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Recommendations for the use of Under Ballast Mats. UBM

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Summary

This leaflet contains recommendations regarding the use of under ballast mats.

The leaflet covers the field of application for Under Ballast Mats (UBM), the exigencies that can be solved by the use of UBM, the technical and physical parameters to take into account for UBM acceptance and a guide to good practices when installing the UBM as well as the limitations for their use.

The leaflet also includes a discussion of the insertion of other elastic components in the track, such as soft rail pads and Under Sleeper Pads (USP).

1 - Introduction

The insertion of elastic layers in the packet between the rail foot and the top of the formation has received increased attention in recent years from railways struggling to decrease the costs of track maintenance and the environmental impact of operation.

This insertion can occur at different levels of the packet, and involve different track components.

In the case of the rail pads, the additional elastic layer is inserted between the rail and its seat on the sleeper. Indeed, the elastic pads have long been used in the construction of modern track, but in recent years there has been a general trend towards adjusting their stiffness, mostly in the direction of reduced stiffness. These adjustments were found to be necessary in order to meet the new demands, arising from increased loads and speeds, in terms of track fatigue, track response in the domain of the vibrations and ride quality. More generally, the rail pads are attributed a subsidiary role in the field of wheel/rail interaction.

In the case of the Under Sleeper Pads (USP - see List of abbreviations - [page 33](#)), the additional elastic layer is inserted between the sleeper and the ballast. In the case of the Under Ballast Mats (UBM - see List of abbreviations - [page 33](#)), the insertion occurs between the ballast and the substructure (see Fig. 1 - schematic cross section).

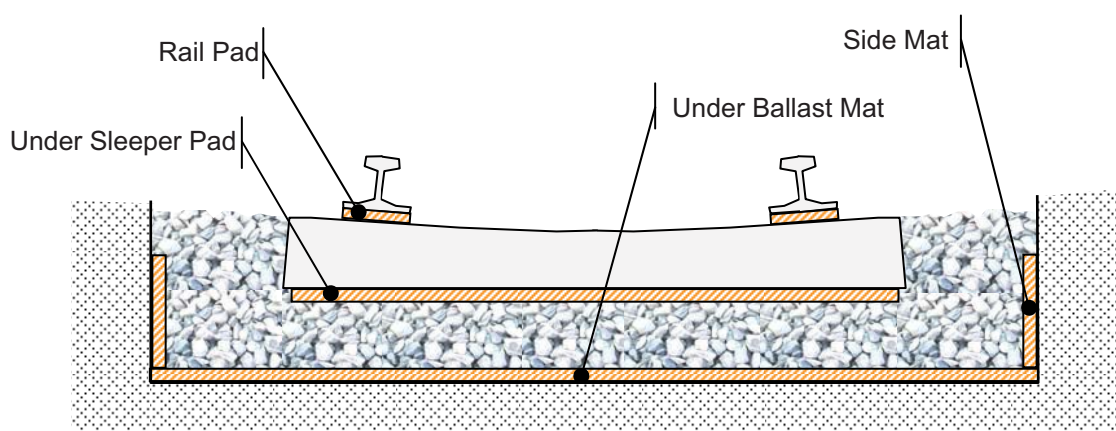


Fig. 1 - Possible insertion level of rail pads, Under Sleeper Pads or Under Ballast Mats

Indeed, while the use of USP and UBM has spread over recent decades, USP and UBM have as yet been implemented mostly in specific situations, since they are not considered to be the common way for track construction.

USP have been successfully used in the construction, renewal and upgrading of conventional ballast tracks. USP allow additional elasticity to be introduced selectively at a specific point of the superstructure. The aim is to achieve advantageous properties in the ballast superstructure. They increase the load-distributing areas between sleeper and ballast since the elastic layer enables the embedding of the ballast stones; the elastic layer between the concrete sleeper and the ballast thus reduces the pressure in individual ballast elements and consequently reduces track maintenance costs.

In the field of railway infrastructure construction, the insertion of under ballast mats between ballast and substructure has received relevant impulse in recent years. One task accomplished by the UBM is the provision of adequate filtering of the vibrations that come from the passing train and arrive at receptors nearby. Another reason for the use of UBM is the lowering of the overall stiffness of the track construction. On bridges and tunnels this characteristic can be a convenient way of reducing the required track maintenance.

Railways have therefore become aware of the need for guidelines regarding the proper use of additional elastic layers between sleepers and substructure, be they under ballast mats or under sleeper pads.

