

Crumb Rubber Modified Bitumen for sub-ballast layer

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1.- Introduction.

Ballasted tracks have a number of benefits, making them the most widely used since the beginning of the railway. However, new railway infrastructure objectives (increase of high-speed traffic, development of new commercial scenarios and the raise of maximum speeds to 350 km/h), require new low maintenance structural solutions. Track structural design plays an important role in the performance of rail service and may be a key issue to improve the operational profitability and promote new investments and renewal lines. Railroad track geometry deterioration due to both ballast and subgrade differential settlement is usually responsible for the most relevant part of track maintenance costs, and one of the main problems confronting the engineers responsible for railway maintenance. Moreover, geometry deterioration due to soft subgrade support will worsen with an increase in train axle loads or operating speeds.

In the last decades, on Europe and around the world, railway conventional ballasted track structures with granular trackbed (composed of crushed stones) have been made and are still operative. These kind of lines present good results but, in most of cases, require notable maintenance to ensure adequate operating conditions. Whereas one of the principal aims of the railway companies is to limit track maintenance costs and increase track availability, the track on ballast must be replaced by a solution with better performance as well as acceptable costs of maintenance and operation. The improvements made on the railway track design have played an important role on the development of the performance of this transport mean.

A modern form of rail track is slab track. This kind of rail track has been used successfully and, in some cases, can be a cost-effective solution. However, slab track may involve significant investments, because the reduction of track maintenance does not offset construction costs, making it still difficult to be profitable, particularly where the line has a low number of bridges and tunnels. In those situations when the advantages of slab track solutions do not compensate their higher construction costs, it is important to find alternative solutions that lead to a satisfactory balance of cost without increasing on the investment. To achieve this objective asphalt layers are normally used in combination with traditional granular layers in various configurations. Effectively, from the point of view of trackbed design, the use of a bituminous sub-ballast may improve the geometric performance of the railway infrastructure and contribute to an effective reduction of track maintenance needs.

According to the Spanish National Transport Plan (PEIT 2020), about 10000 km of high speed tracks (double track, international gauge) are planned to be built. One track km requires around 4000 m³ of subballast, and thus up to 40000000 m³ would be needed during this period.

This paper analyses the performance of a bituminous sub-ballast as an alternative to the conventional sub-ballast granular layers and evaluates the benefits.

2.- Bituminous Sub-Ballast as a alternative to reach high bearing capacity.

In the last few years, railway structure has suffered constant changes. In fact, superstructure must be able to ensuring the correct geometry through the maintenance of layers' dimensions over the years, hence limiting the frequency of maintenance to repair problems related to the collapse or sagging. In this sense, the latest research has confirmed the importance of having a stiff subgrade and maintaining properties during the years.

The conventional sub-ballast materials used in Spain for the layer are gravel and well-graded sand, with good durability and bearing capacity. They must satisfy the following requirements:

- The 100 % of material kept in the number 4 (Nº 5 ASTM) sieve is marked as "crushed". No limestone.
- The subballast should not contain parts of any of the following materials: wood, organic matter, metals, plastics and volatile rocks. Thixotropic, expansive, soluble, decaying, combustible and pollutant (industrial waste) materials are also not allowed.

- Organic matter content under 0.2 % of weight in sieve number 2 (N° 10 ASTM).
- Sulfate content under 0.2% of weight in the fraction passing through sieve number 2.
- Subballast should be made of well graded sandy gravel with a small percentage of fine elements.

Nowadays, this solution might require very high thicknesses to reach the minimum bearing capacity standards, with a consequent increase in construction costs. Finding this kind of material might be also difficult or environmentally damaging as open range quarries and the transport of several millions of m³ of granular material cause a significant visual impact. In addition, these materials transmit noise and vibration generated by vehicles. Open track, special trackwork like switches or turnouts, crossing diamonds, bridge approaches, tunnels and tunnel approaches are some applications where asphalt layer provides a good solution.

