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Long-term effectiveness of under-ballast mats confirmed 30 years after installation

In 1983, whilst the "Am Gasteig" cultural centre in Munich, Germany, which, amongst others, houses the concert hall of the Philharmonic Orchestra, was still under construction, under-ballast mats of type Sylomer® B 851 were installed to protect the building from the structure-borne noise emitted from a nearby railway tunnel during the passage of trains. In-depth laboratory tests and in-track measurements, which were conducted after an extremely high traffic loading of 1,300 million load tons over 30 years, have confirmed that the high structure-borne noise insulation requirements that were placed on the mats at the time of their installation continue to be met. Compared to the measurements taken at the time of their installation, the measured characteristics (static/dynamic) have revealed only slight differences, thus supporting the assumption that the under-ballast mats could well retain their effectiveness for another 30 years.

**Dipl.-Geologe
Wolfgang Daiminger
Head of Accredited Noise
Vibration Test Laboratories
Müller-BBM GmbH
Planegg/Munich, Germany**

**Dipl.-Ing. Mirko Dold
Product Manager, Rail Sector
Getzner Werkstoffe GmbH
Bürs, Austria**

In 1983, during night-time traffic shutdown periods, Sylomer® B 851 under-ballast mats, made by Getzner Werkstoffe GmbH, were installed (retrofitted) in both tubes of a railway tunnel near the "Am Gasteig" cultural centre, over a length of 345 m, using a specially developed process [1], [2]. The tender specifications stipulated that the mats were to have a static bedding modulus of 0.008 +/- 0.001 N/mm^3. The superstructure in the tunnel consists of standard ballasted track with type S 54 rails, timber sleepers at 60 cm intervals and, in general, a ballast bed thickness under the sleepers of 30 cm. Until about 2001, the normal traffic load on the superstructure was imposed by type ET 420 light rail vehicles (LRVs), featuring an axle load of 160 kN, and travelling, in the tunnel, with a maximum speed of 80 km/h. Since 2000, the type ET 420 LRVs were gradually replaced by type ET 423 units, with the latter being the only type in use today.

Results of structure-borne noise measurements conducted before and after installation of the under-ballast mats in 1983, in both tunnel tubes and at the construction site of the cultural centre, during the passage of trains, showed a close correlation with the calculated insertion loss of the mats [3], [4], thus confirming that all requirements of the tender specifications had been met. To date, no significant changes in the effectiveness of this particular measure of structure-borne noise reduction have been detected, as has been confirmed by the results of comprehensive laboratory tests and in-track measurements that were conducted to determine the long-term effectiveness of the mats after nearly 30 years of operation, which are presented in the following.

LABORATORY TESTS

In order to investigate the long-term properties of the Sylomer® B 851 under-ballast mats, a sample of the product was taken from the railway tunnel near the "Am Gasteig" cultural centre in August 2012, i.e. 29 years after installation, and after having been exposed to an extremely high traffic loading of 1,300 x 10^6 load tons. The project was commissioned by Getzner Werkstoffe GmbH and supervised by German Rail (DB AG).

The sample was taken from a very specific track section: i.e. at km point 2+560, in a low-lying area of the track, featuring a small ballast bed thickness under the sleepers of approx. 18 cm. The sample taken was approx. 1,200 x 1,200 mm^2 in size (see also Fig. 1).

Fig. 1: Two pictures showing exposed under-ballast mats – on the surface, the presence of water is clearly visible

The sample was subjected to the following tests:

- a visual assessment of the sample was made, which was carried out by the "Lehrstuhl und Prüfamt für Bau von Landverkehrswegen" (Chair and Institute of Road, Railway and Airfield Construction) at the Technical University of Munich (in accordance with DIN 45673-5 [5], after conducting a fatigue test);
- the static stiffness of the sample was measured, and the results were compared with those obtained from the quality inspection conducted during installation of the product in 1983 [6] and when samples were removed in 2001 [7], [8], [9], [10], [11], [12]. The results have been documented in a separate report [13];
- the dynamic stiffness of the sample was determined by means of measurements that were conducted on a test rig at Müller-BBM GmbH, Planegg/Munich [14].

