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NOISE CONTROL FOR THE VIENNA SUBWAY (SECTIONS UNDERGROUND AND ABOVE GROUND)

J. LANG
VERSUCHSANSTALT FÜR WÄRME- UND SCHALLTECHNIK AM TGM, WIEN

General

The Vienna subway is under construction since 1970. Three lines have been finished until now:

U1 passing under the city north-south, and with tracks above ground in the northern suburbs

U2 underground in the center of the city, parallel to the Vienna Ringstraße

U4 from northwestern suburbs to the western suburbs, using the tracks of the former "Stadtbahn", partly above, partly underground.

At the time being construction work starts on:

U3 underground from the city center to the southeastern suburbs

U6 connected with U4 from western to southwestern suburbs, partly under ground, partly above ground.

Noise control has been started since 1968 with respect to
noise to the environment
- structure borne sound emitted by the tunnel and propagating to adjacent buildings and within these
- air borne noise emitted by sections above ground and propagating to nearby buildings

noise to the passengers
- air borne noise in stations
- air borne noise in the trains.

While U1 passes 10-20 m below the buildings in the city, it passes only a few meters below street level and very near to the buildings (mainly residential buildings) in the southern part. The U2 tunnel is only a few meters below street level and very near to the foundations of the buildings, in some cases passing through the cellars of buildings.

The tracks on elevated structures (concrete) above ground, though in the suburbs, pass residential buildings very closely (at a minimum distance of 30 m).
It was evident, that these conditions need detailed studies of the noise problem, if people alongside the tracks should be protected against noise annoyance.

Structure borne noise

Structure borne noise is the main noise control problem in subways.
A preliminary study of the literature showed, that noise from underground trains passing by may be heard in buildings as far as 20 m from the tunnels with A-weighted sound levels 50-70 dB near the tunnel and 20-40 dB at greater distances (1).

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To design effective measures in an economic way data have to be gathered on
- the vibration levels of the tunnel
- the attenuation of these vibration levels in the ground
- the attenuation from the ground to the building
- the propagation of structure borne sound within the building and its radiation into the rooms.

The vibration level of the tunnel depends on
the tunnel construction (mass, stiffness)
the track support system
the type of train, its weight and its speed
the state of the rails and wheels (corrugation, flat wheels).

The vibration level of the tunnel can be reduced by increasing the mass of the tunnel construction, usually obtained by increasing the thickness (fig. 1) following about

$$\Delta L = 50 \lg \frac{d2}{d1} \quad 1).$$

And it may be reduced by a permanent way on materials with low stiffness.

First measurements were carried out on track models of 10 m length, a second serie of measurements with 10 different test-tracks, each of 100 m length in the Vienna Stadtbahn, comparing the traditional system of rails supported by timber ties in stone ballast with some new constructions without ballast (2). According to the results of these measurements a construction was proposed with rails on polyurethane-sleepers (mainly chosen because of their more precise dimensions compared with timber) in a rubber envelope in a concrete slab floating on a 5 cm mineralwool slab (fig. 2). It was first used in a circular steel-tunnel (U1). The vibration level in the tunnel measured immediately after construction and several years later was the same. The results of measurements in several buildings near the tunnel are shown in the following table.
A house-in-house construction has been used for the tunnel passing through a cellar of a building, with the same track support system.

A small part beneath the river Wien was constructed without mineralwool (all other details unchanged) and gave the possibility to compare the vibration level at the tunnel with and without mineral wool (fig. 3). The level difference shows a resonance frequency of about 20 Hz.

Some years after U1 had been opened U2 was constructed with a rectangular concrete tunnel and rails on the traditional wooden sleepers in stone ballast. As some inhabitants of adjacent buildings complained of noise and vibration the track support system was changed into that used in U1 with concrete floating on mineral wool. This offered the possibility to measure vibration and sound levels with 2 different track support systems (fig. 4). After the resilient track support had been installed no further complaints have been arisen.

1) recent FE-calculations showed that not the mass, but the stiffness increased by increasing the thickness may be the main criterion.

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The results of measurements near the tunnels are shown beneath. General criteria on noise levels caused in dwellings by passing subway trains have not been established. Possibly these should not exceed the background level by more than 10 dB, that means, that in quiet rooms in a courtyard at night the A-weighted levels should not exceed 25-30 dB. Experience shows, that people complain on levels above 30 dB.

buildings	vibration of[0)] the floor	A-weighted sound level (dB)
residential building brickwork with wooden floors 0,5/6 m[1)] from tunnel (steel tunnel)	not sensible	22 - 24
residential building brickwork with wooden floors 1-10/0 m from tunnel (rectangular concrete)	not sensible[2)]	22 - 25[2)]
residential building brickwork with wooden floors 13-20/0 m from tunnel (rectangular concrete)	not sensible[3)]	not to be heard[3)]
residential building brickwork with wooden floors 0/6 m from tunnel (steel tunnel)	not sensible - just sensible	20 - 26
building with concrete skeleton heavy concrete floors 3,3/5,2 m from tunnel (steel tunnel)	not sensible	not to be heard
state opera building 0/8 m from tunnel (steel tunnel)	not sensible	14 - 22 in the rooms nearest to tunnel auditorium 17-20

0) using the scale defined in ÖNORM S 9001

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1) The first number gives the horizontal, the second number the vertical distance from the foundations to the tunnel

2) Before change to floating slab on mineralwool 26-30 dB and weakly sensible

3) Before change to floating slab on mineral wool 33-37 dB and sensible.

