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Mechanical vibration – Resilient elements used in railway tracks – Part 5: Laboratory test procedures for under-ballast mats English translation of DIN 45673-5:2010-08

Mechanische Schwingungen –
Elastische Elemente des Oberbaus von Schienenfahrwegen –
Teil 5: Labor-Prüfverfahren für Unterschottermatten
Englische Übersetzung von DIN 45673-5:2010-08

Vibrations mécaniques –
Éléments élastiques des voies ferrées –
Partie 5: Méthodes en laboratoire pour essayer les semelles pour ballast
Traduction anglaise de DIN 45673-5:2010-08

Together with DIN 45673-1:2010-08, DIN 45673-6:2010-08, DIN 45673-7:2010-08 and DIN 45673-8:2010-08 supersedes DIN 45673-1:2000-05

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Normenausschuss Akustik, Lärmminderung und Schwingungstechnik (NALS) im DIN und VDI
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Foreword

This standard has been prepared by Working Group NA 001-03-15 AA (NALS/VDI C 15) *Schwingungsminderung in der Umgebung von Verkehrswegen* of the *Normenausschuss Akustik, Lärmminderung und Schwingungstechnik* (Acoustics, Noise Control and Vibration Engineering Standards Committee).

It arose from the need to determine in the laboratory the parameters used to describe the static and dynamic properties and fitness for purpose of under-ballast mats on all types of railways and to specify these parameters in product descriptions. The aim is to facilitate the comparison of different products and to enable the calculation of their vibration-reducing or stress-reducing effects.

DIN 45673 consists of the following parts, under the general title *Mechanical vibration — Resilient elements used in railway tracks:*

— *Part 1: Terms and definitions, classification, test procedures*

— *Part 2: Determination of static and dynamic characteristics in the track under operation*

— *Part 3: Experimental evaluation of insertion loss from artificial excitation of mounted track systems (in a test rig and in situ)*

— *Part 4: Analytical evaluation of insertion loss of mounted track systems*

— *Part 5: Laboratory test procedures for under-ballast mats*

— *Part 6: Laboratory test procedures for under-sleeper pads of concrete sleepers*

— *Part 7: Laboratory test procedures for resilient elements of floating slab track systems*

— *Part 8: Laboratory test procedures for continuous elastic rail supports*

— *Part 9: Laboratory test procedures for resilient elements of rail fastening systems and for discrete rail supports*[1)]

Amendments

This standard differs from DIN 45673-1:2000-05 as follows:

a) the scope of testing has been expanded and the test loads have been redefined;

b) information on fitness for purpose and details concerning quality assurance have been included.

Previous edition

DIN 45673-1: 2000-05

1) Under preparation as a supplement to DIN EN 13146-9 which already contains a number of specifications on the determination of stiffness in rail fastening systems.

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1 Scope

This standard specifies laboratory test procedures for determining the parameters used to describe the static and dynamic properties of under-ballast mats.

The main areas of use of under-ballast mats are:

— reduction of vibrations, structure-borne noise and secondary air-borne noise in tramways, underground railways, suburban rapid transit and main-line railway systems;

— reduction of ballast stress at high running speeds on main-line railway lines.

In addition to specifying the basic testing of relevant properties of under-ballast mats, this standard also sets out procedures for testing fitness for purpose and provides information on quality monitoring as part of quality assurance procedures. However, this standard does not contain requirements pertaining to the properties of under-ballast mats.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

DIN 4102-1, *Fire behaviour of building materials and building components — Part 1: Building materials; concepts, requirements and tests*

DIN 45673-1, *Mechanical vibration — Resilient elements used in railway tracks — Part 1: Terms and definitions, classification, test procedures*

DIN 53504, *Testing of rubber — Determination of tensile strength at break, tensile stress at yield, elongation at break and stress values in a tensile test*

DIN 53508, *Testing of rubber — Accelerated ageing*

DIN 53509-1, *Testing of rubber — Determination of resistance to ozone cracking — Part 1: Static conditions*

DIN EN ISO 1798, *Flexible cellular polymeric materials — Determination of tensile strength and elongation at break*

DIN EN ISO 1856, *Flexible cellular polymeric materials — Determination of compression set*

DIN EN ISO 10846-2, *Acoustics and vibration — Laboratory measurement of vibro-acoustic transfer properties of resilient elements — Part 2: Direct method for determination of the dynamic stiffness of resilient supports for translatory motion*

DIN ISO 815, *Rubber, vulcanized or thermoplastic — Determination of compression set*

DIN ISO 1817, *Rubber, vulcanized — Determination of the effect of liquids*

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3 Overview and general principles

Refer to DIN 45673-1 for definitions, symbols, test rig requirements, measurement system requirements, documentation requirements and classification of test procedures.

Under-ballast mats are used to increase resilience between the ballast and the track superstructure on engineering structures such as bridges, track troughs and tunnels. Under-ballast mats reduce vibrations emitted into the environment when the frequency of the vibration lies above the wheel/track resonance frequency. However, when the frequency lies within the resonance frequency range, the vibrations are often amplified. Depending on the position of the resonance frequency and the transmission characteristics of the overall mechanical system, under-ballast mats can reduce vibration immissions and structure-borne noise immissions in the environment, for example within buildings.

Under-ballast mats are mainly used:

— to reduce vibrations, structure-borne noise and secondary air-borne noise;

— to reduce ballast stress at high running speeds.

