Long-term efficiency of ballast mats installed in the rapid transit railway tunnel near the Philharmonic Hall of Munich, Germany

By
Rüdiger G. Wettschureck ¹, Markus Heim ², Markus Tecklenburg ²

¹) Getzner Werkstoffe GmbH, D-82031 Grünwald
²) Getzner Werkstoffe GmbH, A-6706 Bürs/Bludenz

Presented by
Rüdiger G. Wettschureck

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Historical Background

- At the beginning of the 1980s, the cultural centre “Am Gasteig” was built in the immediate vicinity of the main rapid transit railway line in Munich.
- Besides other facilities, this cultural centre houses a
  - Concert Hall for the philharmonic orchestra and a
  - Municipal Library

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Cultural Centre “Am Gasteig”

Bird’s eye view

(1) Philharmonic Hall
(2) Municipal Library
In particular, the Concert Hall had to be shielded from the structure-borne noise emitted from the railway tunnels. Four solutions have been discussed at that time:

- A room within a room construction
- An elastic support of the entire Concert Hall building
- A 20 m deep slot with an elastic filling between the building and the railway tunnels
- Installation of ballast mats in the two tunnel tubes
Room within a room construction

Elastic support of the entire building
Elastic slot between the building and the tunnels

Mitigation measure close to the vibration source

Installation of Sylomer® ballast mats
Ballast mat installation in 1983 using a specially developed procedure

Results of measurements before / after installation in 1983

Insertion loss of the ballast mat type Sylomer® B 851

Results of measurements before / after installation in 1983

Prediction before installation in 1983, using a "SDOF-model" [published first in Acustica 58 (1985)]
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Background (3)

- Over the last 20 years we gathered very good results and positive experiences using ballast mats in railway lines, especially in tunnels.
- Customers are increasingly requesting additional evidence of the long-term functional suitability of the products installed.
- Excellent opportunity to investigate the long-term properties of Sylomer® ballast mats, taking the type B 851 as an example, in the railway tunnel near the Philharmonic Hall of Munich.
- This tunnel is one of the most heavily used rapid transit lines in Germany, with a daily load level of approx. 150,000 load tons.

Removal of ballast mat samples in December 1999

- Two ballast mat samples with a dimension of approximately 600x1200 mm², were removed from the south tunnel tube.
- Removal in two different areas of track:
  - Area 1: normal ballast thickness ⇒ track curve
  - Area 2: extremely small ballast thickness ⇒ tangent track
Removal of ballast mat samples in December 1999

Removing of the upper ballast mat layer at the outside sleeper space

Visible is the lower layer of the ballast mat
Removal of ballast mat samples in December 1999

View to the area of the removed ballast mat:

Water is visible on the tunnel floor in which the ballast mat was submerged.
Visual inspection of the samples: → results
[Technical University of Munich]

- The load distribution layer, i.e. the protection layer in the contact area against the ballast, is in a very good condition.
- The imprint marks caused by the ballast grains are clearly visible on the surface of the ballast mat samples.
- The pattern of the imprints show that the ballast grains are very well imbedded in the surface of the ballast mat.
- The surface shows slight plastic deformations but no damages, for example like perforations.
- The resilient layers are completely intact as well.

Laboratory tests: static and dynamic stiffness of the removed samples

- The static stiffness (load deflection curve) was measured at the Technical University of Munich (Prüfamt für Bau von Landverkehrswegen).
- The dynamic stiffness was measured by Müller-BBM, on a special test rig using the „direct method“ according to ISO 10846-2.
Laboratory tests: → results

- The nominal requirements from the original tender documentation are still complied with even
- After the ballast mats were subject to more than 760 million load tons during 17 years of use
- For example: the average static bedding modulus obtained from the measurements carried out on the two samples was within the range $c_{\text{actual}} = c_{\text{target}} + 10\%$
- For comparison: Nominal value = $c_{\text{target}} \pm 12\%$

Laboratory tests: dynamic stiffness → results

Specific dynamic stiffness of the ballast mat Sylomer B 851
Static preload: 0.06 N/mm²