Care has to be taken that the high airborne sound level in the tunnel does not cause vibration levels in the tunnel wall higher than those caused by the structure borne sound via a resilient track support system.
The influence of the train speed varies with different resilient layers (because of non-linearity) from 3-7 dB increase per doubling of speed, 5 dB is used in our calculations.
Corrugations in rails with curvature were found to increase the noise in adjacent buildings up to 10 dB.

The propagation of noise and vibrations within the buildings is tested by excitation in the basement with a pneumatic hammer or shaker.
Measurements with the passing train and with the shaker excitation in one building compared quite well. It turns out, that the vibration levels decrease only by 1 dB/story or even not at all.
The level decrease with distance from tunnel is calculated only with 3 dB/dd with no additional attenuation in the most important low frequency range.

Airborne noise

For tracks above ground on elevated structures airborne noise has to be considered. The following criteria have to be fulfilled (generally used for new noise sources in a given environment):
L_{eq} with the train noise should not exceed the background level by more than 10 dB or should not exceed the already existing L_{eq}, if this already is higher; the maximum level should not exceed the background level by more than 40 dB daytime and 30 dB nighttime, and at any rate not exceed 75 dB daytime and 70 dB nighttime. For these limits and the emission levels of the trains (fig. 5) it turns out, that noise control measures (i.e. screens) are necessary to protect residential dwellings.

A first test was carried out with a 100 m test screen alongside a tram-track. The results showed, that screens alongside railways are only effective if they are highly absorbing (fig. 6).
A construction therefore was proposed of of concrete screens in Γ shape with absorbing mineralwool, 4 cm thick, covered with perforated metal. Calculations showed, that the screen must have a height of 1,35 m above rail and that a screen has also to be installed between the two tracks (1,09 m above rails). The first line with screens was constructed in the south of Vienna (now tram, but planned for subway); sound level measurements on 11 measuring points with passing trains before and after installation of the screens showed that the A-weighted levels were reduced by 6-15 dB in a distance of 20 and 44 m of the track and by 6-14 dB at a residential building (23 stores) in 100 m distance (fig. 7). Ul in a northern suburb was installed with the same screens. Measurements showed, that in the dwellings in only 30 m distance the passing train was not to

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be heard within the ambient noise (L_{eq} = 50-55 dB nighttime). Measures against noise in the tunnel and station have been described earlier (2).

(1) J. Lang: Meßergebnisse zum Körperschallschutz für U-Bahnen. 7th ICA-Congress 1971 Budapest, 23 N 10.

(2) J. Lang: Measures against airborne and structureborne noise in the Vienna subway. INTER NOISE 76 Washington.

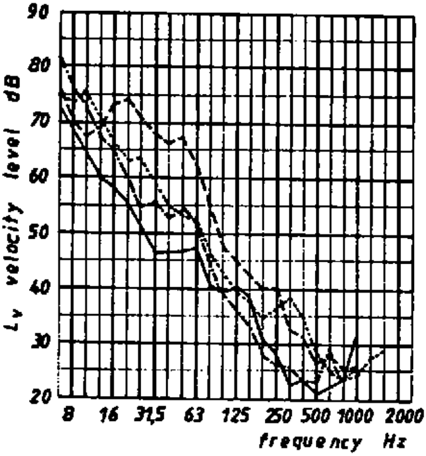

fig. 1: velocity level on tunnel invert,

——— circular concrete tunnel (0,5 m concrete) train speed 80 km/h

·········· circular steel tunnel, outside concrete (850 kg/m²) train speed 80 km/h

—·—·— rectangular concrete tunnel (invert 1,3 m concrete) train speed 80 km/h

– – – – rectangular concrete tunnel (0,75 m invert, 0,3 m sidewall) train speed 40 km/h

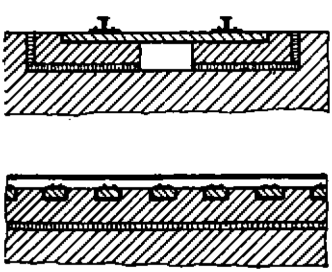

fig. 2: rails on polyurethane-sleepers in rubber-envelope in concrete slab on 5 cm mineralwool-slab

