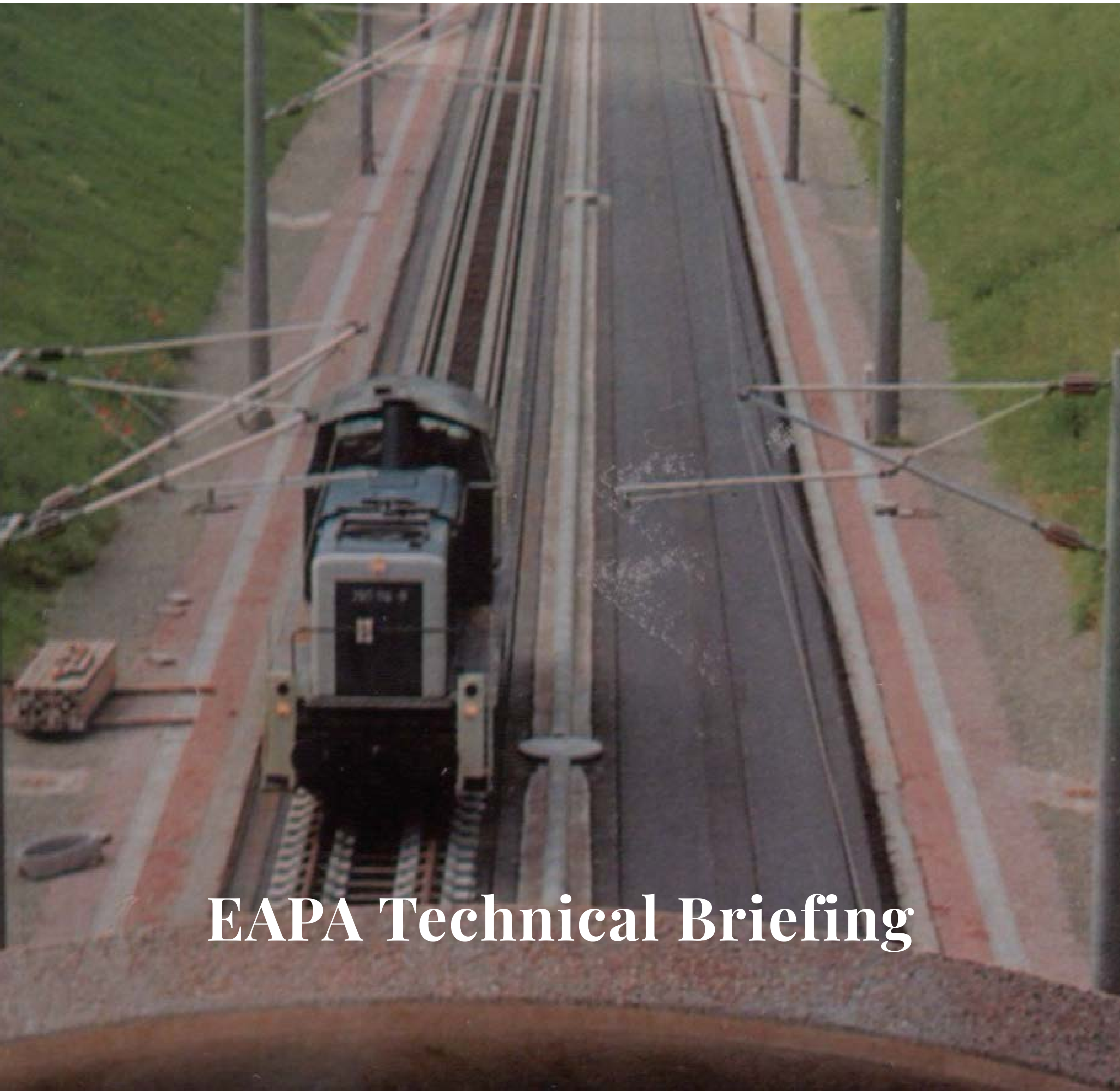
Asphalt in Railway Tracks



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Abstract

One of the measures proposed by the EU Commission and included in the "European Green Deal" is the shift of a substantial part of the 75% of inland freight carried today by road onto rail. Increasing traffic loads and volumes and particularly the introduction of high-speed trains in the last decades, have resulted in the need for new technologies in railways engineering, which now, with stronger EU policies, will become more and more necessary. As a reaction to this, the European Asphalt Pavement Association (EAPA) published an extended state of the art about the main asphalt solutions used around the world. In the mentioned document, also the practical experiences carried out in countries, such as Austria, Czech Republic, France, Germany, Italy, Spain, China, Japan, Morocco and USA were described in detail. This Technical Briefing summarises the key features, benefits and recommendations for the use of these technologies able to significantly improve railways in different aspects, such as better mechanical performance, protection of the substructure, reduction of maintenance needs and costs, as well as greater safety and reliability for users.

Contents

Page

1. Introduction

The "European Green Deal", published by the EU Commission in December 2019, states that to achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050, as these accounts for a quarter of the total EU's greenhouse gas emissions. One of the measures proposed is a strong boost in multimodal transport to increase the efficiency of the transport system. This includes a shift of a substantial part of the 75% of inland freight carried today by road, onto rail and inland waterways. This will require measures to manage better, and to increase the capacity of railways, which the Commission will propose by 2021.

In railway design, as in highway design, increasing traffic loads and volumes and particularly the introduction of high-speed trains in the last decades, have resulted in the need for new approaches, which now, with stronger EU policies, will become more and more necessary. In addition, concern for the environment requires the concept of sustainability to be taken into account in the design process.

Asphalt mixtures have been shown to provide good technical alternatives for several elements of traditional railway construction. In particular, experience with asphalt in the track superstructure (the traditional superstructure consists of the rails, the sleepers, fastenings and the ballast) and in the sub-ballast layer has shown that these types of construction are able to fully meet the requirements of modern railway tracks.

