Research for a guideline for low-frequency noise induced by vibrations of underground railways

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SUMMARY

Nowadays, underground construction becomes more important to enable new infrastructure. New tunnel-bore techniques enable the construction to built underground roads and railways near or even below houses and offices in densily packed city areas. Due to the short distance between the buildings and the new tunnels it appears to be important to account for measures to reduce vibrations and low frequency noise. For vibrations design-targets can be based on special standards for vibrations like the dutch SBR and the German DIN4150. However, no adequate guidelines can be found for low frequency noise.

Within the Dutch Centre for Underground Construction (COB) a project is initiated to create a guideline to handle low frequency noise induced by vibrations of underground railways. This was felt necessary to facilitate large projects in the Netherlands like the new subway in Amsterdam (North/Southline), the high-speed train Paris-Amsterdam (HSL) and the new cargo-line to Germany (Betuweroute). The project should give answers to questions for a preferred maximum noiselevel on train passby and an upper boundary when measures to reach the preferred level appear to be too costly. Those levels should be based on knowledge on annoyance by human beings due to this special type of low frequency noise.

The project is splitted in an inventory of available knowledge around the world and research to get more insights on the annoyance in relation to other types of noise. The first results of a literature search and inventory of opinions of several experts in the field will be summarized.

1. Introduction tunnels and low frequency noise

In the Netherlands and anywhere else around the world underground construction is used more often for new infrastructure. This enables double use of available space in crowded cities or can save areas who need protection. New tunnelbore techniques offer, compared to traditional tunneling, opportunities for construction while saving the existing buildings like townhouses and offices.

In the Netherlands new infrastructure is planned with tunnels like:

- North/Southline Amsterdam (subway under old city)
- Betuweroute (cargo-line from Rotterdam to Germany)
- Sytwende tunnel near the Hague (light rail/cars with houses at 1 m from tunnel)
- Traintunnel Delft (with station in center)
- Tunnel High-Speedline South (Amsterdam-Paris).

Those tunnels are planned near to existing houses (North/Southline, Betuweroute, and HSL-South) or will be constructed under new building areas for houses and offices (Sytwende, Delft). This means that adequate measures need to be developed to protect people from unacceptable vibrations or low-frequency noise (induced by the vibrations of walls and floors).

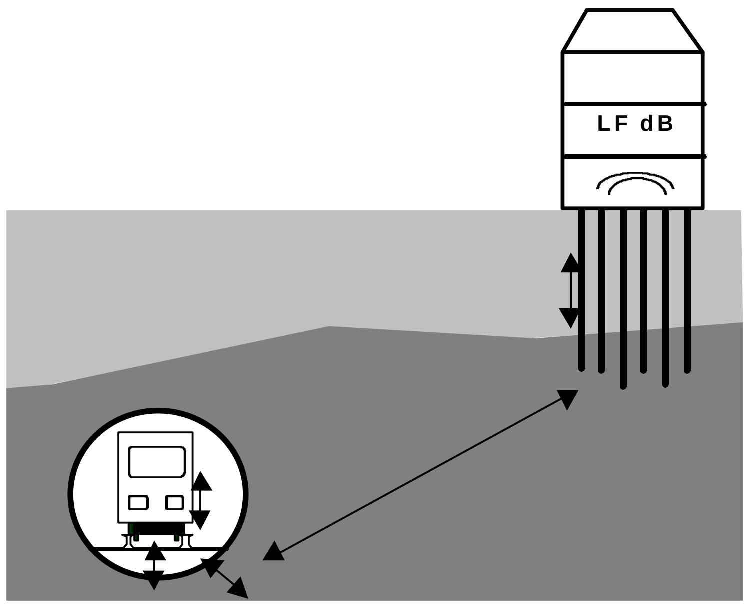

Figure 1 **The passage of a train in a tunnel results in vibration in the subsurface. The vibrations will propagate to the house and can result in an audible low-frequency noise.**

During the design-process of the tunnel it is necessary to account for vibration and low frequency noise. This results in engineering and financial questions like:

- Which measures are needed and/or at best do-able to reduce annoyance for inhabitants.
- How should costs be weighted relative to the target.

In a lot of engineering situations those questions result in an extensive discussion about possible techniques and costs. Costs of possible techniques may differ significant (2-4 times) for a standard construction, embedded rail, track bedding mat or a mass-spring system.

