Track isolation in a light rail tunnel in downtown Berlin

Stephan Achilles[1], Rüdiger G. Wettschureck[2]
[1] *GuD Geotechnik und Dynamik Consult, D-10965 Berlin, Germany, Email: achilles@gudconsult.de*
[2] *Getzner Werkstoffe GmbH, D-82031 Grünwald, Germany, Email: ruediger.wettschureck@getzner-werkstoffe.de*

Introduction

A number of major construction projects are currently being carried out at a site in the center of Berlin (Fig. 1.) Due to the planned utilization of the buildings as high quality hotel rooms, apartments and offices, the comfort requirements are quite high. Unfortunately, however, it was expected that the vibrations and secondary airborne noise emissions from a light rail tunnel located in the vicinity of the structures would cause disturbances. The tunnel, which has four tracks and is heavily used, is located only just a few meters below the surface, immediately adjacent to the basement floors of the planned structures.

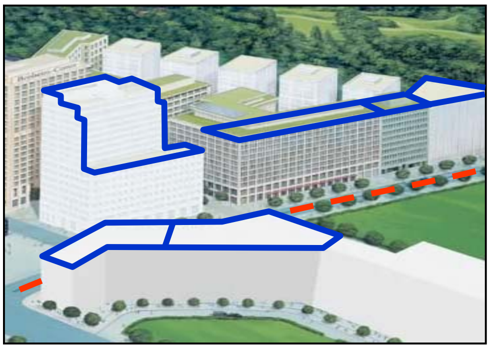

Fig. 1: Construction projects (outlined in blue) on either side of the tunnel (red dotted line). Disturbance due to vibrations and secondary airborne noise emissions was expected. (Figure from [1])

Preliminary studies

When the site was being inspected for construction purposes, the owners commissioned studies to determine the level of vibrations and secondary airborne noise emissions to be expected. Accordingly, the traffic-induced vibrations at the construction site were measured at the planned level of the foundations and at the surface. All of the measurements showed especially high emissions in the 1/3-octave-bands 40 Hz, 50 Hz and 63 Hz, as usual for rail traffic on ballasted track (cf. Fig. 2 left).

In order to make a rough estimation of the building vibrations even before the foundation constructions had been finished, a calculation method from [2] was used. This process is based on mean 1/3-octave-band excitation spectra calculated from a statistically sufficient sample of vibration measurements, charged by logarithmic transmission functions, which contain the spectral changes of the vibrations occurring during the transmission from the subsoil to the ceilings of the structures. Using this method, the transmission functions are varied in such a manner that for natural frequencies, which may occur in the frequency range between 8 Hz and 31.5 Hz, an amplification rate of approximately 12 dB in maximum was assumed. This way the predicted values always reflect the "worst case scenario", i.e. approximate coincidence of the maximum intensities of excitation with the relevant resonances of the structure.

After this, using the spectra of the ceiling vibrations and taking into account stochastic relationships and a room correction factor (cf. [3] e.g.), prognoses for vibration velocities in the floors and for secondary airborne noise in the interior rooms of the structures were derived. While the prognoses for the vibration velocities on the floors of the planned structures were in a tolerable range, with maximum rates of around v = 0,1 mm/s, the mean peak level of secondary airborne noise in the rooms was expected between L_{pA} = 45 dB(A) und 55 dB(A).

Planning the isolation measures

In light of the proposed high quality use of the property these noise levels were not acceptable. Consequently, it was necessary to find suitable measures to reduce the transmission of structure-borne noise. Under the circumstances (five construction projects at various phases of planning and completion, all affected by a single source of emissions), it was decided to undertake measures to isolate the tracks in the tunnel. This solution also enjoyed the advantage that the rail operator was already planning to completely close down the tracks in the tunnel to replace the signaling equipment.

The difference between the projected and required maximum level of secondary airborne noise levels ranged from 15 dB(A) to 25 dB(A). In the 1/3-octave-bands 40 Hz, 50 Hz and 63 Hz, the goal was to achieve a reduction of at least 20 dB. Calculations based on the model described in [4] and the latest field results from another successful project in downtown Berlin indicated that these requirements could best be fulfilled by installing ballast mats, type Sylodyn® CN 235. With a static bedding modulus of 0.02 N/mm³ as per [6], this type of mat is designed for the kind of application in this specific case "Light rail track with speeds up to 120 km/h" and has been developed to meet the most demanding requirements in terms of reducing structure-borne noise. An average value of 0.022 N/mm^2 can be taken as characteristic for the dynamic stiffness of the ballast mat for the frequency range in question, in light of the specific load of roughly 0.06 N/mm^2, which could be expected from the track superstructure and the operation of the light rail trains. Using this value, the insertion loss as per [4] achieved by installation of the ballast mat was calculated.