The first main area of use pertains to tramways, underground railways, suburban rapid transit and main-line railway systems. The use of under-ballast mats to reduce ballast stress is only found on main-line railways at high running speeds.

To guarantee their long-term functionality, under-ballast mats are subjected to defined fitness-for-purpose tests. As under-ballast mats are likely to come into contact with and absorb water once they have been installed, the water absorption capacity of the mats is determined as part of the fitness-for-purpose testing.

4 Under-ballast mats for reducing vibrations, structure-borne noise and secondary air-borne noise

4.1 Static bedding modulus

4.1.1 Bedding modulus C_{stat}

4.1.1.1 General

The parameter C_{stat} is used to estimate the static compression under service loading. C_{stat} can be easily measured either as part of the product qualification process or during continuous quality assurance monitoring of the production process. The static bedding modulus C_{stat} serves as a means of comparing different under-ballast mats. It also prescribes the test load used in mechanical fatigue strength testing and is required for the determination of the dynamic stiffening ratio.

NOTE As the measurement of the static bedding modulus C_{stat} is carried out repeatedly at the loading and unloading rate specified in 4.1.1.2 without any recovery phase, the measured quantity is actually a quasistatic quantity. However, the designation C_{stat} and the manner in which the test is carried out ensure that comparisons can be made with existing product descriptions and earlier test procedures.

Once C_{stat} has been determined and a full recovery phase has been completed, a further load is applied that yields the at-rest value $C_{stat\,0}$ of the static bedding modulus (see 4.1.2). This at-rest value is used to estimate the static deflection under a dead load (e.g. a reference vehicle of known load).

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4.1.1.2 Test parameters

— Dimensions of test object: 300 mm × 300 mm × product thickness. In the case of resilient mats with studs or other geometrically deformable structures, the dimensions of the test object shall be modified accordingly.

NOTE 1 If required by the test rig set-up, test object dimensions of 200 mm × 200 mm are permitted. In that case, this reduced size of the test object also applies to the determination of the dynamic bedding moduli $C_{dyn\,1}$ and $C_{dyn\,2}$.

— Number of test objects: Three

— Conditioning: Test object shall be dry at the relevant test temperature for at least 16 h prior to the start of the test

— Test temperature: (23 ± 3) °C and, if used out of doors, (–20 ± 3) °C

— Manner of load application:

Flat loading plate – Under-ballast mat – Flat loading plate

The loading plate is made of steel with a sanding disc (K120 grit on a rigid linen backing cloth) inserted between the loading plate and the test object.

NOTE 2 Deviations from this specification for the loading plate are permitted for the purposes of quality assurance.

— Applied load (expressed as normal force per unit area) as given in Table 1

NOTE 3 The values in Table 1 take into account the higher levels of mechanical stress experienced by under-ballast mats due, for instance, to reduced ballast bed thickness or shorter sleepers.

Table 1 — Applied loads (normal force per unit area) used in determining the bedding modulus

Range of applied loads	Evaluation range	Example
σ_u = 0,01 N/mm² to σ_o = 0,06 N/mm²	σ_1 = 0,02 N/mm² to σ_2 = 0,05 N/mm²	Tramway[a]
σ_u = 0,01 N/mm² to σ_o = 0,08 N/mm²	σ_1 = 0,02 N/mm² to σ_2 = 0,07 N/mm²	Underground railway[a]
σ_u = 0,01 N/mm² to σ_o = 0,11 N/mm²	σ_1 = 0,02 N/mm² to σ_2 = 0,10 N/mm²	Suburban rapid transit[a]
σ_u = 0,01 N/mm² to σ_o = 0,25 N/mm²	For medium ballast compaction: σ_1 = 0,02 N/mm² to σ_2 = 0,10 N/mm² For high ballast compaction: σ_1 = 0,02 N/mm² to σ_2 = 0,20 N/mm²	Main-line railway[a]
[a] For typical axle loads, see DIN 45673-1.		

The product of the load to be applied σ (expressed as normal force per unit area) and the area of the test object A yields the force to be applied by the test rig $F = \sigma \cdot A$.

— Loading and unloading rate: Continuous, 0,01 (N/mm²)/s

— Number of load cycles: Three.

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4.1.1.3 Procedure and evaluation

Three load cycles shall be applied with no rest period between cycles. Each load cycle shall consist of applying a load that increases from σ_u up to the maximum load of σ_o followed by complete unloading. The third load cycle shall be recorded. Based on the measured deflections s_1 and s_2, the static bedding modulus C_{stat} shall then be calculated in N/mm^3 as the secant modulus between the evaluation range limits σ_1 and σ_2 using:

$$C_{\text{stat}} = \frac{\sigma_2 - \sigma_1}{s_2 - s_1} \quad (1)$$

On main-line railway networks, the static bedding modulus C_{stat} shall also be calculated for the high ballast compaction range.

The difference $s_2 - s_1$ is the difference in the extent of deflection measured for the loads σ_2 and σ_1 during the third load cycle.

The mean average static bedding modulus shall be calculated from the results with the three test objects and reported together with the respective evaluation range given in Table 1. The average characteristic load-deformation diagram shall also be reported for the loading range used.

