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1. Introduction

In railway design, as in highway design, increasing traffic loads and volumes and particularly the introduction of high-speed trains in the last decade, have resulted in the need for new approaches. 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 mix asphalt is a mixture of mineral aggregate and bitumen. The mineral aggregate varies from very fine dust (filler) to a maximum particle size, which is usually around 40 mm. Bitumen is the result of the distillation of crude oil.

By varying the composition of the mixture, the ratio of the various constituents and the particle size distribution of the aggregate, the properties of the eventual mixture can be adapted to suit the specific requirements of the construction. Depending on the mix composition and the quality of the constituent bitumen and aggregates, the asphalt mixture may be either stiff and of high stability or, on the other hand, very flexible. Some mixtures are impermeable, whilst other compositions result in permeable porous asphalt.

The use of special additives or of polymer-modified bitumen offers the possibilities of complying with specific requirements (heavy duty, lower temperatures, noise/vibration reduction) for the mixture or the construction.

The production of asphalt mixes takes place in either mobile or static mixing plants where, in a continuous or batch process, the mineral aggregate is dried and heated and where the hot bituminous binder is added to the required aggregate composition. Production takes places at temperatures of 130 – 190 °C. After production the hot asphalt mix is transported to the site in insulated trucks. On site, application takes place using pavers that place and partially 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.

An asphalt construction may consist of one or more separate layers of possibly different composition. Depending on the design the various layers each perform a specific role in the construction.
3. **Application of asphalt in railway construction**

The properties of bitumen and asphalt offer good opportunities to apply this type of material in railway track construction. This has been proven in various applications, both for heavy loaded tracks and for high-speed tracks. The use of asphalt in railway construction provides a positive contribution to the bearing capacity of the structure. It improves both the stability and the durability of the structure, which contributes to the reduction in the need for maintenance. In addition, the use of asphalt also helps to reduce vibration and noise.

The use of asphalt may reduce the total construction height of the superstructure, which is of importance in the case of tunnels and bridges.

Applications of asphalt in railway construction can be divided between use as sub ballast layers and use as full depth (asphalt) construction, also called the ballast-less track.

### 3.1 Asphalt as sub ballast layer.

The rail ballast absorbs the train weight and distributes it from the rails to the sub grade, thereby avoiding any deformation. The railroad can thus keep its geometrical features. The rapid decay of the railroad level which occurs with traditional ballast construction is mainly due to the unsatisfactory "fatigue behaviour" of the ballast; this is mostly due to embankment settling.

By interposing a special semi-rigid layer (the so-called "sub-ballast") in the area between the ballast and the embankment, the behaviour of the overall structure is greatly improved. The sub-ballast is normally laid on a highly compacted embankment layer.

The sub-ballast functions are:

- to create a working platform on which subsequent work operations, such as installation of electric lines, ballast and rail laying, are more easily undertaken;
- to assist in distributing the loads transmitted by passing trains;
- to protect the embankment body from the seepage of rain-water and from seasonal thermal extremes (frost and thaw cycles);
- to eliminate contamination of the ballast from fine material migrating up from the foundation;
- to distribute the concentrated pressures and eliminate any "rupture" of the embankment.

A railway structure with sub-ballast works almost exclusively on compression and, therefore, differs from a traditional structure. This consequently eliminates fatigue cracking.

Especially on high-speed tracks maintaining levels and profile is of high importance. This can be achieved by increasing the stiffness of the structure. A higher stiffness has as a consequence a better load distribution to the ballast and sub ballast material. This will prevent an early deterioration of the rail geometric. In this case the use of asphalt in a sub-ballast layer can offer the solution.

The application of asphalt as a sub-ballast layer will contribute to the following aspects:

**Bearing capacity**

The application of a monolithic layer (0.1 – 0.2 m) of asphalt, as a sub-ballast layer will increase the stiffness of the total structure. The fact that an asphalt layer is also capable of withstanding tensile forces gives an extra positive contribution to this effect.
- Geotechnical stability
  The relatively high stiffness of the asphalt sub-ballast layer will make a positive contribution to the compaction of the layers on top of the asphalt layer. This improves the total stability. So the asphalt mix sub-ballast contributes to keeping the railroad geometry unaltered.