Visual assessment

Because the under-ballast mat sample had been lying in water on the tunnel floor when it was removed (see Fig. 2), it had to be dried before it was tested, so that it would be in the same condition as the samples used during the investigations conducted in 1983 and 2001.

Fig. 2: Presence of water on the tunnel floor

As also reported in [13], the visual assessment yielded clearly visible indentations on the surface of the under-ballast mat sample, caused by the ballast (ballast imprints): the load distribution layer (protective layer in contact with the ballast) was in a very good condition; the ballast grain indentations had caused no damage – there were no perforations (Fig. 3). Also, the pattern of the indentations showed that the ballast grains were very well embedded in the surface of the under-ballast mat. Further, the two resilient layers underneath were also completely intact.

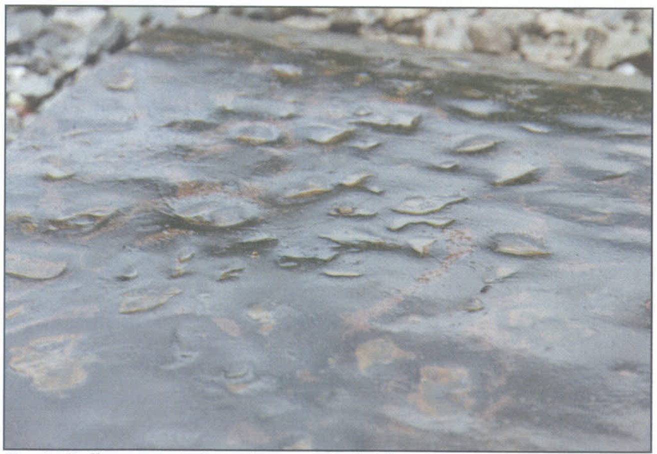

Fig. 3: Ballast grain indentations on the load distribution layer of the ballast mat

Static stiffness

For the static stiffness measurements, which were carried out by the aforementioned testing institute of TU Munich, the static load deflection curve in the load range of up to 0.25 N/mm^2 and at a testing velocity of 0.16 kN/s was determined for a sample 200 x 200 mm^2 in size that had been taken from the same location as the under-ballast mat sample.

In accordance with the special requirements that were defined in the tender specifications for the installation of the under-ballast mats in 1983 – that differ from those defined in [15], from the load deflection curve, a bedding modulus c_{actual} for the sample was derived and compared with the requirements defined in the tender specifications c_{target}. This revealed that the value of the bedding modulus determined from the measurements carried out on the under-ballast mat sample was within those defined in the tender specifications, i.e. $c_{actual} = c_{target} + 0.001\ N/mm^3$. In other words, despite the fact that the under-ballast mats had been exposed to an extremely high traffic loading of 1,300 x 10^6 load tons over 29 years, the target value defined in the tender specifications at the time of their installation was still being maintained.

Dynamic stiffness

The dynamic stiffness of the under-ballast mat sample was determined using the so-called "direct method" as per ISO 10846-2 [16], under the boundary conditions specified in [15] and [17]. The measurement method and the results obtained have been described in [14].

The measured dynamic stiffness value found was slightly lower than that obtained in 2001 [10]. In this respect, it should be noted that the quality assurance requirements associated with the supply of under-ballast mats permit deviations of ± 15% from the specified target value.

The result obtained demonstrates that the dynamic characteristics of the Sylomer® B 851 under-ballast mats have barely changed despite 29 years of extremely high traffic loading. Even the fact that the mats had been lying in water on the tunnel floor, as noted earlier (see also Fig. 2), has not had any negative impact.

Long-term effectiveness confirmed

The results of the laboratory tests have shown that the effectiveness of the structure-borne noise measure installed in 1983 [6] has remained undiminished, given comparable conditions in the tunnel (rolling stock, rail running surface, track stiffness, etc.), see also the table below.

Comparison of static / dynamic characteristics			
	2012	**2000**	**1983**
[1] C_{stat} [N/mm^3]	0.0090	0.0087	0.0083
[2] C_{dyn} [N/mm^3]	0.0392	0.0396	0.0388
[1] evaluated as a secant modulus between 0.01 and 0.02 N/mm^3, third loading, as per tender specifications [2] preload: 0.03 N/mm^2, frequency 20 Hz			

Comparison of results obtained regarding static and dynamic stiffness of the under-ballast mats (1983, 2000 and 2012)

STRUCTURE-BORNE NOISE MEASUREMENTS IN THE TUNNEL DURING THE PASSAGE OF TRAINS

In order to assess the long-term characteristics of the under-ballast mats already identified by the laboratory tests also under "real" rail traffic conditions, it was necessary to carry out structure-borne noise measurements in the tunnel at the measurement points that were installed in 1983.