While the use of USP is covered by the *UIC Leaflet 719*, the present leaflet only intends to address the use of the UBM.

It provides information on the characterization of UBM from the point of view of their mechanical characteristics, on possible beneficial uses and on some limitations.

2 - Purpose of laying UBM

This leaflet deals with the application of UBM in ballasted tracks with a standard gauge.

It provides a guide to where UBM can be an optimum resource in view to solving specific technical demands in special cases related to railway operation.

UBM are used in several fields of application, covering nearly all different types of railway transportation: conventional main lines, urban or high speed lines, light rail and metro lines.

Under Ballast Mats are used in tunnels, bridges, elevated stations, underpasses, cuts, embankments, switches and railway stations.

Different types of UBM are used for different purposes, with the main difference being the vertical stiffness of the mat. This corresponds with the fact that the specific tasks performed by the UBM are highly dependent on the elasticity of the mat itself, which has to be well adapted to the vertical loads of the passing trains.

UBM must be chosen to provide the optimum static and dynamic properties and the type of material should be chosen carefully on the basis of track use (main line, urban line, light rail and metro) and purpose (reduction of vibration, ballast and structure protection, transition zones).

Where the aim is to increase the elasticity of the track, the introduction of additional layers closer to the surface, such as rail pads or under-sleeper pads is regarded as an alternative solution.

For the "prevention of rapid ballast deterioration at the sleeper / ballast interface, i.e. on bridge decks (steel or concrete troughs) or tunnels", the insertion of UBM on the substructure surface prevents the ballast from damage.

There is experience that UBM give reliable performance over a very long service life under any climatic conditions.

The UBM is characterized by the bedding modulus C [N/mm^3], that is to say the stiffness [N/mm] per unit area [mm^2] relating to the area of the UBM situated under the sleeper that actually supports the load.

For orientation, Table 1 - page 5 contains the definition of very soft, soft, medium and hard UBM in relation to their dynamic bedding modulus C_{dyn} , together with the expected dynamic track vertical deflections under passing loads.

The values of C_{dyn} are in relation to the reference axle load of 225 kN and to train speeds up to 200 km/h, to 2,6 m long concrete mono-block sleepers, 60 cm sleeper spacing and 50 cm ballast thickness on a concrete invert of a tunnel and 60E1 rails.

Table 1 : Increase of the vertical track deflection due to UBM use [SBB]

Type of UBM	Expected increase of the vertical track deflection up to 225 kN axle load (measurements [SBB]) mm ^a	Dynamic bedding modulus N/mm ³ ^{bcd}
Very soft	1,5 ÷ 2,0	$0,03 \leq C_{dyn} < 0,05$
Soft	1,0 ÷ 1,5	$0,05 \leq C_{dyn} < 0,09$
Medium	0,5 ÷ 1,0	$0,09 \leq C_{dyn} < 0,22$
Hard	$\leq 0,5$	$0,22 \leq C_{dyn}$

- a. Measured with an SBB moving measuring car at 10 km/h (200 kN axle load "Einsenkungsmesswagen").
- b. Estimated values for the dynamic bedding modulus C_{dyn} are only valid for very stiff foundations (e.g. concrete).
- c. For sleepers with smaller dimensions the C_{dyn} are shifted towards higher values. Lower axle loads imply a shift of the reference dynamic bedding modulus towards lower values. In contrast, higher train speeds in principle require a higher UBM bedding modulus in order to control ballast destabilization phenomena.
- d. SBB: with 0,06 N/mm² preload and $\pm 0,04$ N/mm² load at 20 Hz, using a flat steel plate.
- e. Lower C_{dyn} values are expected using a ballast plate.

2.1 - UBM for vibration reduction and ground-borne noise

Rail operations generate noise and vibration

Trains generate vibrations, which are transmitted through the ground to adjacent buildings.

People in the buildings can feel the vibrations directly through their bodies. On the other hand, walls, floor and ceiling oscillate due to the vibrations and emit ground-borne noise, which is perceived as noise.

Many countries have defined specific limit values in their regulations to avoid intolerable nuisance to people. The limit values are below the level that would cause damage to buildings.

If vibration problems are expected, UBM are an effective mitigation device in ballasted tracks to reduce ground-borne noise levels in tunnels and on bridges, and to a lesser extent on normal track and turnouts.

Definitions and scales of measurements for noise and vibration are presented in Appendix A - page 17.

Limited research suggests that the use of UBM does not affect the airborne noise emissions produced from the operation of a surface rail line (Ref [6] and *UIC Leaflet 719* - see Bibliography - page 34).