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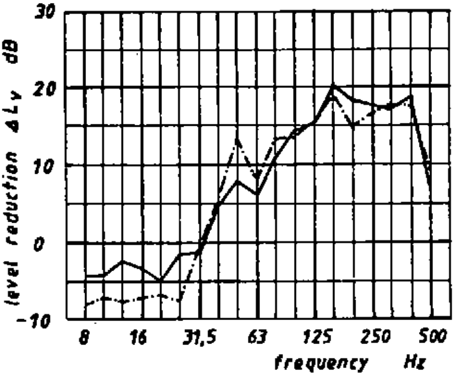

fig. 3: level-reduction in tunnel with mineral-wool below concrete slab compared with tunnel without mineralwool

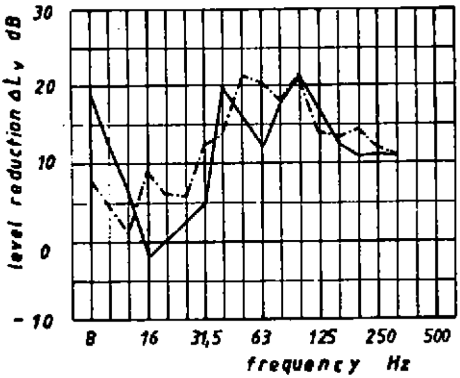

fig. 4: level-reduction on floor in 2 residential buildings near tunnel by changing sleepers on ballast to concrete slab on mineralwool

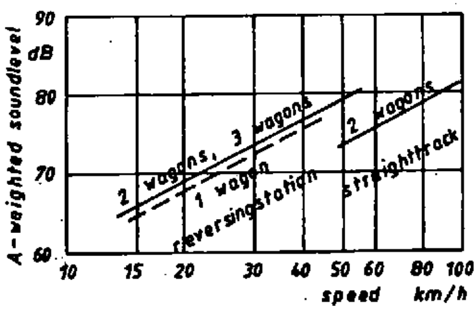

fig. 5: maximum A-weighted sound level, 28 m from track

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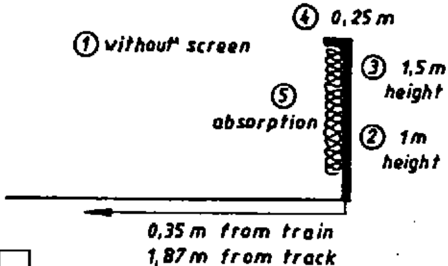
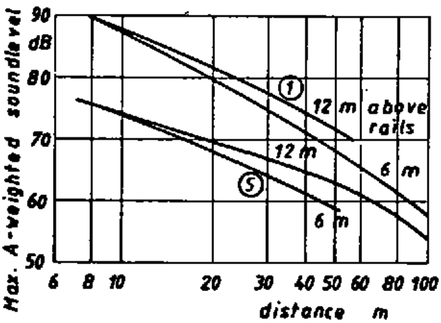
fig. 6: noise reduction by a screen close to the track





L_{max} for 60 km/h

distance	①	②	③	④	⑤
25 m	80	79	80	77	68 dB
50 m	72	70	71	69	63 dB

12 m above rails

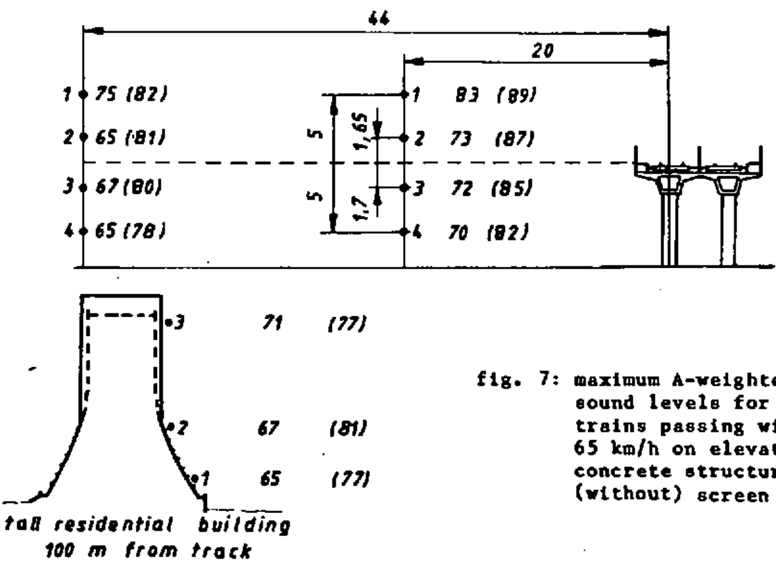


fig. 7: maximum A-weighted sound levels for trains passing with 65 km/h on elevated concrete structure with (without) screen