Worldwide experience has shown that use of asphalt can offer a good alternative in modern railway construction. Thanks to the specific properties of asphalt mixtures the materials are able to comply with many of the requirements.

2. Asphalt

Hot and warm mix asphalt are mixtures of mineral aggregate and bitumen. The mineral aggregates can vary from very fine dust (filler) to coarse particles, which could be as large as 40 mm. Bitumen is a product of the crude oil distillation.

By varying parameters, such as the composition of the mixture, the ratio of the various constituents, the aggregate particle size distribution and the type and composition of the binder, the characteristics of the mixture can be adapted to suit the specific requirements of the construction. The resulting mix can be either stiff with high stability or very flexible to resist deformations. Some mixtures are dense and waterproof, whilst other are porous and permeable.

The production of asphalt mixes takes place in either mobile or static mixing plants where, in a continuous or batch process, the mineral aggregates are dried and heated and later the hot bituminous binder is added to the required aggregate composition. After production the hot or warm asphalt mix is transported to the job site by trucks. On site, application takes place using pavers that place and pre-compact the material in the required thickness and width, following which final compaction is achieved using rollers. Immediately after the last passage of the compaction roller the asphalt is ready for use.

Figure 1. Compaction of asphalt layer

3. Application of asphalt in railway construction

Over the last decades, the use of asphalt layers within railway trackbeds has been gaining importance in order to cope with higher performance requirements of modern railway transport and construction. This alternative solution has been increasingly used in European countries, such as Austria, France, Germany, Italy or, more recently, Spain, as well as in other countries, such as China, Japan and the United States, getting to be considered as an appropriate technology to improve track quality in high speed and heavy traffic lines [1, 2]

It is necessary to mention that the current European Union's strategy includes the construction of maintenance-free slab tracks in appropriate sections (e.g. tunnels), which is an opportunity for asphalt and bituminous materials as one of the alternatives for traditional track designs. In addition, there are numerous ongoing investigations to develop new methods and designs for slab track with asphalt or asphalt mortar [3].