The technical effectiveness of the under-ballast mats after such a long period under operational conditions was determined and evaluated by comparing the measurement results with those obtained immediately before and after installation of the mats in 1983.

Peripheral conditions of the structure-borne noise measurements

In order to ensure that all the measurements delivered verifiable and reliable results, all the peripheral conditions that could influence the generation of structure-borne noise had to be kept as constant as possible. Since, in practice, this was more or less impossible for many of the parameters (effects of consolidation, water, quality of the sleepers and rail fastenings, etc.), special attention was paid to the condition of the rail running surface – for comparing the measurement results, the condition of the rail was a decisive factor. Studies have shown that short-pitch rail corrugation can increase the level of structure-borne noise by up to 20 dB in the frequency range of about 200 Hz.

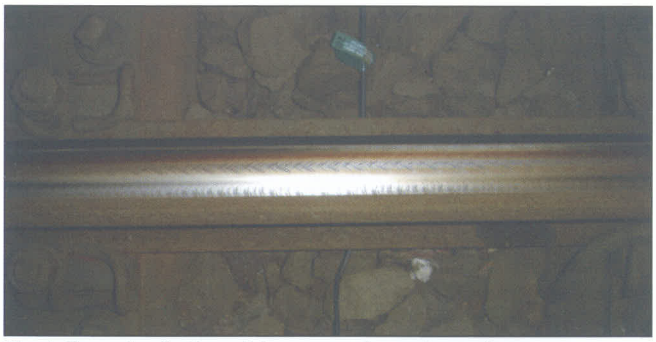

Fig. 4: Example of rail condition – smooth running surface – at the time of the structure-borne noise measurements

In December 2011, when plans for the measurements were drawn up, an inspection of the tunnel was conducted, together with representatives from German Rail (DB AG), in order to determine where the under-ballast mat sample should be removed from. An investigation into the condition of the rails was not deemed necessary at the time, as plans had already been drawn up to replace the rails in some track sections and grind the rails in other sections during the summer of 2012 (the rails in the vicinity of the measurement points were simply ground, not replaced). In Fig. 4, the "smooth running surface" of the rail is depicted (along the outer edge of the rail head, beyond the running surface area, marks caused by the rotating grinding discs of the rail grinding train are clearly visible).

A major change in the peripheral conditions was caused by the complete changeover in the type of LRV operated on the light rail transit network of Munich. When the measurements were made during the installation of the mats in 1983, only type ET 420 LRVs were in operation. However, by the time the measurements in 2001 were conducted, the first few LRVs of type ET 423 had been introduced and, thus, in that year measurements were also conducted during the passage of type ET 423 LRVs; the results obtained, however, were omitted from the overall evaluation in 2001. However, as since the end of 2003, only type ET 423 LRVs have been in operation, the evaluation of the measurement results after 30 years of operation of the under-ballast mats had to be confined to type ET 423 LRVs.

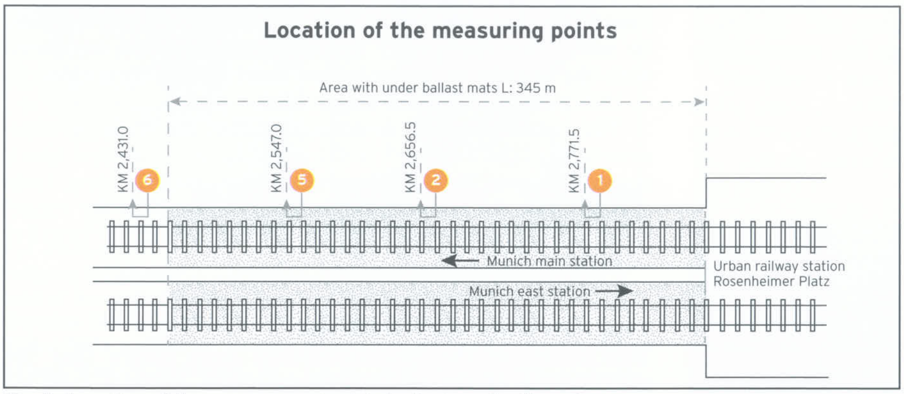

Fig. 5: Location of the measurement points in the tunnel – the noise generated by a total of 34 train passages was measured

