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STRUCTURE BORNE NOISE FROM TRAINS IN ROCK TUNNELS

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ABSTRACT

A measurement method for maximum structure borne noise is presented, in which the max value is defined as the 95 % confidence value, and a microphone position in a corner is included. Results of measurement of structure borne noise in dwellings from trains in different rocktunnels in the Oslo area is given. Formulae for structure borne noise as a function of distance from track to foundation is presented. The structure borne noise levels is strongly dependent on the stiffness of the track. Stiff track gives high levels. However, the possible insertion loss from ballast mats are much higher on a stiff track than on a "soft" track.

1 - INTRODUCTION

In the Oslo area many tunnels in rock for railway and subway trains is situated below dwelling areas. In some cases the highest structure borne noise levels in the dwellings are in the order of $L_{p,max}$=50 dBA, time constant "fast". In the new building regulations in Norway, the limit for structure borne noise from tunnels is $L_{p,max}$=32 dBA in dwellings.

In this paper are presented results of studies concerning measurement methods, empirical formulae for structure borne noise levels, and the effect of remedial actions.

2 - MEASUREMENTS AND DEFINITION OF MAX LEVEL

The spectrum of the structure borne noise levels often have a high degree of low frequency content. The sound pressure level then varies very much across the rooms, and a number of microphone positions should be used. In a recent Nordtest project, concerning measurements of noise from technical installations in buildings, it was concluded that it is necessary to include a microphone position in a corner, and the "strongest" corner should be found. [1] The inclusion of this corner position will reduce the measurement uncertainty, and improve the correlation to the true room average. If the corner position is not included, there will be a negative bias in the measured mean value for the room. The results of the Nordtest project is expected to be implemented in a new CEN standard on measurement of noise from technical installations.

When the noise is time varying structure borne noise from different trains, it will be complicated and time consuming to find the "strongest" corner. It also is necessary to measure each microphone position at the same time. In order to simplify the measurements, but still include a corner position, the measurement method in ordinary dwelling rooms is defined as follows; The noise level in the room is the mean value of three microphone positions, one of these are in a corner of the room, 0,5 m from the walls, and 1,5 meter above the floor. The two other positions are randomly chosen in the room. They should be located at least 0,5 meter away from the walls, floor and roof. If two channel equipment are used, one position in a corner and one in the room shall be chosen. The mean value is calculated from three values, being the corner, and the room position with double weight.

The noise limit is stated as the maximum level from the train passages. It is necessary to define this maximum level. In a new norwegian standard for measurements of vibration in buildings from landbased transport, the maximum level is defined as a statistical maximum value, being the 95 % confidence value. This implies that there is 5 % probability for a randomly selected passing to give a value that is higher than the statistical maximum value. [2]. This definition also is applied to the maximum structure borne noise level. The statistical maximum structure borne noise level is calculated from:

$$L_{A,str,95} = L_{A,str,mean} + 1.65s \tag{1}$$

The maximum values from each train passage is assumed to be normal distributed. $L_{A,str,mean}$ is the mean value of the measured maximum structure borne noise levels, and s is the standard deviation. At least 10 single passings must be measured. For railway at least 30 % of the passages shall be of the train type that gives the highest levels. In most cases, this will be freight trains.

3 - CALCULATION OF STRUCTURE BORNE NOISE LEVELS

If the vibration level at the foundation positions of the house is known it is fairly simple to calculate the structure borne noise levels in the building, using well known formulae for sound radiation and if necessary thumb rules or theoretical methods for noise reduction per floor. The calculations of the vibration transmission in the rock from the rail to the foundation is more complicated. The finite element – or boundary element method may be used. However, idealized material models for the rock may be very wrong. The rock is often cracked and non homogenous, and the results therefore are uncertain.

We have measured structure borne noise from heavy railway and subway trains in tunnels in the Oslo area. The maximum structure borne noise level, $L_{A,str,95}$ have been measured in rooms in which the floor is founded directly on the rock. Fig. 1 shows measured structure borne noise level from railway. trains.

The vibration attenuation in the rock consists of a geometrical spreading, proportional to $-10\lg d$, and material dissipation, proportional to $-\alpha d$. An empirical formula, plotted in fig 1, for structure borne noise level in dBA as a function of distance, d, for heavy railway is:

$$L_{A,str,95} = 56 - 10\lg d - 0.05d \tag{2}$$

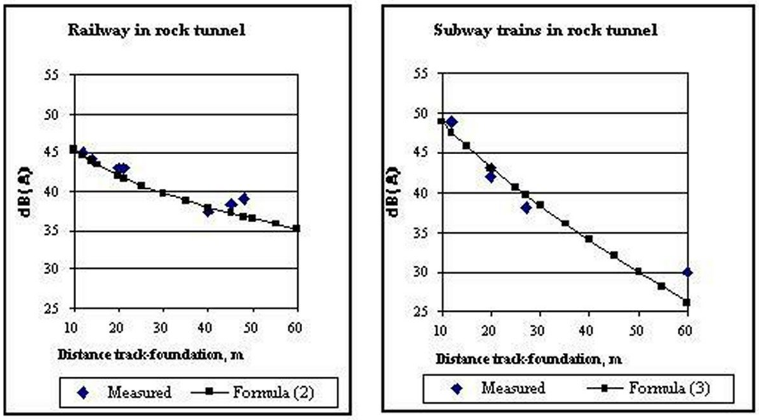

Figure 1: Structure borne noise level, $L_{A,str,95}$ from railway and subway trains.