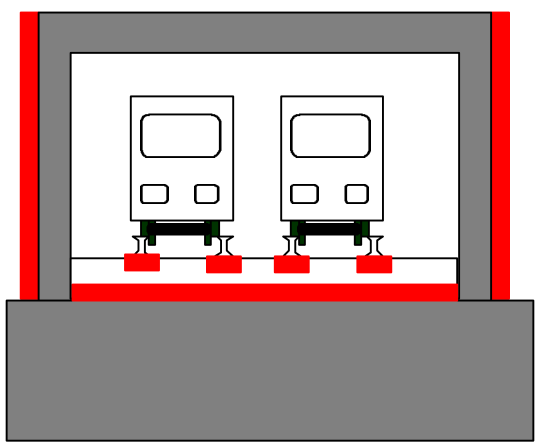

Figure 2 **Attenuation of vibrations of a passing train in a tunnel is possible with measures at the source like the rail, a track bedding mat or by isolation of the wall of the tunnel.**

2. Project D100: Guideline low frequency noise

The project D100 is initiated by the Dutch Center for Underground Construction. The main reason is that practical guidelines or standards for vibrations from railways are made in several countries. However for low frequency noise of underground railways no general or specific standards are available. Also, results of researchwork or expert knowledge can not be found in scientific literature. Although recently, in the Netherlands a guideline has been written for handling of low frequency noise, it does not give specific information of passage noise of trains. This means that it is not easy for project-engineers, consultants or municipalities to set a preferred maximum level for a specific project (figure 3) and weight this level against the cost of measures.

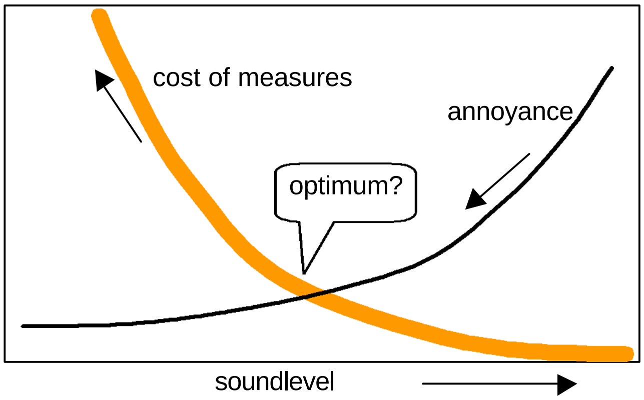

Figure 3 **The reduction of annoyance asks for additional reduction of vibrations with measures. This will add costs to the project. The question is to find an acceptable annoyance level for reasonable costs.**

This lack of guidelines and knowledge leads to the main questions:

- What is an acceptable level for low frequency noise and can something be said on the resulting annoyance at this level?

Subsequent questions are:

- What can be learned from general scientific knowledge concerning background noise?
- Is it possible to find or define a function of the amount of annoyance (mild and severe) dependent on the low frequency noise (thus not steady state)?
- Can a difference in annoyance be found between continuous low frequency noise and passage noise generated by cars or trains?
- What appears to be best engineering practice in the Netherlands and anywhere else around the world?
- Is this based on empirical knowledge or other insights?
- Is it possible to increase knowledge by special audiological listening and annoyance tests with subjects?

The project D100 is split in an inventory of actual knowledge (Phase 1) and further investigations to fill white spots needed to define a good guideline (Phase 2).

3. Results of inventory by specialists

3.1 Impact of low frequency noise

Disturbance by noise may result in annoyance. This annoyance may result in unhappiness and fatigue (especially when sleep is disturbed). Complaints with respect to low frequency noise are mostly described with:

- it is hard to determine directions
- it dominates everywhere in the house
- it can not be ignored
- during nighttime's it is stronger
- the sensibility for the noise raises with time, especially for elderly people.

The sound is not judged as loud, but as striking and intervening. Measurements show levels between 25 and 30 dB(A).

3.2 General accepted noiselevels in the Netherlands

The Dutch law for abatement of noise fixes the standard level for 'ordinary' noise inside a house. For situations with new infrastructure or industry an equivalent noise, inside the living and bedrooms, is set of 35 dB(A) during daytime, 30 dB(A) in the evening and 25 dB(A) during the night. Dependent on the type of noise a penalty can be given for music or impulsive noises. The penalty for music is 10 dB(A) resulting in levels of 25, 20 and 10 dB(A) for day, evening and nighttime. Contrary to this, for railnoise 2 dB(A) higher levels are accepted of 37, 32 and 27 dB(A) for day, evening and night. This is based on statistics showing less annoyance for railnoise than other noisetypes. Nothing is said on noise with low frequency content.

