$$P = P_0 \cdot \frac{d}{4 \cdot \alpha \cdot L} \cdot \left(1 - e^{-\frac{4 \cdot \alpha \cdot L}{d}}\right)$$

3. DETERMINATION OF THE PARAMETER α

The parameter α, the tunnel absorption coefficient, can be determined by measuring the time history of single vehicles passing through tunnels. This has been done for two Norwegian highway tunnels:

- Ringnes, a blasted hard-rock tunnel, 342 meters long, with a 58 m^2 theoretical cross-section, and a surface of blasted rock covered with PE foam.

- Hamang,a cut- and cover concrete construction, 350 meters long, a cross-section of 46 m^2. The surface is untreated concrete.

In both cases, a tape recording was made with careful note taken of each passing vehicle. The microphones were placed some 20 meters from the tunnel opening. The sound pressure levels are not required to determine α, only the slope of the level versus time as the vehicle progresses through the tunnel. Only the time history while the vehicle is inside the tunnel is of interest.

5 vehicles had an acceptable time history through the Ringnes tunnel, 7 through the Hamang tunnel. From these time histories, the average slope, S_t, in dB/s was calculated in dBA and the octave bands from 63 Hz to 8000 Hz. The change in level per meter of tunnel length, S_l, is then calculated as follows (eq. 3):

Equation 3

$$S_l = S_t / v$$

where v is the speed of the vehicle in m/s.

α can then be calculated using the follwing formula (eq. 4):

Equation 4

$$\alpha = \frac{d}{4} \cdot \ln\left(10^{\frac{S_l}{10}}\right)$$

In table 1 below, the resulting α is given for the two tunnels:

TABLE 1: α, determined from vehicles passing through tunnels

	Frequency (Hz)								
Tunnel(PRIVAT)	63	125	250	500	1000	2000	4000	8000	dBA
Ringnes	0,037	0,081	0,054	0,039	0,048	0,061	0,034	0,015	0,046
Hamang	0,012	0,012	0,012	0,013	0,013	0,017	0,021	0,008	0,015

4. PRACTICAL PREDICTION OF NOISE FROM ROAD TUNNELS

So far, this paper has been consemed with the radiation from and attenuation of sound through a road tunnel. This is not sufficient for practical purposes. There must also be a way to predict noise at immission points near tunnel openings.

One possible way of calculating noise impact near a tunnel opening is the assumption that the total sound power P is radiated equally well from both tunnel openings, and that each tunnel opening can be considered a point source radiating from the centre of the opening.

5. MEASURED VALUES

One test of the method has been Slottsfjellet tunnel in Tønsberg, Norway. In this case, as in many practical cases, the contribution from the open stretch of road is roughly equal to the contribution from the tunnel. In table 2 below, calculated and measured values are given.

Table 2, test of the tunnel model

	Calc. from tunnel	Calc. from open road	Calc. total	Measured
L_{Aeq}	62	63	66	67

6. FURTHER RESEARCH AND VALIDATION

The model described has been in use for several years to predict noise from road tunnel openings. One problem with measurements near road tunnel openings is that there is almost always a component coming from road in the open. This means that a verification of the tunnel model is difficult, as the result is strongly influenced by noise from the open part of the road.
Measurements will be made on other tunnels to get more data on different types of tunnels, including railway tunnels and tests of sound absorbing materials in tunnels. There will also be more investigations into the source description. So far, we have assumed a point source centrally located in the tunnel opening. Quite possibly, a distributed source is somewhat better, although our experinece so far is that the point source is good enough for practical purposes.

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