We also have made similar measurements above rock tunnels for suburban trains. The results are shown in fig. 2a. The empirical formula for structure borne noise level in dBA as a function of distance, d, for subway trains is:

$$L_{A,str,95} = 62 - 10\lg d - 0.3d \tag{3}$$

The dissipation term is different for the two types of trains. This is mainly because the frequency content is different. For the heavy trains the 63 Hz octave band usually dominates in the noise spectrum. This is because of amplification at the resonance frequency for the mass, consisting of unsprung wheelset, rail and sleepers, on a spring, consisting of the sum of elasticity in rail pad, ballast and subgrade. For the subway trains, the 160 – 200 Hz are the dominating bands, even when the distance d is very long. The maximum speed of the trains is 70 km/h. The top in the spectrum is the frequency from corrugation in wheel and/or rail having wavelengths in the order of 80 mm. In addition the resonance frequency is increased to well above 100 Hz because of lighter wheelsets

The dissipation terms in the formulae are empirical values, and is explained not only from the material dissipation. Because of long wavelengths in the rock compared to the tunnel dimensions and distances, the relevance of using a line source model is not complete theoretical correct. In addition the length of the subway trains are not very long compared to the longest distances to the foundations. The dissipation terms therefore is not only because of dissipation, but compensates in some extent for the lack in the geometrical model.

At small distances from the track, wheelflats on freight wagon wheels often gives the highest structure borne noise levels. However a single wheel flat is a point source, at greater distances this noise therefore is less dominating. At short distances the formula (2) may underestimate the structure borne noise levels if very pronounced wheel flats occurs.

4 - EFFECT OF TRACK AND TUNNEL TYPE

A very important factor for the structure borne noise level is the resultant impedance below the rail, Z_{tot}, which is calculated from the expression:

$$\frac{1}{Z_{res}} = \frac{1}{Z_{pad}} + \frac{1}{Z_{bal}} + \frac{1}{Z_{sub}}$$

Z_{pad}, Z_{bal} and Z_{sub} are the impedances for the rail pads, the ballast, and the subgrade. It is essentially the stiffness terms in the impedances which is important.

The results of the measurements which is presented in fig 1 are from old tunnels. The rail pads are stiff, the ballast thickness is often very small, and there is no subgrade between the ballast and the rock. The maximum rail deflection is in the order of $0{,}5 - 0{,}7$ mm. In new norwegian tracks the rail pads are relatively soft, and the ballast layer is at least 600 mm. When the tunnels are build, longer augers are used, so that the rock surface becomes like a sawtooth with about 5 meter length between each tooth. It therefore is a considerable thickness of subgrade between the ballast and the rock. We have recently measured the rail deflection in a newly build tunnel. The mean value of rail deflection for all trains in 24 hours was 1.4 mm, the 95 % confidence value, as defined in (1), was 1,8 mm.

For a linear mass/spring system the force transmitted to the foundation is proportional to 20 lg stiffness. Halving the stiffness should give a 6 dB reduction in noise level. The situation is not that simple, but a considerable reduction could be expected. Measurements above the new tunnel gave about 8 dB lower structure borne noise levels than expected from fig. 1a. The values in fig. 1 and the formulae should be modified for new tracks and new tunnels.

5 - EFFECT OF BALLAST MATS

The structure borne noise level from norwegian tunnels are lower above new tunnels than above old tunnels. However, the effect of ballast mats will be lower in the new tunnels. In [3] is shown in an example that about 10 dB less insertion loss will be obtained from a ballast mat when it is installed on compacted subgrade in above-ground lines compared to installation on a concrete tunnel floor. Similar effects should be expected when ballast mats are installed in some modern rock tunnels. It is of great importance that in the calculations of the insertion loss, the complete impedance for the track before and after installation is considered.

REFERENCES

1. **Christian Simmons**, *Measurements of Sound Pressure Levels at Low Frequencies in Rooms*, NORDTEST Project no 1347-97, SP report 1997-27, Borås, Sweden, 1997

2. **Norwegian Building Standardization**, *Measurement of vibration in buildings from landbased transport and guidance to evaluation of its effects on human beings*, 1999

3. **R.Wettschurec, M.Heim, S.Mühlbacheler**, Reduction of structure-borne noise emissions from above-ground railway lines by means of ballast mats - Analytical model and measurements, *Inter-noise 97 proceedings*, pp. 577-580, 1997