4.1.2 At-rest value $C_{stat\,0}$ of the bedding modulus

While each test object is still clamped in place and after allowing it to recover for a period of 5 min in its unloaded state, the test object shall be subjected to further loading as follows:

Step 1: Apply load at a rate of 0,01 (N/mm^2)/s until the load σ_1 has been reached; maintain load for a duration of 10 min; record value of s_1

Step 2: Increase load to σ_2 at a rate of 0,01 (N/mm^2)/s; apply load for a duration of 10 min; record value of s_2

The at-rest value of the static bedding modulus shall then be calculated from:

$$C_{\text{stat 0}} = \frac{\sigma_2 - \sigma_1}{s_2 - s_1} \quad (2)$$

For main-line railways, only a value of 0,20 N/mm^2 is used for σ_2.

The final result shall be recorded as the mean average of the results from the three test objects.

4.2 Lower-frequency dynamic bedding modulus $C_{dyn\,1}(f)$ for determining track dynamics

4.2.1 General

The parameter $C_{dyn\,1}(f)$ can be used to estimate the lower-frequency bending deformation of the rail under the influence of the rolling wheel that results from the interplay of the bending elasticity of the rail and the sleeper including ballast.

4.2.2 Test parameters

— Dimensions of test object: See 4.1.1.2

NOTE 1 If required by the test rig set-up, test object dimensions of 200 mm × 200 mm are permitted. In that case, the reduced size of the test object also applies to the determination of the static bedding modulus C_{stat}.

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— Number of test objects:

Tests at room temperature: Three test objects

Tests at other temperatures (see Table 3): One test object

— Conditioning: See 4.1.1.2

NOTE 2 The design of some under-ballast mats and the properties of the materials from which they are made can mean that they will absorb water; see 6.4.2.

— Manner of load application: See 4.1.1.2

— Applied load (expressed as normal force per unit area) as given in Table 2

Table 2 — Applied loads (normal force per unit area) used in determining the lower-frequency dynamic bedding modulus

Load range identical to evaluation range	Example
between $\sigma_u = \sigma_1 = 0{,}02$ N/mm^2 and $\sigma_o = \sigma_2 = 0{,}05$ N/mm^2	Tramway[a]
between $\sigma_u = \sigma_1 = 0{,}02$ N/mm^2 and $\sigma_o = \sigma_2 = 0{,}07$ N/mm^2	Underground railway[a]
between $\sigma_u = \sigma_1 = 0{,}02$ N/mm^2 and $\sigma_o = \sigma_2 = 0{,}10$ N/mm^2	Suburban rapid transit[a]
between $\sigma_u = \sigma_1 = 0{,}02$ N/mm^2 and $\sigma_o = \sigma_2 = 0{,}10$ N/mm^2	Main-line railway[a]
[a] For typical axle loads, see DIN 45673-1.	

The product of the load to be applied σ (expressed as normal force per unit area) and the area of the test object A yields the force to be applied by the test rig $F = \sigma \cdot A$.

— Type of load: Harmonic excitation

NOTE 3 The harmonic excitation has a mean average value $\sigma_m = (\sigma_2 + \sigma_1)/2$ and an amplitude $\hat{\sigma} = (\sigma_2 - \sigma_1)/2$.

— Test conditions as given in Table 3

Table 3 — Test temperatures and test frequencies

Test temperature ± 3 °C	Test frequency
Room temperature (23 °C)	f_j = 5 Hz, 10 Hz, 20 Hz, 30 Hz
30 °C, 0 °C, −10 °C, −20 °C	f_j = 10 Hz

The relevant required temperature shall be continuously monitored and maintained during testing.

4.2.3 Procedure and evaluation

The load shall be reduced to σ_1 for a rest period of about 3 min between the individual test frequencies. Evaluation shall begin approximately 10 s after the application of each dynamic load. Ten complete periods shall be recorded for each frequency and the mean average value computed (see Figure 1). For each test frequency f_j (and test temperature), the lower-frequency dynamic bedding modulus $C_{\mathrm{dyn}\,1}(f_j)$ shall be calculated in N/mm^3 as the secant modulus between the evaluation range limits σ_1 and σ_2 (which are in this case equal to the loading range limits) using:

$$C_{\mathrm{dyn}\,1}(f_j) = \frac{\sigma_2 - \sigma_1}{s_2 - s_1} \qquad (3)$$

The difference $s_2 - s_1$ is the difference in the extent of deflection measured for the loads σ_2 and σ_1.

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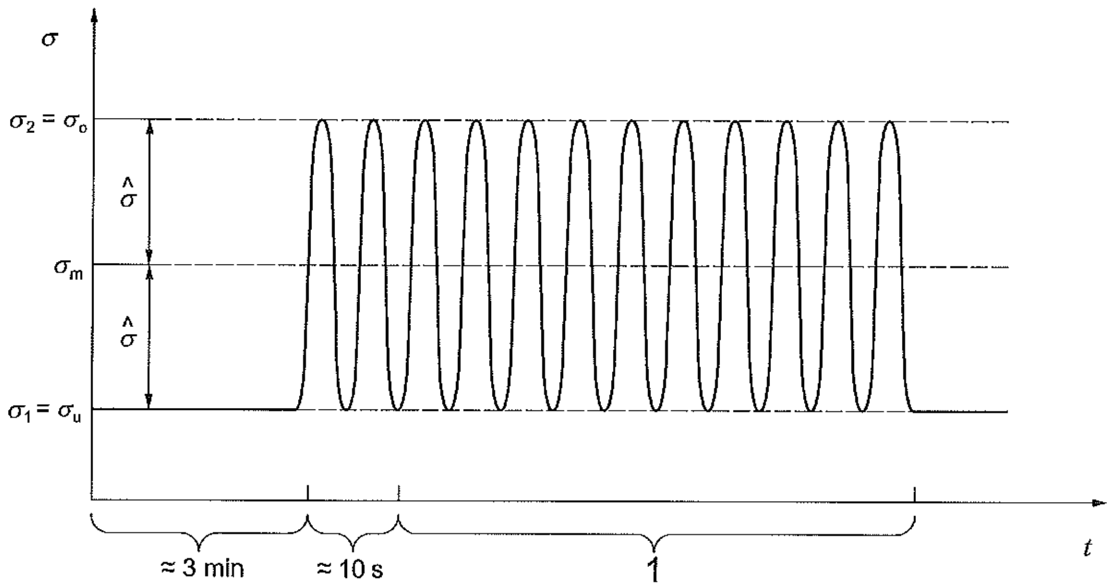