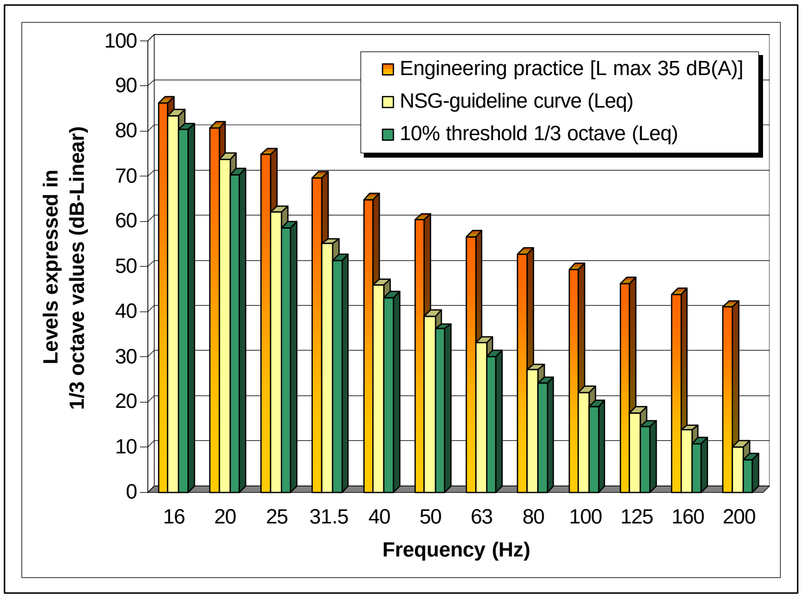

Figure 4 Soundlevels for threshold of hearing (10% group) and NSG-guideline expressed in 1/3 octave band levels. The Lmax 35 dB(A) value (engineering practice see section 3.3) is added as reference and expressed in 1/3 octave bands assuming that the level is determined by the level in one octaveband (correction of -5 dB re 35 dB(A)).

The Dutch Foundation against Annoyance by Noise (Dutch abbreviation NSG) has published a "Guideline Low Frequency Noise". This Guideline is meant as help for measurement and judgement of continuous low frequency noise. In this guideline also levels are given to do a first judgement of the low-frequency noise. Figure 3 gives this curve and also the average threshold for hearing (A-weighting) and the 35 dB(A) level for maximum passages (see next section). All values are expressed as 1/3 octave band levels. The purpose of the low-frequency noise curve of the NSG is to help the acoustician and complainant to decide whether the complaint is originating from an existing 'audible' low frequency noise or is maybe the combined result of other hard to measure noise and an ear disease. The NSG-curve is chosen 2 dB above the threshold of hearing.

3.3 Thresholds in projects

The inventory of the D100-project shows that within most projects and most countries a best engineering approach is used. No standards or guidelines were found. The thresholds are mostly set to a certain value based on a discussion of practical values, best technical means and costs. On the average values are used as summarized in table 1 with a (large) deviation of -5 to +5 dB dependent on the choices made within the project.

Table 1 Summary of maximum thresholds for one passage of a train as used in several projects.

Description	Maximum level for one train passage [dB(A)]	Example
High protection needed	25	Concerthall/studio
Average protection needed	35	House/Hospital
Office	40	Office/Museum
Industry	50	Factory buildings

During the inventory no data were found on annoyance by people exhibited to low frequency noise levels from infrastructure only. Common sense is that annoyance is not so high that it results in complaints. However, from figure 4 it is very clear that for most people one single passage will be clearly audible. Noise from trains has it dominant frequency in the range between 25 and 80 Hz. If an overall level of 35 dB(A) is accepted than it is 20-30 dB above the threshold in this frequency range.

4. Discussion

Based on the results of the inventory it can be concluded that no standards or guidelines are available. The best engineering practice shows values of 35 dB(A) for average protection with thresholds 5 dB up or down. The threshold is mostly set for the maximum level of one train passage (Lmax).
Based on these values it seems to be easy to conclude that a 35 dB(A) threshold appears to be a logical value. However, this is most likely a too simple conclusion for future projects:

- Tunnels are nowadays often constructed near or under existing roads. This means that the low frequency noise is masked by daily car noise. For people living in the houses it is not clear whether they are annoyed by the trafficnoise (cars), which cumulates with the low frequency noise. Any complaints will point towards the car noise without knowing whether it is also triggered by the low frequency noise.
- New tunneling techniques (e.g. tunnel bore method) enable construction of tunnels in residential areas with low environmental sound levels. The passage of a train is not masked and will be clearly audible. The amount of annoyance and eventual complaints will be more clear. Especially, for those people who first slept well in a quiet bedroom but now are awakened by train passages.
- New houses do have a better sound insulation for outside noises. This means that low frequency noise, which is the result of vibrations of the house, will hardly be masked. Expectations on a quiet living or bedroom by tenants are not fulfilled and will result in extra complaints. This is also true for programs to improve sound insulation of existing houses. The noises from daily traffic are reduced, the low frequency noise stays.

From these points it will be clear that better knowledge on annoyance by low frequency noise is necessary for new tunnel projects. Especially for those projects crossing quiet residential areas or nearby houses. It is important to have a better understanding of the impact of low frequency noise on health and chance for annoyance.