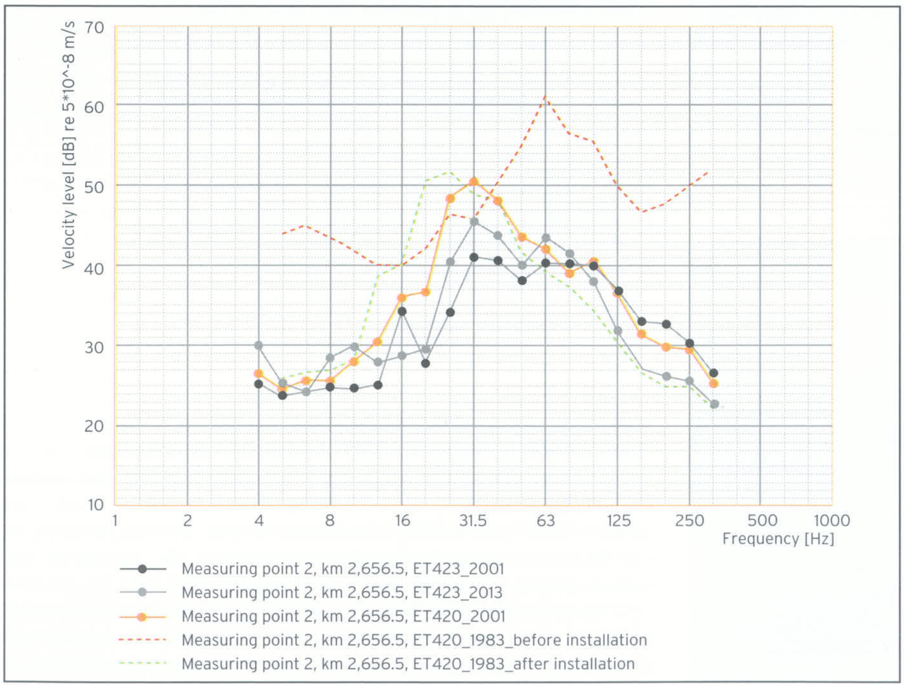

Fig. 6: Measurement results obtained at measurement point 2, before/after ballast mat installation in 1983, as well as those obtained in 2001 and 2013

Measurement procedure

By the end of January 2013, rail grinding was completed and, in May 2013, the structure-borne noise measurements were carried out. Thus, the rail running surface conditions were comparable to those at the time of the measurements immediately before and after installation of the under-ballast mats in 1983, when the rails were also in an optimum condition. Measurements were conducted at four points in the northern tube of the tunnel, i.e. at a selection of the measurement points used in 1983 with the historical designations 1, 2, 5 and 6 (see Fig. 5). Measurement point 6, located outside the area with the under-ballast mats, served as a reference point. It was possible to fit the sensors to the same fastening points that were originally used in 1983 (aluminium plates bonded to the tunnel wall).

Evaluation of measurement results

The individual train passages were evaluated in the form of Max-Hold third-octave spectra (rms, time constant "Slow" 1 second); the evaluation was therefore exactly the same as in 1983 and 2001. For each measurement point, energetic mean values of the Max-Hold third-octave spectra were calculated from the results of the individually evaluated train passages. The velocity level third-octave spectra were shown in the frequency range of between 4 Hz and 315 Hz.

By way of an example, all the results obtained for measurement point 2 were compared: i.e. those before and after installation of the under-ballast mats in 1983, as well as those resulting from the long-term effect measurements conducted in 2001 and 2013 (Fig. 6).