Key

σ_m Mean value of the applied load

$\hat{\sigma}$ Load amplitude

t Time (not shown to scale)

1 Evaluation range covering ten periods

Figure 1 — Test sequence diagram

4.3 Lower-frequency dynamic stiffening ratio $\kappa_{\text{dyn }1}(10\ \text{Hz})$

The lower-frequency dynamic stiffening ratio $\kappa_{\text{dyn }1}(10\ \text{Hz})$ at the test frequency $f = 10$ Hz shall be computed as the quotient of the lower-frequency dynamic bedding modulus at 10 Hz, $C_{\text{dyn }1}$, and the static bedding modulus, C_{stat}, as follows:

$$\kappa_{\text{dyn }1}(10\ \text{Hz}) = \frac{C_{\text{dyn }1}(10\ \text{Hz})}{C_{\text{stat}}} \tag{4}$$

The values of the bedding moduli C_{stat} and $C_{\text{dyn }1}$ shall have been determined on the same test objects. The size of the test object shall be stated together with the lower-frequency dynamic stiffening ratio.

4.4 Higher-frequency dynamic bedding modulus $C_{\text{dyn }2}(f)$ for determining the efficiency of mitigating structure-borne noise

4.4.1 General

The parameter $C_{\text{dyn }2}(f)$ of an under-ballast mat influences the natural frequency f_0 of the elastically supported track as an oscillatory system and thus the insertion loss D_e.

In contrast to the method used to determine the lower-frequency bedding modulus (see 4.2), this test procedure involves static preloading.

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4.4.2 Test parameters

- Dimensions of test object: See 4.1.1.2

  NOTE If required by the test rig set-up, test object dimensions of 200 mm × 200 mm are permitted. In that case, this reduced size of the test object also applies to the determination of the static bedding modulus C_{stat}.

- Number of test objects: Three
- Conditioning: See 4.1.1.2
- Test temperature: See Table 3
- Manner of load application: See 4.1.1.2
- Preloading in three stages:

  $\sigma_v = 0{,}03$ N/mm^2

  $\sigma_v = 0{,}06$ N/mm^2

  $\sigma_v = 0{,}10$ N/mm^2

  The product of the normally aligned compressive pre-stress σ_v and the area of the test object A yields the vertical preloading force to be applied by the test rig, $F = \sigma_v \cdot A$.

- Type of load: Harmonic excitation with a particle velocity amplitude of 7 mm/s (corresponding to a particle velocity level L_v = 100 dB relative to the standard reference particle velocity of 5 × 10^{-8} m/s)
- Test frequencies f_j: 8 Hz to 200 Hz in one-third octave intervals.

4.4.3 Procedure and evaluation

After applying the static preload, the test object shall be subjected to harmonic excitation at each of the test frequencies in succession so that the relative motion between the two loading plates exhibits a constant particle velocity amplitude. Measurements of force and deformation and the determination of dynamic stiffness shall take account of DIN EN ISO 10846-2. The dynamic bedding modulus $C_{dyn\,2}(f_j)$ is the dynamic stiffness determined relative to the surface of the test object. For each test frequency, the arithmetic mean shall be calculated from the individual values for the three test objects.

To demonstrate the possible existence of a significant dependence of the dynamic bedding modulus on the size of the displacement amplitude, at least two values of the dynamic bedding modulus shall be recorded at the test frequency f = 40 Hz, one of which shall have been determined using a particle velocity level whose magnitude was 10 dB lower, i.e. with a particle velocity amplitude of 2,3 mm/s.

4.5 Higher-frequency dynamic stiffening ratio $\kappa_{dyn\,2}$(20 Hz)

The higher-frequency dynamic stiffening ratio $\kappa_{dyn\,2}$(20 Hz) at the test frequency f = 20 Hz shall be computed as the quotient of the higher-frequency dynamic bedding modulus at 20 Hz, $C_{dyn\,2}$, and the static bedding modulus, C_{stat}, as follows:

$$\kappa_{dyn\,2}(20\text{ Hz}) = \frac{C_{dyn\,2}(20\text{ Hz})}{C_{stat}} \tag{5}$$

The values of the bedding moduli C_{stat} and $C_{dyn\,2}$ shall have been determined on the same test objects. The size of the test object shall be included when stating the higher-frequency dynamic stiffening ratio.

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4.6 Loss factor η

4.6.1 General

The magnitude of the loss factor η of an under-ballast mat influences the dynamic magnification in the region of the natural frequency f_0 of the elastically supported track as an oscillatory system and determines the edge steepness of the amplitude response and thus the insertion loss D_e of the overall system. In the tests described below, it is assumed that the under-ballast mat behaves essentially linearly when the vibrational motion is centred around the preload.