- Resistance to vertical deformation
  The relatively high stiffness of the asphalt layer compared to granular material will lead to less permanent vertical deformation by trainloads. The vertical loading conditions and the relatively short loading time are relatively small, so there will be no permanent deformation in the asphalt layer.

- Drainage
  When a layer of dense asphaltic concrete is used as a sub-ballast layer, optimal drainage of the total structure will be realised. The impermeable asphalt sub-ballast layer can prevent possible contamination of the sub-structure by vertical hydraulic transport of mud and fines.

- Durability
  Because of the confinement of the ballast by the asphalt layer, the ballast layer is strengthened and deterioration of the ballast is reduced. The asphalt sub-ballast layer increases the foundation modulus, providing a more rigid foundation, with the effect that there is a reduction of tension and shearing stress inside the ballast material, with consequently less fatigue and less degradation and wear of the individual aggregate particles. Because of the low air voids in the asphalt mix (1 – 3%) and because the asphalt layer is buried, weather effects (temperature changes, Ultra Violet radiation, oxygen) will not affect the hot mix, so no deterioration (aging) of the asphalt or bitumen will take place. Even if limited deformation of the sub-soil does take place, this will not affect the asphalt layer because it is capable of withstanding the deformation without losing its integrity because of the visco-elastic properties of asphalt.

- Noise and vibrations
  The mechanical properties of the asphalt layer will lead to a reduction in the vibrations and noise produced by passing trains. The use of modified asphalt (polymer modified bitumen, rubber crumb) can further improve the vibration dampening effect of the sub-ballast.
3.2 The ballast-less track / The direct application of the sleepers on the asphalt

For many years there have been developments aimed at improving the stability of the traditional rail-track structure of rail, sleepers and ballast. The introduction of high-speed trains and the desire for less maintenance led to the development of the ballast-less track. 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 flat and level surface in order to comply with the narrow 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.

The first successful application of the ballast-less tracks dates back to the beginning of the 1990’s, in Germany. Other experimental tracks have been built since then, mostly in Germany.
4. Experiences

4.1 Italy
The first experience with asphalt mixes in high-speed railway construction in Italy date from the early 1970s. Hundreds of kilometres have been built in the last 20 years. The results have been very satisfactory and have shown that the application of an asphalt sub-ballast layer contributed to the stability of the rail geometry. In particular, at critical points such as switch points, expansion joints, level crossings and in areas between concrete structures (bridges) and embankments, where dynamic forces are substantial, the asphalt sub-ballast layer introduced a remarkable improvement of the superstructure stability.

Within a few years, more than 1200 km of high speed lines will be equipped with a sub-ballast layer.

Experience with polymer modified bitumen in asphalt mixes for sub ballast layers has shown that the application of this type of mix is also very promising with regard of the reduction of noise and vibration. This is another positive contribution of asphalt to both the comfort of rail passengers and to the environment.

The Italian Asphalt Association (SITEB) and the Italian Railways (FS) have carried out extensive research in this field.

The sub-ballast is made up of an asphalt mix (100-140 mm thickness), laid by normal paving machines. It has the typical behaviour and well-known advantages of visco-elastic materials. In Italy there is a good geographical spread of asphalt production units, ensuring that there are no real difficulties with the logistics of asphalt supply. Moreover, site vehicles can be driven on asphalt just a few hours after the laying.

When the asphalt mix solution is compared with cement mix solutions for the sub-ballast, the following advantages are evident in favour of asphalt:
- reduced use of aggregates due to the lesser thickness of the asphalt sub-ballast layer (average 120 mm thickness compared to at least 200 mm);
- cracks are less likely to emerge;
- there is no need to protect the finished surface by means of bitumen membranes or emulsion spray;
- time for "hardening" is much shorter.