Different test samples in 1983, before/during installation

Removed sample after 17 years of use
Test rig for dynamic measurements

Test rig for dynamic measurements of resilient elements according to ISO 10846-2: „Direct Method“
Featuring an Installation for ballast mats

Photo: P. Hofmann, Müller-BBM GmbH

Vibration measurements in the tunnel near the Philharmonic Hall during train operation

- **Inspection** of the boundary conditions, i.e. especially the condition of the rail running surface
- **Serious rail corrugations** were found in some track areas
- **Replacement of the rails** planned by DB AG because of these serious rail corrugations
- „**Preventive**“ grinding of the new rails after replacement
- **Vibration measurements** in the tunnels at „historical“ measurement points carried out by Müller-BBM
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June 2000, before replacement of the rails

Serious rail corrugations in some areas of track

“Short waves”, wave length approx. 8 - 10 cm

“Short waves” on the surface of the low rail in a curve
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![Graph showing deterioration caused by “short waves”](image1)

**Deterioration caused by “short waves”**

- Approx. -20 dB
- 200 Hz

![Graph showing insertion loss of the ballast mats](image2)

**Insertion loss of the ballast mats**

- Approx. +20 dB
- 200 Hz

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May 2001, after replacement of the rails and rail grinding

![Image of smooth rail running surface](image3)

**Smooth rail running surface after “preventive grinding”**
**Measurement evaluation and results**

- Evaluation in an **identical manner as** was carried out in 1983
- **Time frame of 4 seconds** around the maximum point of the time scale of each train passage
- Filtering using digital **1/3-octave-band filters**
- **Integration** to the vibration velocity, **time constant “SLOW”**
- **1/3-octave-band spectra** of velocity levels ⇒ **"Max-HOLD"**
- **Energetic mean value** for all train passages per Mp
- **Comparison** with the corresponding spectra measured before and after the installation of the ballast mats in 1983
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Measurement results
Tunnel North: Mp 7

Area without ballast mat

1/3-octave-band velocity level spectra
- Before
- After
- 18 years after installation of the ballast mat Sylomer® B 851

Area with ballast mat

1/3-octave-band velocity level spectra
- Before
- After
- 18 years after installation of the ballast mat Sylomer® B 851
Measurement results
Tunnel South: Mp 8
Area with ballast mat

1/3-octave-band velocity level spectra
- Before
- After
- 18 years after installation of the ballast mat Sylomer® B 851

Mean velocity level difference
Tunnel North:
Mp 1, Mp 2 and Mp 5

- After installation
- 18 years after installation of the ballast mat Sylomer® B 851, related to the situation before installation, respectively
Mean velocity level difference

**Tunnel South:**

Mp 8, Mp 11 and Mp 12

- After installation
- 18 years after installation

of the ballast mat Sylomer® B 851, related to the situation before installation, respectively

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Formula for calculation of $\Delta L_{eq}$ of a ballast mat:

\[ \Delta L_{eq} = 20 \log \left( 1 + \frac{s_s}{s_M} \right) \left( \frac{f}{f_0} \right)^2 dB \]

Where:

- $s_s$: stiffness of ballast;
- $s_M$: stiffness of ballast mat;
- $f_0$: resonance frequency
- $M$: dynamically effective mass

\[ f_0 \approx \frac{1}{2\pi} \sqrt{\frac{s_s}{M}} \]

[unsprung mass of wheel set plus contribution of superstructure]
Conclusions

- The Sylomer® B 851 ballast mat has performed exceptionally well over a period of 18 years under extremely high operational loads of more than 760 million load tons.
- The stringent requirements set for the reduction of structure-borne noise when the mats were installed in 1983 are still complied with fully.
- Even the fact that the mats were submerged in water, as was found when the samples were removed, had no detrimental impact on the efficiency of the ballast mats.
Conclusions (2)

- The Test Institute of the Technical University of Munich summarises the report on the tests carried out as follows:
  - "...Based on these results, full functionality of the ballast mats can be expected for at least another 30 years, provided that the loads on the mats remain at the same level"
  - "...For further clarification we recommend another removal of samples in about 10 years, or after exposure of another 500 million load tons, respectively"
- Our plans call for complying with this recommendation around 2010 by carrying out the tests described again

Thank you very much for your attention!