4.6.2 Procedure and evaluation

When excitation is harmonic as described in 4.4.2, the loss angle ζ shall be determined as the angular phase shift between the fundamental harmonic component of the applied force and the resulting deformation. The loss factor η can then be determined from $\eta = \tan \zeta$. Evaluation shall be carried out analogously to the method described in 4.4.3.

NOTE The degree of damping ϑ is given approximately by $\vartheta \approx \frac{1}{2} \tan \zeta$.

5 Under-ballast mats to reduce ballast stress at high running speeds

5.1 Static bedding modulus

See 4.1

5.2 Dynamic bedding modulus for determining track dynamics

See 4.2

5.3 Lower-frequency dynamic stiffening ratio

See 4.3

5.4 Horizontal static bedding modulus $C_{\mathrm{stat,h}}$

5.4.1 General

This parameter serves as a means of assessing load dissipation in the longitudinal direction of the track.

5.4.2 Test parameters

- Dimensions of test object: See 4.1.1.2
- Number of test objects: Three
- Conditioning: Dry at test temperature for at least 16 h prior to the start of the test
- Test temperature: (23 ± 3) °C
- Manner of load application: See 4.1.1.2, with upper loading plate displaced horizontally. It is important to ensure that the sanding disc on the loading plates is not displaced.

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— Horizontal load (force per unit area) σ at an applied compressive pre-stress σ_v = 0,012 5 N/mm^2 in accordance with Table 4

Table 4 — Applied load (force per unit area) in horizontal direction

Range of applied loads	Evaluation range	Example
σ_u = 0 to σ_o = 0,007 5 N/mm^2	σ_1 = 0,001 0 N/mm^2 to σ_2 = 0,006 5 N/mm^2	Main-line railway

The product of the normally aligned compressive pre-stress σ_v and the area of the test object A yields the vertical preloading force to be applied by the test rig $F = \sigma_v \cdot A$.

— Loading and unloading rate: See 4.1.1.2

— Number of load cycles: Three.

5.4.3 Procedure and evaluation

Three load cycles shall be applied with no rest period between cycles. Each load cycle shall consist of applying a load that increases from σ_u up to the maximum load of σ_o followed by complete unloading. A period of 5 min between the loading and unloading cycles shall be allowed to enable extensive relaxation of the deformation. The third load cycle shall be recorded and the horizontal static bedding modulus $C_{stat,h}$ of an under-ballast mat then calculated in N/mm^3 as the secant modulus between the evaluation range limits σ_1 and σ_2 using:

$$C_{stat,h} = \frac{\sigma_2 - \sigma_1}{s_2 - s_1} \tag{6}$$

The difference $s_2 - s_1$ is the difference in the horizontal displacements at the loads σ_2 and σ_1.

6 Fitness for purpose

6.1 General

To guarantee the long-term functionality of the under-ballast mats, the mats intended for use shall be subjected to the tests described below. When testing fitness for purpose, the user shall specify which additional properties are to be tested and under which conditions.

Changes in the dynamic properties of the overall system can, however, occur for a variety of reasons, including:

— the manner in which the under-ballast mats were installed during the construction phase;

— entrapment of water, e.g. in cavities or voids;

— railway operations (e.g. accumulation of ballast fines in cavities or voids).

The possible effects of these factors are not examined in the following fitness-for-purpose tests.

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6.2 Mechanical fatigue strength

6.2.1 General

This test, which is carried out as a pulsed-load fatigue test, serves to verify fatigue strength under laboratory conditions by simulating vertical service loading in a ballast trough.

6.2.2 Test parameters

— Dimensions of test object: At least 1 000 mm × at least 1 000 mm × product thickness. The test object shall include one mat joint in the area in which the test load is applied.

— Number of test objects: One

— Conditioning: Dry

— Test temperature: (23 ± 3) °C

— Ballast trough: Minimum dimensions 1 000 mm × 1 000 mm

— Manner in which load is applied in the test rig (from top to bottom, see Figure 2):

Flat, inflexible, circular loading plate (D = 60 cm) that is placed on the upper surface of the ballast layer

New track ballast (class S as per DBS 918 061) is required for each test, i.e. for 12,5 × 10^6 load cycles. After compaction, the ballast shall have a thickness of (30 ± 2) cm.

Steel plate rigidly mounted on a base

— Load given in Table 5 applied normal to surface

NOTE The values in Table 5 take into account unfavourable conditions that might arise from, for instance, reduced ballast bed thickness or shorter sleepers.

Testing shall be performed at two consecutive load levels: 10 × 10^6 load cycles at load level 1 followed by 2,5 × 10^6 load cycles at load level 2.

Table 5 — Load applied normal to the surface during pulsed-load fatigue testing

Static bedding modulus C_{stat} of the under-ballast mat, determined in accordance with 4.1.1 N/mm³	Load level	Upper load F_o in kN (lower load F_u = 10 kN)				Number of load cycles
		Tramway[a]	Underground railway[a]	Suburban rapid transit[a]	Main-line railway[a]	
≤ 0,01	1	50	50	–	–	10 × 10^6
	2	66	66	–	–	2,5 × 10^6
0,02	1	–	56	56	–	10 × 10^6
	2	–	75	75	–	2,5 × 10^6
0,03	1	–	–	56	56	10 × 10^6
	2	–	–	75	75	2,5 × 10^6
≥ 0,06	1	–	–	–	75	10 × 10^6
	2	–	–	–	100	2,5 × 10^6
For intermediate values of the static bedding modulus (e.g. 0,05 N/mm³), the upper load F_o shall be interpolated from the relevant neighbouring values in the table.						
[a] For typical axle loads, see DIN 45673-1.						