A wide range of asphalt materials have been used in different implementations, such as mastic asphalt, hot (HMA) and warm mix asphalt (WMA), with or without polymer modifications, as well as bituminous emulsions for ballast stabilisations. The four most common applications of asphalt in railway tracks are summarised in Figure 2. As it can be seen, asphalt can be introduced as a component of the railway support system in combination with other ballast and sub-ballast layers or as part of a ballast-less system, where no ballast is used at all.

4. Application of asphalt pavement as a component of railway support system

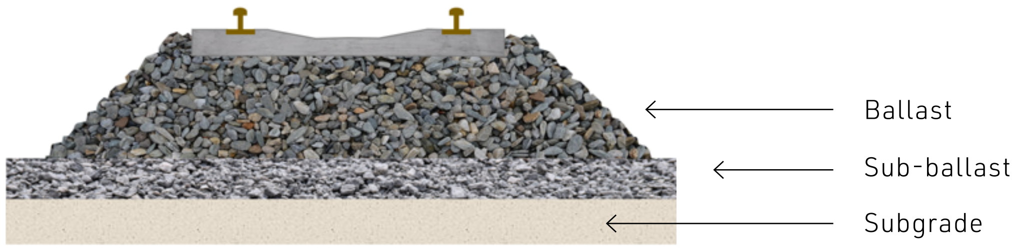
4.1 Asphalt pavement with ballasted tracks

The most common asphaltic configuration used in the world consists on the application of a bituminous layer, similar to HMA conventionally applied in base and binder road layers, between the sub-ballast and ballast layers or directly substituting the sub-ballast layer [1,4]. In order to obtain an optimal performance, the asphalt sub-ballast is normally laid on a highly compacted capping layer.

Figure 2 represents a section overview, where the ranges of values were defined by considering specifications and successful practical experiences in the countries described in Section 6. Test methods to obtain certain values (e.g. subgrade bearing capacity or stiffness and fatigue resistance of asphalt layer), can be different from country to country. For this reason, the Figure must be understood only as a reference or starting point and not as a specification or design recommendation.

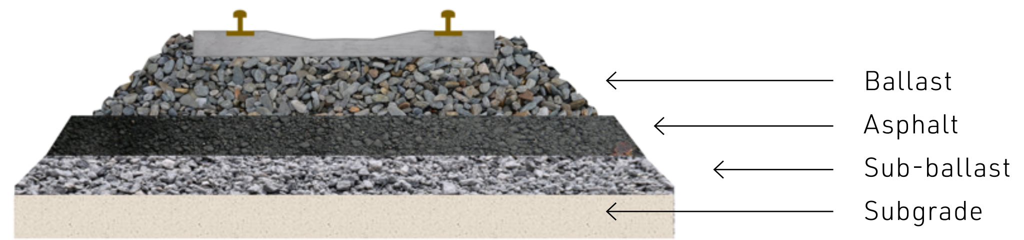
Usually, with such configuration, the bituminous layer extends about 30 cm beyond the cross tie's ends on both sides. The material is commonly made of a dense-graded mixture containing coarse aggregate with maximum size up to 25 - 37.5 mm [5].

a) Traditional design without asphalt:

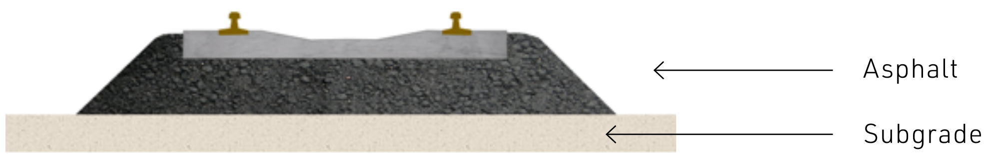


b) Asphalt-ballast combination: Asphalt sub-ballast:

c) Asphalt-ballast combination: Asphalt intermediate layer:



d) Ballast-less configuration: Asphalt slab track:



e) Ballast-less configuration: Asphalt intermediate layer:

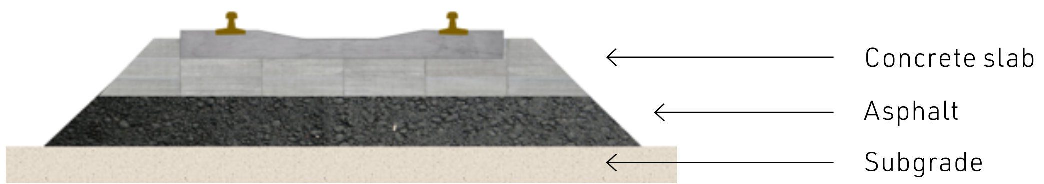


Figure 2. Most common use of asphalt in railway tracks

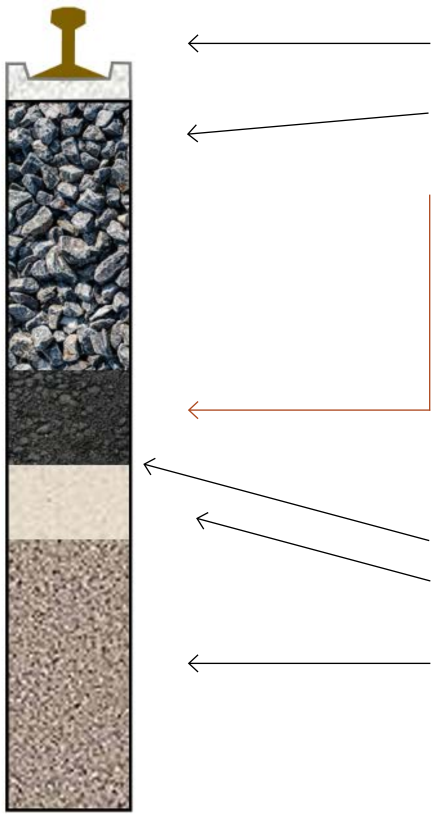
It has been observed [6] that, with this configuration, stress and strain at the bottom of asphalt sub-ballast reduce when its thickness increases. The same happens with the vertical acceleration measured on the sleepers [7, 8]. All this helps to improve the global structure's stability and reduce maintenance frequency, what makes asphalt sub-ballast especially recommendable in sensitive sections, e.g. at-grade rail crossings.

This system also optimises drainage, as without affecting the structure, it prevents water from entering the subgrade [9, 10] and its possible contamination by vertical hydraulic transport of mud and fines [11, 12]. This reduces variations in the moisture content in the subgrade and, consequently, also displacements amplitude, permanent deformations and track geometry deterioration [13].

Asphalt layers can also create a working platform during construction, which allows conventional machinery (with wheels) to drive and access the job site on multiple points. Hence, subsequent work operations, such as installation of electric lines, ballast and rails are faster and more easily undertaken than in conventional ballast railway tracks, where the execution is linear, requiring the construction of the whole structure before accessing along to place rails and other equipment. Consequently, asphalt layers help to secure the planning of the project.

Depending on the size of the project, the required equipment can vary significantly [14]. For large projects, mainly new construction with a prepared subgrade, the process is similar to that carried out in road construction, with the asphalt being laid down by a conventional paver and compacted by large vibratory rollers. However in this case, less hand-work and smoothness concerns are necessary, which allows to finish the process in a shorter time.

For the case of smaller projects, such as maintenance and rehabilitation, the old track panel is removed, asphalt is normally back-dumped on grade and spread by a trackhoe, small dozier, bobcat, or similar, and compacted by a conventional vibratory roller. The cost of this is practically the same than placing conventional granular sub-ballast. As it replaces the granular sub-ballast, the extra cost of the asphalt material delivered to the job site is usually not significant, added to the costs of track removal and replacement. Also, and provided the track is to be removed and the underlaying ballast/sub-ballast replaced with new ballast, the added time to the track outage to place asphalt is insignificant.