The reduction of vibrations and ground-borne noise (caused by substructure vibrations as a result of trains) by an UBM is highly dependent upon the frequency content of the emission and the bedding modulus of the mat.

Soil conditions also greatly influence the reduction of vibrations and ground-borne noise.

The model comprising a single degree of freedom mass-damper-spring system permits a basic understanding of how the vibrations are reduced.

At above the natural frequency (eigenfrequency) of this system there is a reduction of the vibrations emitted. Depending upon the damping of the system, amplification can occur at around the natural frequency of the track with UBM.

The mass here consists of ballast, sleeper, rail and un-sprung axle load of the trains, with the spring being the under ballast mat and the elasticity of the substructure.

UBM isolate the track structure from the supporting foundation or substrate, and can attenuate the transmission by several dB depending mainly on soil conditions and the bedding modulus of the UBM.

UBM work best over hard rock and in tunnels and are less effective over soft soils of open lines (see Tables 2 and 3 - page 7).

The softer the UBM in terms of dynamic bedding modulus the higher the reduction. Normally the reduction values are largely independent of rolling stock and train speed.

The following tables summarize the results of a few different test sites, depending on UBM bedding modulus (SBB report - see Bibliography - page 34).

These results are related to three specific 1/3 octave band frequencies; the global insertion loss over the total, wider range of frequencies caused by the trains can be lower.

Table 2 : Vibration reduction UBM in % and VdB, at the side way of tunnels with invert or hard substructure (mean of measurements) for 1/3 octave band frequencies

Frequency	31,5 Hz	63 Hz	125 Hz
UBM bedding modulus (C_{dyn})			
Around 0,03 N/mm ³	55 % 7 VdB	90 % 19 VdB	90 % 19 VdB
Around 0,06 N/mm ³	40 % 4 VdB	85 % 16 VdB	85 % 16 VdB
Around 0,12 N/mm ³	- 15 % - 1 VdB	80 % 14 VdB	85 % 16 VdB
N.B. : negative values mean amplification of vibration. N.B. : insertion loss was calculated taking the difference of the measurements between different places of the same embankment with and without UBM with the same train running. N.B. : the results come from 3 to 5 situations of European tunnels and represent the mean values; C_{dyn} values have been measured with different test procedures; therefore they should not be applied to a specific case.			

Table 3 : Vibration reduction by UBM in % and VdB for embankment at 8 m apart from the track (mean of measurements) for 1/3 octave band frequencies

Frequency	31,5 Hz	63 Hz	125 Hz
UBM bedding modulus (C_{dyn})			
Around 0,03 N/mm ³	50 % 6 VdB	75 % 12 VdB	75 % 12 VdB
Around 0,06 N/mm ³	- 10 % - 1 VdB	70 % 10 VdB	80 % 14 VdB
Around 0,12 N/mm ³	- 90 % - 6 VdB	30 % 3 VdB	65 % 9 VdB
N.B. : negative values mean amplification of vibration. N.B. : insertion loss was calculated taking the difference of the measurements between different places of the same embankment with and without UBM with the same train running. N.B. : note that the results are referred to some specific cases.			

As shown in Table 2 - page 6 and 3 the reduction in vibration for tunnels (31,5 Hz to 63 Hz) is normally above 40 %, whereas for open tracks (31,5 Hz) there may even be an amplification of around 10 % in many cases ($C_{dyn} = 0,06 \text{ N/mm}^3$).

For the frequencies involved in ground-borne noise (63 Hz to 125 Hz) the vibration is reduced for tunnels by up to 85 % (16 VdB) whereas for open lines (63 Hz) the reduction for a stiff substructure is about 70 % (10 VdB). These reduction values are indicative for the medium UBM dynamic bedding modulus of around 0,06 N/mm³ and an usual emission situation.

2.2 - UBM for ballast protection

If ballast deterioration is recorded in relation to rigid substructures, the following two aspects can be taken into account:

- the loads transmitted by running trains via the sleepers into the ballast are more important on rigid platforms such as bridges and tunnels: the distribution of the axle loads is concentrated over a more limited number of sleepers;
- the ballast, which is a rigid element, is crushed at its rigid interfaces with the substructure or sleeper as loads are transmitted via very weak surfaces of contact.

Regarding the first point, the insertion of a UBM introduces extra flexibility that allows a wider distribution of the axle load over the sleepers. Therefore, the maximum load supported by the sleepers is reduced and the pressure exerted on the ballast and substructure reduced; in the case of using very soft UBM the increase of rail foot stress should be taken into account.