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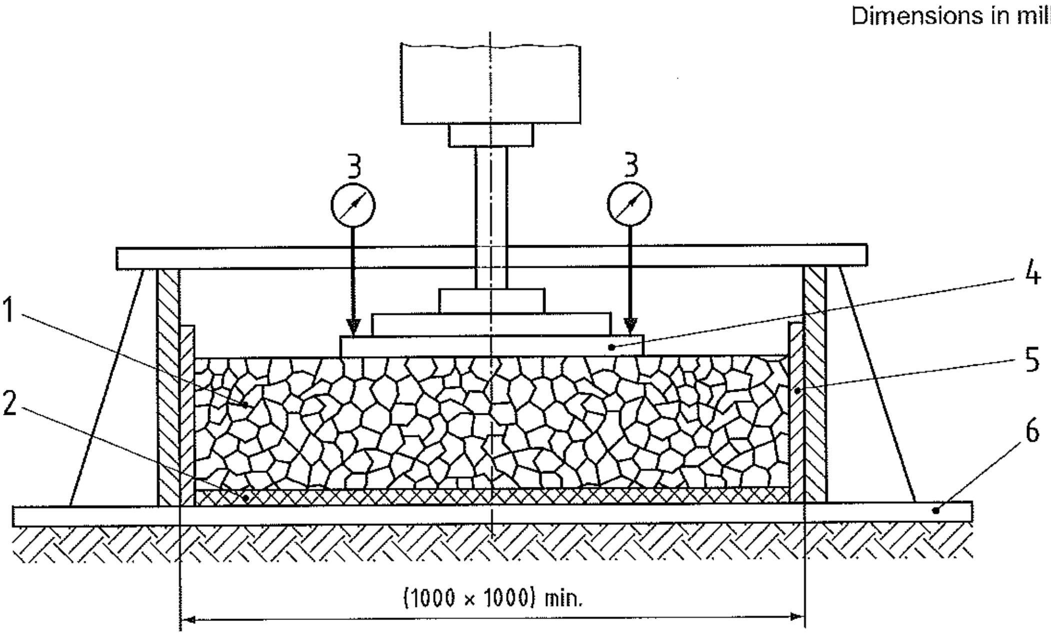
— Type of load: Harmonic excitation with $f \approx$ (3 to 5) Hz

— Test constraint: If the temperature of the under-ballast mats might rise above $T = 40\,°C$, the frequency shall be reduced or the mat shall be cooled to prevent the temperature exceeding $T = 40\,°C$.

6.2.3 Procedure and evaluation

The test shall be conducted in a ballast trough (see Figure 2). The test object (under-ballast mat) shall be placed onto the flat steel plate. Before adding the ballast, the static bedding modulus shall be determined using the circular loading plate and the loads and evaluation range for the third load cycle as given in 4.1.1.2. The ballast shall be poured into the trough, evenly levelled and then compacted using a lightweight plate vibrator (e.g. a steel plate attached to a formwork vibrator) until it has the specified depth. The static bedding modulus shall then be determined on the upper surface of the ballast layer using the circular loading plate and the loads and evaluation range for the third load cycle as given in 4.1.1.2. Harmonic loading shall then be applied at load level 1 for 1×10^6 load cycles.

Dimensions in millimetres



Key

1 Ballast

2 Under-ballast mat

3 Gauge on a rigid reference frame

4 Circular loading plate

5 Elastic liner (rigidity of liner is lower than that of the under-ballast mat to impede ballast creep)

6 Steel plate rigidly mounted on a base

Figure 2 — Test rig set-up with ballast trough

The following quantities shall be recorded and documented during testing:

— number of load cycles;

— average compression set of loading plate as measured at regular intervals by three gauges;

— vibrational peak-to-peak amplitude of the loading plate.

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After completing load level 1, i.e. after 10×10^6 load cycles, the static bedding modulus shall be determined on the upper surface of the ballast layer using the circular loading plate and the loads and evaluation range for the third load cycle as given in 4.1.1.2. The ballast shall then be removed and the static bedding modulus determined on the upper surface of the ballast layer using the circular loading plate and the loads and evaluation range for the third load cycle as given in 4.1.1.2. The mat shall be visually inspected for evidence of perforations, cracks, crushing or other damage If no serious damage is apparent, the experimental set-up shall be reconstructed as described above. After a further determination of the static bedding modulus on the upper surface of the ballast layer using the circular loading plate, the test shall be resumed for $2{,}5 \times 10^6$ load cycles at load level 2.

After completing load level 2, the static bedding modulus shall be again determined on the upper surface of the ballast and (after the ballast has been removed) on the under-ballast mat. The under-ballast mat shall be visually inspected to detect any damage. The percentage change in the static bedding modulus as determined using the loading plate, the vibrational amplitude data during both loading levels, and the result of the visual inspections shall be documented.

6.3 Material identification testing

In order to be able to identify under-ballast mats at a later date, the following values shall be indicated:

— the specific mass of the product and all its components,

— the results of a suitable chemical analysis as selected by the manufacturer.

The values determined in product qualification testing shall act as the reference values for quality assurance and quality monitoring procedures.