Sleepers and rails

Ballast: 200-350 mm
- Most of experiences in Europe have 350 mm

Asphalt layer: 120-150 mm (up to 200 mm for high-impact areas and 80-120 mm in low speed/traffic railways)
- Binder content: > 4,75% (over mass of asphalt mix)
- Maximum aggregate size: 25-32 mm
- Void content EN 12697-8 (EN 13108-20 annex B): < 5%
- Water sensitivity (EN 12697-12 ITS test method 15°C): >85%
- Dynamic stiffness modulus (EN12697-26 annex C): 3700-7100 (20°C)
- Fatigue resistance: ε_6>110µε (EN12697-24 method A) ε_6>120µε (EN12697-24 method B)

Surface dressing with fine aggregate: 0,8 kg bitumen/m^2

Super-compacted granular adjustment layer: 100-400 mm

Subgrade: Bearing capacity > 80 MPa*
- If this is an embankment with lower bearing capacity (>40 MPa), then the super-compacted layer must have > 80 MPa

*Differences in test methods used in different countries

Figure 3. Design recommendations based on experience in different countries

Example of application: High-speed line Bretagne Pays de Loire (HSLBPL)

One of the newest (2017) and most important implementations are the 105 km of the new high-speed line Bretagne Pays de Loire (HSLBPL) built with asphalt sub-ballast. More than 100 sensors, such as accelerometers, extensometers, humidity probes, temperature sensors and anchored displacement sensors were placed [9, 10], showing significant improvements in the mechanical performance and a minimal water infiltration under the bituminous layer. This experience in France represented a small revolution, as after the satisfactory results, the technique was approved by SNCF and is used in other projects, such as the LGV Sud Europe Atlantique high-speed railway and the Nimes-Montpellier bypass.

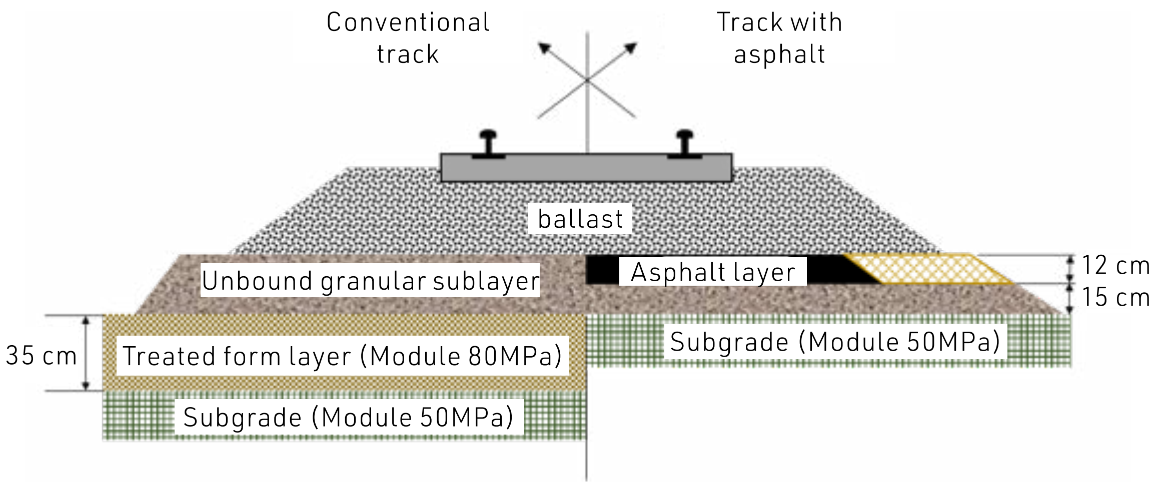


Figure 4. Cross-section of high-speed line Bretagne Pays de Loire (HSLBPL)