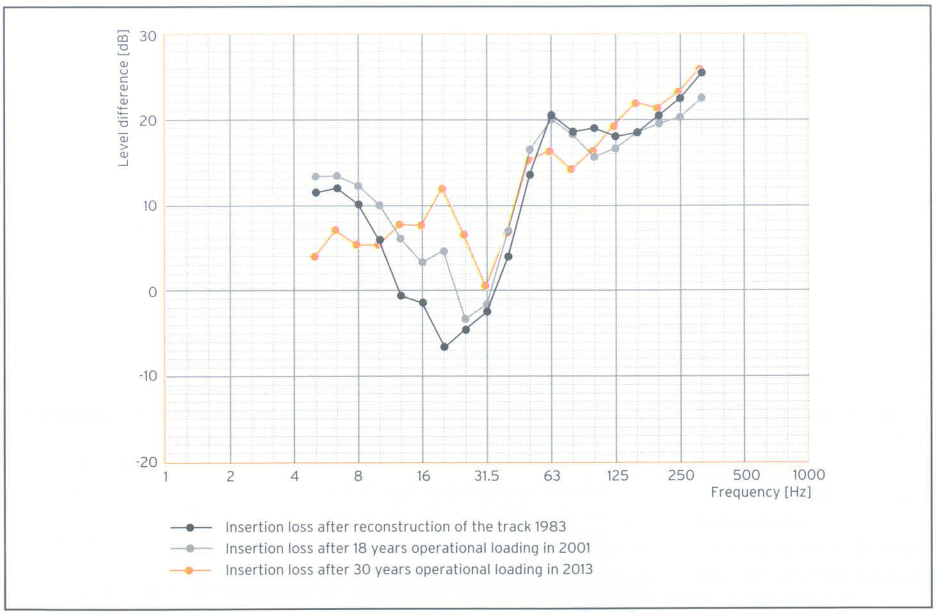

Fig. 7: Calculated insertion loss resulting from measurements conducted during the passage of trains for the years 1983, 2001 and 2013

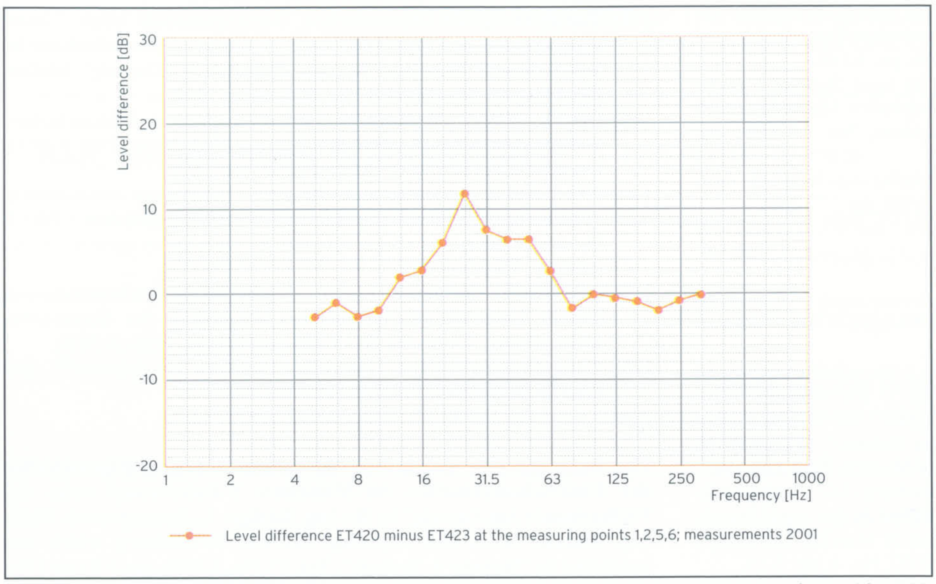

Fig. 8: Calculated mean difference in level obtained for passages involving type ET 420 and ET 423 LRVs