6.4 Material and component testing

6.4.1 General

The materials used for under-ballast mats should be resistant to typical environmental influences (e.g. water, ozone, oil). Furthermore, storage out-of-doors should not change the properties of the under-ballast mats. The necessary tests to be carried out shall be appropriate to the materials used (rubber, polyurethane, etc.) in the under-ballast mats. If an under-ballast mat comprises several layers, the layers and, if necessary, the bonding between the layers (e.g. adhesive bonds) shall be tested individually.

6.4.2 Water absorption capacity

As under-ballast mats are likely to come into contact with and thus absorb water once they have been installed, the water absorption capacity of the mats shall be determined as follows and reported as both a percentage by volume and a percentage by mass.

A test object with the dimensions given in 4.1.1.2 is weighed in its dry state (mass: $m_{P,t}$). The test object shall then be completely immersed in distilled water in a trough of mass m_W for a period of 24 h at room temperature (23 ± 3) °C. During the first 2 h in the water bath, the test object, which has its ballast-side surface in contact with the profiled loading plate, shall be subjected to pulsed compressive loading by applying loads from $\sigma_u = 0{,}05$ N/mm^2 to $\sigma_o = 0{,}15$ N/mm^2 at a rate of 30 strokes per hour.

NOTE Information on obtaining the profiled loading plate NSP can be obtained from *Normenausschuss Akustik, Lärmminderung und Schwingungstechnik* at DIN, 10772 Berlin, Germany, Fax: +49 30 2601-1231, E-mail: nals@din.de.

Once the 24-h conditioning period has been completed, the test object is removed from the water bath and weighed in its wet state. The profiled loading plate is removed from the trough, the wet test object returned to the trough and the water level readjusted to the height h of the test object (see Note 2 and Figure 3). The trough, the water it contains and the test object shall then be weighed together (total mass: m_L).

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The quantity of water between the test object and the trough is determined geometrically and its mass m_u calculated. The mass m_F of the water in the test object is then calculated as follows:

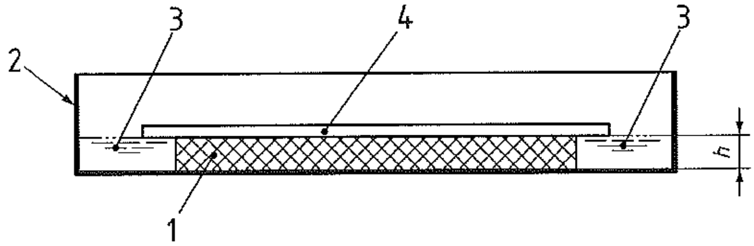
$$m_F = m_L - m_W - m_{P,t} - m_u \tag{7}$$

This mass corresponds to the volume of water V_F in the test object. The total volume V_0 of the test object is the product of the base area of the wet test object and its height h in its unloaded state. The water absorption capacity of the test object shall be calculated as a percentage by volume $V_F / V_0 \times 100$.

The water absorption capacity shall be expressed as a percentage by mass by comparing the mass of the test object before and after its storage in water and then stating this difference as a percentage increase in the dry mass of the test object.

NOTE 2 In order to prevent the possibility of the test object floating and to enable the water level at the upper edge of the test object to be determined exactly, the test object can be covered with a glass plate, though no air is to become entrapped in the process. The glass plate is removed once the water level has been achieved.

NOTE 3 The water absorption capacity expressed as a percentage by volume lies somewhere between 0 and 100 % and is independent of the density of the material. The value of the water absorption capacity as a mass fraction in percent depends on the dry mass of the test object.



Key

1 Test object with the dry mass $m_{P,t}$

2 Trough of mass m_W

3 Water of mass m_u that lies between the test object and the trough

4 Glass plate

Figure 3 — Determination of the water absorption capacity as a percentage by volume

6.4.3 Water resistance

The material from which under-ballast mats are made shall be resistant to the effects of water. The test objects (standardized dumbbell test pieces) shall be tested in accordance with the methods given in the standard relevant to the particular elastic material (DIN 53504 or DIN EN ISO 1798) and the changes in the tensile strength and the elongation at break shall be measured and recorded. Before testing begins, the test pieces shall be stored at 30 °C in air for a period of 168 h (7 days). Surfaces that could falsify the test results (e.g. vulcanization skins) shall be removed prior to testing. The following test shall then be performed.

Test medium: Distilled water

Test temperature: 50 °C

Duration of test: 168 h

Test object: At least three (in the case of extrudates or anisotropic materials, three per direction).

The percentage change in the tensile strength and the elongation at break shall be calculated from the mean and/or median values of the tensile strength testing carried out before and after storage in the test medium at room temperature on both wet and dry test objects and the results documented.

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6.4.4 Freeze-thaw resistance

6.4.4.1 General

Under-ballast mats that are used outdoors shall be resistant to freeze and thaw cycles. Freeze-thaw resistance shall be tested as follows.

6.4.4.2 Test parameters

— Dimensions of test object: 300 mm × 300 mm × product thickness to 500 mm × 500 mm × product thickness

— Number of test objects: One

— Test medium: Distilled water

— Conditioning: 24 h in a water bath at room temperature, see description of procedure.

6.4.4.3 Procedure and evaluation

Before conditioning starts, the reference value of the dynamic bedding modulus $C_{\mathrm{dyn}\,1}(f)$ shall be determined at room temperature on a dry test object. The test object shall then be fully submerged in distilled water at room temperature for 24 h. During the first 2 h in the water bath, the test object, which has its ballast-side surface in contact with the profiled loading plate, shall be subjected to pulsed-load fatigue testing by applying loads from σ_{u} = 0,05 N/mm^2 to σ_{o} = 0,15 N/mm^2 at a rate of 30 strokes per hour.