Regarding the second point, the installation of UBM will allow the ballast not to be any more in direct contact with the substructure.

If UBM are installed, the use of medium / hard UBM is recommended in order to achieve an acceptable balance between the effect of the reduction of ballast pressure and the increase in track deflection.

If the priority is the protection of the ballast by reducing the pressures exerted on the ballast itself (at speeds higher than 160 km/h), then USP or other means of introducing extra track flexibility, such as soft sleeper pads, are often better suited because their installation is more economic.

2.3 - UBM on existing structures with reduced ballast thickness

If there is not enough space to build in the required ballast thickness, for example in an existing tunnel (e.g. when the catenary has to be installed and the available height is insufficient or where a wider structure gauge has to be obtained) or on an existing bridge or underpass, the use of UBM can be considered in principle, in order to ensure a sustainable track quality.

On the other hand, with reduced ballast thickness the vertical stresses on the UBM increase and, wherever possible, the ballast thickness should not be less than 25 cm, because there must be enough space between sleeper and substructure to tamp the track.

Because of these conflicting considerations in the case of reduced ballast thickness, the use of other solutions, such as USP or very soft rail pads, should be considered in alternative to the use of UBM.

In cases not involving the reduction of vibration, the use of medium UBM is recommended.

2.4 - UBM for transition zones

Transition zones make it possible to pass from a rigid zone, characterized by a low vertical track deflection, to a soft zone, characterized by a higher vertical track deflection, and to harmonize those deflections.

This is the case for transitions from the invert of a tunnel or bridge concrete deck with UBM or slab track to the adjoining embankments.

Control of the bedding modulus of the UBM and knowledge of the vertical behavior of UBM in track are very important for achieving a proper transition zone.

The transition zones shall be realized in such a way to obtain a gradual passage from the rigid zone to the soft zone.

Steps with a intermediate vertical deflection change of about 0,5 mm are recommended.

Each intermediate zone should have a length corresponding to 0,5 - 1 second in vehicle running time. In any case, a minimum length corresponding to the length of a trailing car (approx. 25 m) should be adhered to.

For example, in the case of the passage from an embankment with a stiff subsoil to a concrete substructure, the installation of a single step can probably be realized with a medium UBM.

For the introduction of the required extra track flexibility, the use of other solutions, such as USP or very soft rail pads, should also be considered in alternative to the use of UBM.

The solution with UBM is recommended if there is also a need to protect the platform of bridges and tunnels; if the priority is only the realization of the transition zone, other more economical means of introducing the required extra track flexibility, such as very soft rail pads, USP, etc. can be considered.

3 - UBM properties

3.1 - General characteristics

UBM consist of ageing-resistant elastomers.

UBM can be subdivided into profiled mats, bonded granular mats, foam mats and combined mats (elastic material in the matrix of an elastomer).

UBM are available in the form of single-layer or multi-layer mats.

UBM may consist of one or several bonded layers, which comprise the main two functions "protection of the mat" and "elasticity".

The protective layers have to protect the mat against ballast stone penetration and fine particle penetration in the case of open cell elastomers, and ensure the required friction angle between ballast and UBM. The elasticity layers have to fulfill the main objective of a UBM, which is to give the track some extra elasticity. Under ballast mats are available with different characteristics such as varying thickness, single or multilayer and delivery on reels or in plates.

The thicknesses of UBM are typically 15-30 mm; nevertheless the use of UBMs with a max. thickness of 40 mm is not unknown.

The width and length of UBM are chosen according to the needs of the project and the installation conditions in question. The mats can be pre-cut to a uniform width in the factory according to the site specifications or delivered in fixed dimensions to be made up on site.

UBM must maintain their physical characteristics for temperatures ranging between - 25 °C and 45 °C.

Physical and chemical characteristics of the materials concerning the fire safety are ruled by the national regulation.

3.2 - Mechanical and physical properties

3.2.1 - Static bedding modulus

The parameter based upon the static bedding modulus C_{stat} is the vertical track deflection in the case of very low train speeds.

For the normal traffic condition the vertical average stress in the UBM is about 100 kPa (TU_Graz_2 - see Bibliography - [page 34](#)) including the stress due to the permanent load of track and ballast.

The static bedding modulus shall be assessed with very low stress rates between those two stress values. The secant C_{stat} modulus shall be taken into consideration.

In the practice lowest values of 0,01 N/mm³ (light train traffic) and highest values of 0,15 N/mm³ (ballast or structure protection) are recorded.