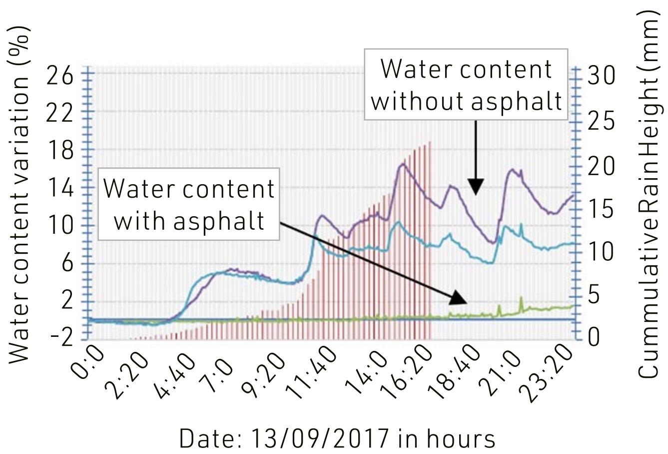


Figure 5. Water infiltration over a rainy period under asphalt sub-ballast (GB) and granular sublayer (GNT) in the new high-speed line Bretagne Pays de Loire [10]

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4.2 Asphalt pavement with ballast-less tracks

In this form of construction, the ballast is replaced by a rigid monolithic element that directly supports the sleepers. The aim is to find a track structure having a good elasticity, independent of the foundation stiffness.
One of the solutions is a system in which the track frame of rail and sleepers is placed directly on an asphalt construction. The most important requirement of the top asphalt layer is to have a perfectly smooth and even surface to comply with the stringent tolerances that are required for the rail level (± 2 mm). Modern asphalt laying machines can fulfil this requirement because they make use of the most sophisticated levelling equipment.

The horizontal anchoring of the rail track in order to prevent transverse movement can be achieved by various anchoring systems. The advantages of these systems are the elasticity of the asphalt layer, especially when polymer modified asphalt is used, and the ease of construction and maintenance. Another important factor in favour of this system is the ability to carry out minor corrections without demolishing and reconstructing the base.

Because this system eliminates the use of ballast it has the great advantage of lowering the track base, allowing the construction of tunnels with smaller diameter.

Figure 6. ATD system

In USA, for maintenance purposes, this configuration is mostly limited to the lines with heavy freight traffic [4]. However, this method is more popular in European countries, specifically in constructing high speed railways and urban transit. The first successful application of the ballast-less tracks dates back to the beginning of the 1990's, in Germany, after which, several sections of high-speed railway with asphalt base slab track would follow. Different variations have been developed, such as ATD (Asphalt base course with a rail web), SATO (Concrete sleeper on Y-steel sleeper with double base), FFYS (Y-steel sleepers with basic body casting made of supportive girder profiles), Getrac (German Track Corporation Asphalt) or Walterbau (German Track Corporation Asphalt), all of them having shown to be very successful to date. Some advantages of ballast-less tracks are:

- Asphalt can be paved without joints due to its visco-elastic characteristics; stresses arising from the effects of load and temperature are reduced.
- Asphalt can also be used with extreme super-elevation because no separation arises from the high internal friction in the paved state.
- Asphalt can be paved at a precise tolerance (±2 mm) due to its material characteristics.
- Load can be put on the asphalt immediately after it cools down; shorter construction times are achieved by using it.
- Corrections in the position that may be needed (e.g. due to settlement of the embankment) can be quickly and easily made either by milling off or by putting on another layer.

For these reasons, the solid railway trackbed made of asphalt resulted a promising alternative to a ballast-type track or concrete slabs.

Table 1 Specification of asphalt base ballast-less system [15]

Method	Asphalt Thickness (mm)	Superstructure Overall Thickness (mm)
ATD	300	1021
SATO	300	909
FFYS	300	909
Getrac	300	1021
Walter	300	929

Regarding design criteria, and as it can be seen in Table 1, the thickness of asphalt layer in solutions commonly used in Europe is 300 mm. Nevertheless, in other countries, such as Japan, the asphalt layer with a thickness of 150 mm is laid on a 150-mm-thick layer of well-graded crushed stone.

In addition, the requirements for the asphalt layers are, in general, determined by the load type and traffic. In the case of the solid railway trackbed, loading frequency is at a lower level than with asphalt roads. In contrast, the axle loads and consequently the wheel loads are far higher. Nevertheless, in this case there is a considerable load distribution over the rail and the sleeper. Thus, a wheel load of 11.25 tons only produces in rail tracks approximately one-third of the stress produced on roads by a wheel load of 5,75 tons. Despite this advantage, it is also necessary to consider that asphalt trackbeds for railway tracks also need to be designed to be long-lasting (e.g. up to 100 years lifetime in countries, such as France), flexible and dense in order to avoid maintenance work.