NOTE Information on obtaining the profiled loading plate NSP can be obtained from *Normenausschuss Akustik, Lärmminderung und Schwingungstechnik* at DIN, 10772 Berlin, Germany, Fax: +49 30 2601-1231, E-mail: nals@din.de.

The profiled loading plate is then removed and the test object while still in the water bath shall be placed into a climate controlled cabinet and frozen for 11 h at −20 °C. The test object is then thawed by raising the temperature in the climate controlled cabinet again to 30 °C within the space of 1 h and then maintaining this temperature for the following 11 h. The temperature in the climate cabinet is subsequently reduced within 1 h to −20 °C and held at that temperature for the next 11 h (see Figure 4). The freeze-thaw test cycle shall be repeated 50 times.

Once the 50 test cycles have been completed, the dynamic bedding modulus $C_{\mathrm{dyn}\,1}(f)$ shall be determined on the statically drained test object (see 6.4.2) at room temperature and compared with the reference value determined previously. The change in the dynamic bedding modulus shall be documented. In addition, the test object shall be assessed visually for evidence of cracking or swelling and the results documented.

6.4.5 Ageing resistance

Ageing resistance shall be demonstrated appropriately for the materials used. Testing shall be conducted in accordance with DIN 53508. The test objects shall be kept in a heating cabinet with forced ventilation and fresh air intake for a duration of 168 h (7 days) at a temperature of (70 ± 1) °C.

The static bedding modulus shall be determined in accordance with 4.1 before and after ageing.

The percentage change in the mass shall be calculated from the mean average results of weighing the same test object before and after the accelerated ageing process.

In addition, the change in compression set shall be determined in accordance with the relevant standard (DIN ISO 815 or DIN EN ISO 1856) and documented as a percentage change.

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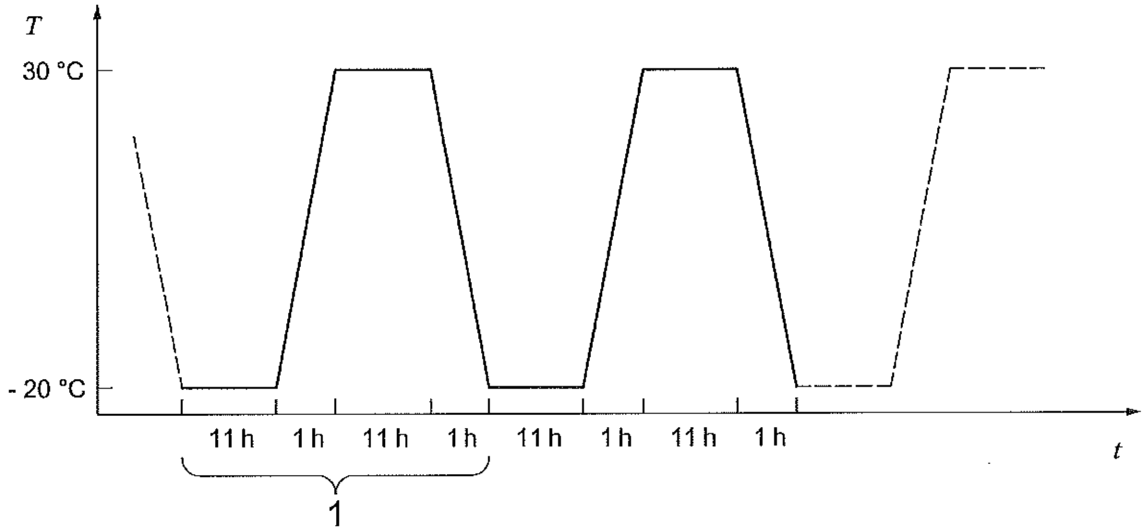

Key

T Temperature

t Time (not shown to scale)

1 One test cycle

Figure 4 — Timing diagram for freeze-thaw resistance test sequence

6.4.6 Other quantities

a) Ozone resistance: Testing shall be performed in accordance with DIN 53509-1 (Method A).

NOTE The test object should be exposed to an ozone concentration of 50 pphm at room temperature at a static tensile strain of 20 % for a period of 48 h.

b) Resistance to the effects of oil and grease: Testing shall be conducted in accordance with DIN ISO 1817.

c) Flammability shall be determined in accordance with DIN 4102-1.

7 Quality monitoring, quality assurance

The static and dynamic bedding moduli of the under-ballast mats shall be checked prior to delivery. However, such checks shall not be made immediately after the mats have been manufactured. When the checks are performed, the material shall be in a state in which its properties remain essentially constant. Tests shall be performed in accordance with Clause 4.

NOTE A realistic value for the permissible measurement scatter is approximately 15 % centred about the target value.

The number of mats to be tested shall be agreed for each project individually. As a rule six samples shall be tested from each production batch. It shall be ensured that tests are carried out on mats from different production batches.

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2) This *Deutsche Bahn* (German Railways) standard is available from *DB Kommunikationstechnik, Medien- und Kommunikationsdienste, Logistikcenter (Drucksachenzentrale)*, Kriegsstraße 136, 76133 Karlsruhe, Germany, dzd-bestellservice@bahn.de, Tel. +49 721 938-1435.

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