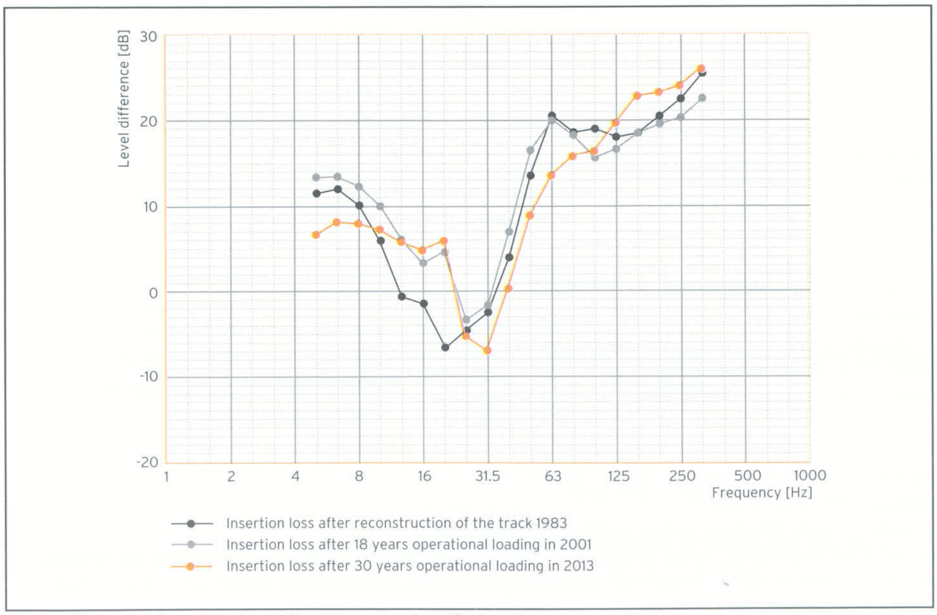

Fig. 9: Corrected insertion loss after 30 years of traffic loading

The effectiveness (insertion loss) of the implemented structure-borne noise reduction measure can be represented by differences in velocity level, which were computed from the difference in results obtained before and after installation of the mats in 1983.

The following velocity level differences for the measurement points in question were calculated, which allowed a comparison of the individual results to be carried out:

— results before installation minus results after installation in 1983;

— results before installation minus results after 18 years of operation in 2001;

— results before installation minus results after 30 years of operation in 2013.

The arithmetic mean of the velocity level differences for measurement points 1, 2 and 5, which were studied in 2001 and 2013, were also compared (see Fig. 7). Positive values indicate a reduction, whereas negative values denote an increase in the level of structure-borne noise, as compared to the original measurement results obtained before installation of the mats in 1983.

When interpreting these results, it should be borne in mind that the measurements of 1983 and 2001 involved type ET 420 LRVs, whereas only type ET 423 LRVs were in use in 2013 (in 2001 also a number of passages involving type ET 423 LRVs were measured, but were not included in the evaluation at the time, as noted earlier).

The results of vibration measurements, conducted on the tunnel wall in 2001 and involving type ET 423 LRVs, displayed lower levels in the frequency range below the 63 Hz third-octave band. In the higher frequency range above the 63 Hz third-octave band, somewhat higher levels for passages involving type ET 420 LRVs were recorded.

From the year 2001 measurements, the differences in level between the results of passages involving ET 420 and ET 423 LRVs were determined and the arithmetic mean was calculated for the measurement points 1, 2 and 5, as well as for the reference point 6.

The diagram in Fig. 8 shows the mean difference in level obtained for the two types of LRV at the respective measurement points. The results of the 2013 measurements were corrected using this LRV type-specific difference in level and compared with those of the 1983 and 2001 measurements (Fig. 9).

CONCLUSIONS

The results of the investigations described in this article have demonstrated that the Sylomer® B 851 under-ballast mat has easily withstood the extremely high traffic loading of more than 1,300 million load tons that was imposed on it during 30 years of operation. The high structure-borne noise insulation requirements placed on the mats at the time of their installation continue to be met. Even water, which was present in the area where the mat sample was removed from, has had no impact on the effectiveness of the under-ballast mat. Similarly, the small ballast bed thickness (18 cm), the resulting higher specific load and mechanical stress also has had no adverse effects.

The investigations have confirmed that the use of Sylomer® B 851 under-ballast mats ensures a consistently high degree of effectiveness. Based on the results of this investigation and the findings of other long-term studies [18], it can be assumed that the under-ballast mats will remain fully functional for at least another 30 years. If the under-ballast mats had not been present, higher operating costs might have been incurred due to a more frequent maintenance of the track; it is even quite possible that the entire superstructure would already have had to be replaced. Thus, in addition to reducing vibrations and structure-borne noise, under-ballast mats also have a positive impact on the life-cycle costs (LCC) of the track.

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