During construction, the use of pavers with a screed providing a high level of pre-compaction is mandatory. The compaction itself needs to be done with a small smooth-wheeled roller.

Finally, it can be added that asphalt trackbeds are also excellent solutions for trams in urban areas. In this case, designs, such as a 2-layers base of 160 mm in total or a high-modulus base of 100-120 mm can be used with a layer on top of asphalt concrete (0/11). The sleepers with the rails are laid directly onto this top layer and therefore the specifications with regard to evenness can be extremely high (±2mm in both longitudinal and transverse directions).

5. Bitumen stabilised ballast (BSB)

Particles composing the granular ballasts can get degraded due to stresses at contact points produced by traffic and maintenance operations. This phenomenon known as fouling, can reduce the mechanical integrity, leading to undesired changes in the track geometry [16]. Tamping is a common treatment used to preserve the structural integrity of fouled ballasts. However, such operations produce themselves further degradation, leading to a vicious circle where the more maintenance is applied, the more maintenance is needed [17].

In order to reduce material consumption and ballast maintenance costs, which account for 30% of the total maintenance costs [18], a new low-cost technique is gaining recent importance: the ballast stabilisation by bitumen emulsion. The technique, which basically consists on pouring the emulsion from above during a routine maintenance operation, can significantly increase the ballast durability without compromising its drainability [16]. When the sleeper is raised during the maintenance process, a system similar to that used by the stoneblower would spray the bitumen emulsion over the surface of the ballast.

Recent studies showed that BSB has potential to improve short-term and long-term in-field ballast deformation behaviour, especially when harder bitumens are used. This proves that the solution is effective increasing interval between tamping operations. Results also suggest that this technology might be a good solution to reduce vibrations and noise. In addition, it has been calculated through Life Cycle Costs Analysis that the use of SBS can produce savings up to 25% compared to traditional ballasted track-beds.

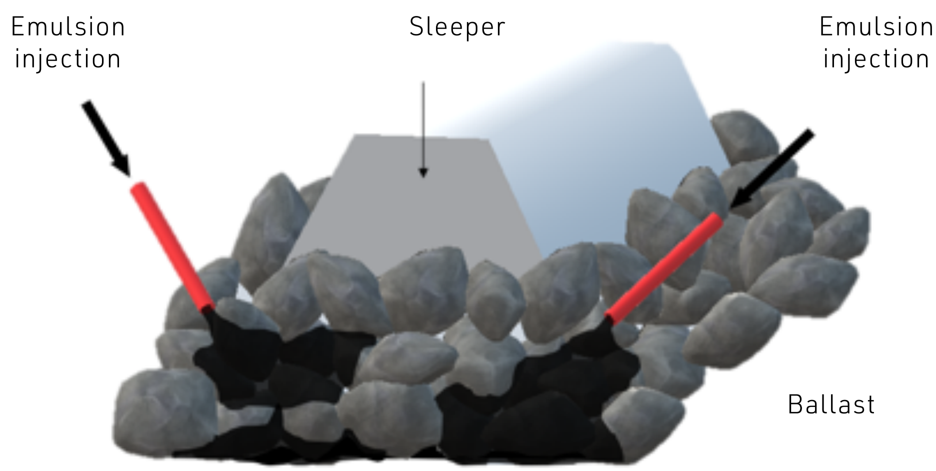

Figure 7. Illustration of ballast stabilisation process with bitumen emulsion

6. Practical experiences of use of asphalt in railway tracks

United States
The use of asphalt track beds has steadily grown since the early 1980's. Conceived as a solution to rehabilitate specific sections, which historically required significant maintenance, such as crossings, switches, bridge approaches or tunnels. Improvements led to rail agencies starting to routinely specify the use of asphalt in unstable sites. Over 300 km of asphalt trackbed design have been placed during new track construction The two main configurations used are the asphalt sub-ballast and the partial replacement of granular sub-ballast layer.

