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VIBRATIONS IN THE MILAN UNDERGROUND - TYPES OF TRACKS AND TRAIN SPEEDS

G.F. Capponi

Azienda Trasporti Municipali
Foro Buonaparte 61 - 20121 Milano, Italy - Telex 330564 ATM I

INTRODUCTION

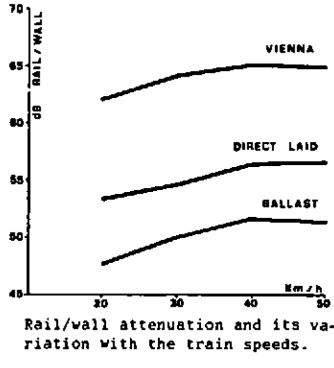
The A.T.M. - Milan Transit Authority - operates 2 Underground lines: 27 km in tunnel + 18 on the surface. In 1978, 1979 and 1982 we performed vibration measurements on different types of tracks and at different train speeds with the aim of comparing the attenuation of vibration velocity between rail foot and tunnel wall.

FIELD MEASUREMENTS

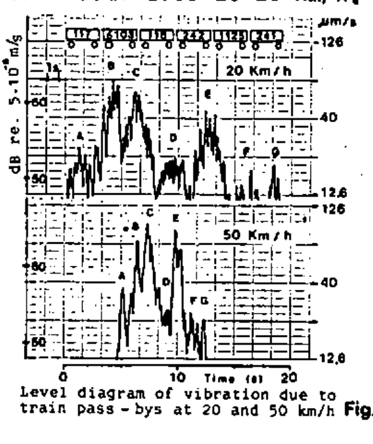
To perform the measurements we followed, as far as possible, UITP standards "Test code for vibration measurement inside Underground tunnels".
On the rail foot a piezoelectric accelerometer was mounted vertically. On the tunnel wall a condenser servoaccelerometer (sensitivity 1 $V/m/s^2$) was also vertically mounted.
We considered measurements along one axis only instead of triaxally, because we found experimentally that in this way an error of only 1 dB was introduced.
For every single track examined, we recorded magnetically the vibrations caused at night by an off duty train running at speeds of 20, 30, 40 and 50 km/h.
For each train speed, on each track we recorded vibrations from several train passages to obtain statistically reliable results.

RESULTS

The acceleration signal has been integrated by a low pass filter with 8 Hz cut-off frequency.
The vibration velocity level has been recorded (integration constant "fast") and for every runby the max. vibration velocity has been determined.
The results of vibration level measurements are summarised on the following diagram. (fig.1).
The ordinate values shown represent the rail/wall attenuation and the abscissae values the various train speeds.
We can see that the attenuation increases, i.e. all tracks perform better when the trains are travelling faster and the vibration is greater.
Yet the 3 examined tracks behave in a quite different way.
We can see that the ballasted track attenuates the vibrations less: this confirms, therefore, that it is inappropriate for application in urban tunnels.
Going from 50 to 40 km/h, the vibration diminishes much less than going from 40 to 30 km/h.
The other figure - see fig.2 - compares the vibration velocity (ballasted track) at 2 different train speeds (20 and 50 km/h).
The peaks have been related to the bogies.
As we can see, the B group, which generated high vibration levels at 50 km/h, keeps the same value also at 20 km/h.

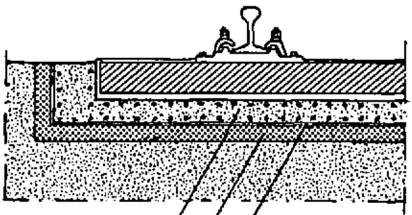


Rail/wall attenuation and its variation with the train speeds. **Fig.1**



Level diagram of vibration due to train pass - bys at 20 and 50 km/h **Fig. 2**

Owing to that the vibration calculated - as we have seen - at the maximum levels of every pass-by, does not diminish appreciably when the train speed falls.
Well maintained bogies (groups D; F; G) generated vibrations about 10 dB lower.
Decreasing the train speed obviously increases the duration of such vibration.
The ballasted track is the one for which the vibration of the train speed influences transmitted vibration least.



This track was demonstrated to be the best among the three examined. Fig. 3

The best track among the examined ones - 64 dB attenuation wall/rail - is the one called "Vienna" - see fig.3 - consisting of polyurethane sleepers wrapped in a layer of rubber resting on concrete slabs. Between these slabs and the invert, a layer of rock wood is interposed.

SPECTRAL ANALYSIS

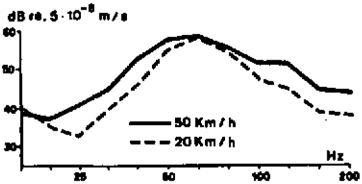
For brevity reasons, we will consider only the one third octave spectrum of the vibration in the ballasted track.
Figure 4 shows, superimposed, the averaged spectra on the wall with trains at 20 and 50 km/h. From each of them the background noise (which had been recorded previously) was subtracted.
As we see, the behaviour remains the same, namely reducing the train speed does not mean translating the spectrum to lower frequencies, but rather to attenuate - nearly uniformly - all the spectral components of the signal.
The highest one third octave band is at 63 Hz, in which the level does not depend on the train speed.
Notice that the highest levels undergo the minimum variation; therefore the overall attenuation of the signal is also relatively small.
The last figure - 5 - shows, superimposed, the functions

$$\frac{\text{vibration on the rail}}{\text{vibration on the wall}}$$

As we can see, the points nearly coincide - in accordance with the theory. Except for the one third octave band at 50 Hz, where at 50 km/h there is a higher attenuation than at 20 km/h. On the other hand also considering the overall value - see fig.1 - we had found that at higher train speeds the tracks attenuate better.

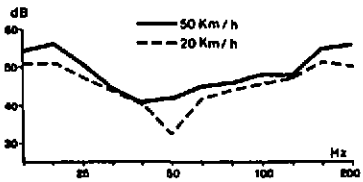
CONCLUSIONS

- Tracks attenuate better at higher train speeds.
- Ballasted track is confirmed as the least suitable for applications in urban tunnels.
- The increase in vibration with train speed is not the same for all tracks; by increasing the train speed from 20 to 50 km/h, the vibration increases between 6.5 dB to 1.5 dB, depending on the track.
- The vibration increase with the train speed is not linear, even on a logarithmic scale.
- If the maintenance condition of the rolling stock is poor, it can cause a vibration increase on the tunnel wall of over 10 dB.
- Reducing train speed does not shift the spectrum components.
- It is wrong to try to reduce vibrations by reducing the speeds of Underground trains.
  The way to follow is, on the contrary, to optimise the maintenance, especially of the rolling stock.



One third octave band spectrum of vibration on the tunnel wall (bal lasted track).

Fig. 4



Rail/wall attenuation at 2 diffe rent train speeds.

Fig. 5