Installation of the ballast mats

Based on the results of the preliminary studies, it was possible to convince all of the site owners and project managers of six construction projects of the advantages of isolating the tracks with ballast mats and to reach an agreement on the joint financing of the track isolation.

A closure period of eight weeks was available for installation of the ballast mats. Working in day and night shifts, two track construction teams were able to install the mats in 1,080 m of track, including five switches, two crossings and two double crossings. The work involved successive removal of the ballast and ties in roughly 10-20 meters sections of track, exposure of the tunnel floor, installation of the ballast mats and reconstruction of the track. Special problems were posed by the frequent and widely varied irregularities in the tunnel floor, many of which first became visible when the ballast had been removed. In this respect, installation of two layers of ballast mats proved to a great advantage. Due to the separation into the top and bottom mats with thicknesses of 20 mm and 15 mm and staggered installation, full isolation of the tunnel floor was possible even in the most difficult situations.

Effect of the isolation measure

As the rail operator stipulated the closure period, installation of the ballast mats had to be finished when the construction projects just commenced. Hence, it was possible to undertake measurements of the vibrations before and after completion of the track isolation measures especialy in the tunnel. Prior to installation of the mats completed basement levels were accessible for measurements in only two of the construction projects.

The measurements were carried out at seven various locations on the tunnel wall and at three locations in the basement level of one of the structures, using electro-dynamic vibration pick-ups. The time signature of the vibration velocities was measured for approximately 20 to 30 train passages. Following completion of the track isolation measures, a reduction of at least 50% in the previously measured maximum rates of vibration velocity was found at all measurement points.

Using the individual vibration records, 4-second cuts from time signatures with maximum amplitudes and quasi-stationary stochastic signal behaviors were derived as per the recommendations set forth in [7] and 1/3-octave-bands were calculated based on these results.

Typical average 1/3-octave-band velocity spectra are illustrated in Fig. 2 on the left. In the 1/3-octave-bands where the levels had previous been the strongest, a reduction of approximately 20 to 35 dB was found subsequent to installation of the ballast mats. The level differences illustrated on the right in Fig. 2 clearly show the reductions in the level, and further allows for a comparison with previously calculated level of insertion loss.

It is recognizable that the measured reductions in noise level are somewhat higher than the predicted, especially in the very low frequencies. On the one hand, it must be assumed that this circumstance is due in part to the improvement in track geometry after reconstruction and the subsequent tamping and adjustment work, so that a minimal decline in the level differences may be expected in the future.

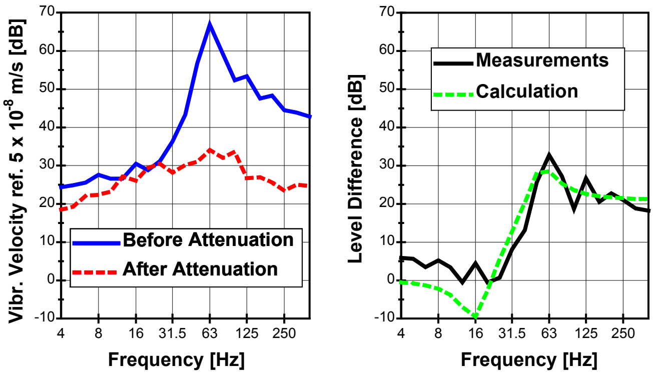

Fig. 2: Average 1/3-octave-band spectra of vibration velocities from the measurements on the tunnel wall before and after installation of the ballast mats (left); measured level differences and insertion loss calculated previously as per [4], on right.

On the other hand, various measurements before and after comparable insulation measures have shown that the level increases in the 1/3-octave-bands of the system resonance of the resiliently mounted track superstructure are smaller in practice than would be theoretically expected. If one takes into account that the natural bending frequencies of ceilings occur in this frequency range in general, one positive effect is that the generally feared excessive increase of floor and ceiling vibrations at their resonances is lower than estimated.

Concluding remarks

Four of the six construction projects on either side of the tunnel have been completed in the meantime. The measurements of vibration and noise levels undertaken up to now have provided results which comply with the owners' requirements in terms of comfort for the buildings' inhabitants. Once again, track isolation with ballast mats has proven itself as a reliable measure for reducing emissions of structure-borne noise and vibrations.

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