Experience shows that the presence of an asphalt sub-ballast layer in the railway structure also results in a reduction in the vibrations transmitted by the passing trains to the surrounding environment; the asphalt sub-ballast then acts as a damping medium.
4.2 Germany - Solid Railway Trackbed

4.2.1 General Issues
The rail web (rails and sleepers) with ballast bedding type of construction has reached a level that is hardly capable of improvement as a classical construction method for railway track. Furthermore, in the case of routes designed for very rapid passenger traffic, it has been found that wear and tear takes place much more quickly than expected through stone displacement, breakage and abrasion because of the dynamic traffic loads on the railway ballast. As a result, track bed deterioration occurs more frequently and requires maintenance work at more frequent intervals. This maintenance work is costly and disrupts normal railway operations.

The load-bearing ballast can be replaced by asphalt. This construction method was used for the first time in Germany around 25 years ago, with an asphalt base course. Since then, seven different systems of the asphalt construction method have become approved by the DB AG. They are the following, in detail:

- SBV Sleepers with bituminous sealing
- FTR Prefabricated frame
- ATD Asphalt base course with a rail web
- SATO Concrete sleeper or Y-steel sleeper with double base
- FFYS Solid railway trackbed with Y-steel sleeper
- Walter System Walterbau
- GETRAC [A] German Track Corporation Asphalt.

In addition to the fastening technique, paving at the precise height is extremely important. Although, in the beginning, milling off was still necessary in part to achieve the required height precision, evenness of paving has since been improved to ± 2 mm, with reference to 4 m, through multi-layer paving and laser-supported paving technology.

With the above-mentioned systems, several sections have been constructed in Germany to date.

4.2.2 Requirements for the asphalt layers
In general, the requirements for the asphalt are determined by the load type. 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. On roads, the actual distributed load results in a wheel load of 5.75 tons for a truck with an 11.5-ton axle, which works out to around 0.8 MPa for a surface area of around 710 cm². For railways, however, there is a considerable load distribution over the rail and the sleeper. The wheel load of 11.25 tons results in stress on the bottom of the sleeper of around 0.25 MPa, and thus only around one-third of the load experienced on roads.

The asphalt needs to be designed to be permanent, flexible and dense in order to avoid maintenance work and subsequent improvements, which are practically impossible. The lifetime of the solid railway trackbed has been estimated to be around 60 years. Experience in Germany has shown that asphalt types with a high binder content and a low void content have proven to be reliable.
4.2.3 Paving
The paving can be done with the normal types of finishers available today. However, there has to be careful planning of the asphalt work and the paving in order to achieve the required precision (heights, axes). The surveying programs used for road construction cannot be used for the solid railway trackbed; electronic data-processing programs specially developed for this have proven to be reliable.

The guide-wire and supports used to control pavers operating on road construction sites cannot be directly adopted for railway construction. Instead, modifications to the support equipment are necessary to permit fine adjustment. In addition, the supports need to be set up at shorter intervals (< 5 m) in order to avoid sagging of the wire. The structure of the solid railway trackbed will depend on the particular fastening system. As a rule, the asphalt will be laid in at least 4 or 5 layers in order to achieve the required evenness. At least 4 layers are necessary with an overall thickness of 30 cm for the ATD system. The position of the guide wires requires to be checked on a regular basis during the paving. In addition, the height behind the finisher requires to be checked after every layer is paved.

Compaction of the asphalt after paving could result in a change in the finished level and evenness. The use of finishers with a screed providing a high level of pre-compaction is therefore indispensable. The compaction itself needs to be done with a small smooth-wheeled roller. Further requirements are a uniform composition of the mixture, continuous transport in order to avoid a standstill in the paving, a constant paving speed and a steady paving temperature.

4.2.4 Advantages
The solid railway trackbed laid in Germany to date has been shown to be very successful. This success is fully justified by the reliable paving and by the material-specific characteristics of the construction material asphalt:

- 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 because of this.
- 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.

The solid railway trackbed made of asphalt is a promising alternative to a ballast-type track and other construction methods for the solid railway trackbed.
5. **Literature**


*(English)*