Germany
Different systems developed and approved by Deutsche Bahn AG over the last 35 years: ATD. SATO, Walter, Getrac. The solid railway trackbed laid to date has been shown to be very successful, which made it a promising alternative to a ballast-type track and other construction methods

Czech Republic
One trial section of 80 m was realised in 2017 using 70 % RA to check the potentials of using in the future asphalt concrete with very high RA content. The specification for asphalt mix for railway beds was prepared. It will be published in 2020 as a part of the new Czech national standard as well as a more detailed Annex to the design and construction specifications for railroad tracks as published by the Czech Railroad Tracks Administration.

China
A common adopted solution to avoid high maintenance costs in high-speed lines, was the use of a continuous concrete base layer and bearing boards supporting the rails. In order to adjust levels while buffering the high-speed heavy loading, in between both previous elements, it is placed a layer of bitumen emulsion mixed with fine aggregate and additives, which help to control the on-site emulsion performance.

France
Different big high-speed line projects with asphalt sub-ballast, such as the new high-speed lines LGV East (from Paris to Strasbourg), LGV Sud-Europe Atlantique, LGV Bretagne – Pays de la Loire and LGV Contournement Nîmes-Montpellier (CNM, designed for passengers and freight). After the success of first trials, SNCF decided to use this solution for all the new tracks for High Speed Train.

Japan
In Japan asphalt track beds have been widely used in railway ballast tracks for many years on both high-speed lines and regular lines. Three standard track designs were established, out of which, two include asphalt layers. These provide a firm support for the ballast reducing track irregularities. They also reduce the load level on the subgrade to prevent subgrade deformation.

Spain
Asphalt sub-ballast was tried in 4 rail lines. Results will determine whether the solution will be stablished for the more than 2000 km of new high-speed lines planned to be built in the coming years. There is also one ballastless test between Las Palmas de Castellón and Oropesa del Mar (Castellón)

Morocco
The new high-speed line (under construction) has a solution, which includes asphalt sub-ballast along the entire length of the line (180 km). Its characteristics are very similar to those applied on LGV in France

Italy
First experiences in the 1970s. More than 1200 km built with asphalt sub-ballast in the last 30 years. Great stability of rail geometry, especially at critical points, such as switch points, expansion joints, level crossings and in areas between concrete structures (bridges) and embankments.

Austria
Experience since 1960s. A clear separation between sub- and superstructure is produced by using an 8-12 cm asphalt layer under the ballast bed. This technique produces annual deterioration rates 50% lower, compared to granular trackbeds, and reduces by 67% the levelling-lining-tamping frequency.

Countries with great experience (years and km)
Countries where great use of asphalt solutions are expected in the coming years
Countries where the technology is starting

7. Conclusions

As explained throughout the paper, asphalt is a material that, when used in rail tracks, can contribute to:

- secure the planning of the project by creating a working platform during construction, suitable for conventional machinery and with multiple access points to job site, on which subsequent work operations, such as installation of electric lines, ballast and rail laying, are faster and more easily undertaken;
- assist in gradually distributing the loads transmitted by passing trains (lower vertical stress transmitted to the supporting embankment), eliminating any "rupture" of the embankment and producing higher and more homogeneous vertical stiffness values (this can also lead to reduce thickness compared to a conventional granular design);
- protect the embankment body from the seepage of rain-water and from seasonal thermal extremes (so protecting the upper part of the embankment from freeze/thaw action);
- eliminate contamination of the ballast from fine material migrating up from the foundation;
- reduce the vertical acceleration of the superstructure components, extending their service life and increasing travel comfort.
- slow down the degradation rate of the track geometry and reduce maintenance operations and costs.
- increase performance and structural reliability due to increased modulus and uniformity
- reduce life-cycle cost on the infrastructure from reduced subgrade fatigue
- increase homogenization of the track bearing capacity on the longitudinal profile and better ballast confinement
- reduce ballast fouling due to improved drainage

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