During last years, certain railway administrations and the asphalt paving industry have developed layers of hot-mix to be used within the track structure in lieu of conventional all-granular subballast, becoming a common consideration for specific conditions and replacing the traditional track. However, the asphalt layer is normally used in combination with traditional granular materials, as an intermediate solution between ballast track and slab track. This solution was employed in the first Italian high-speed line and also in Japan, for example. The experience obtained in Italy after 20 years evidenced a good long-term structural behaviour, leading to the generalization of its use.

Nowadays new materials are being investigated; some of them even incorporating waste surpluses from other areas such as scrap tires, hence considering the possible use of these with the benefits of recycling.

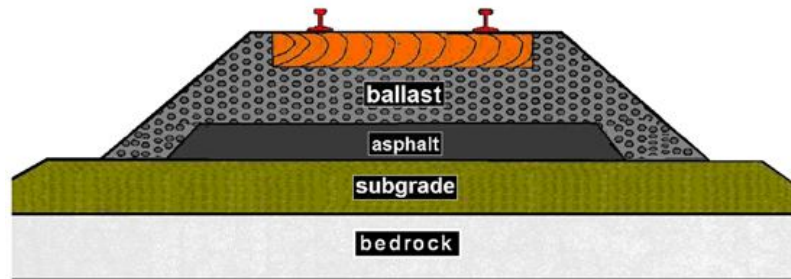


Figure 1. Schematic asphalt Underlayment trackbed with asphalt subballast layer [1].

3.- Track design with bituminous sub-ballast and experiences

The use of traditional sand and gravel layers aims to fulfill an accurate protection of the formation not only against railway traffic loads throughout life cycle, but also against weather effects and external actions. Asphalt trackbeds for railway must be designed and constructed to ensure a proper performance for the traffic, climate, and soils in given areas. Recent efforts in materials selection, mixture design and performance testing are being developed by principal railway administrations, asphalt industries and their research groups. Mixtures need to be optimized to resist rutting or fatigue cracking, depending upon which layer and conditions are being considered. 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.

In order to predict and assess the structural behaviour of bituminous sub-ballast it is possible to study the response of the rail track using a numerical model based on finite element. A simple study to obtain the minimum requirements for the bituminous sub-ballast was made and compared with a traditional solution of granular sub-ballast with thickness of 30 cm, which is the typical set of lines.

To develop this study we used the ANSYS software. Usual assumptions in such models were adopted, which are described below:

- Concerning the material properties: for soil and granular layers, Drucker-Prager elasto-plastic constitutive laws were used, while both elastic and visco-elastic model were used for the bituminous subballast. An elastic railpad stiffness of 100 Kn/mm was considered.

- Concerning model geometry: the track model geometry considers 11 sleepers, a width of 9 m considering the base of landfill and 3 m of subgrade depth with QS3 quality is adopted. Usual symmetries on vertical plans are assumed as usual boundary conditions.
- Concerning track load: an equivalent dynamic axle load was obtained by considering Eissenmann's criterium for current high-speed vehicles.
- Concerning finite elements type: 20-nodes hexahedral elements (SOLID95).
- Concerning contact elements: contact interface were considered for the interaction between sleeper and ballast, so as to substitute rigid nodes between these two surfaces of contact: double nodes were considered and displacements on the surface plan were allowed while restricted on the perpendicular direction.

The results obtained performed for track show that the thickness required stands between 12 cm and 14 cm to guarantee a good theoretical behaviour in terms of displacements and stresses (Figure 3). These considerations were further validated through elastoplastic finite element modelling. No significant differences in behaviour were found, but there were an increase of the computation time and convergence problems. However, due to good performance of asphalt mixtures, the thickness can be reduced to 9 cm. From another point of view, the service life is at least equivalent to the current track. This means that considering fatigue criteria based on horizontal tensile strain on the bottom of the layer (determined by Asphalt Institute and current Spanish roadway standards) it is found that this fatigue will occur after the fatigue of the subgrade, hence behaving properly over the life cycle.

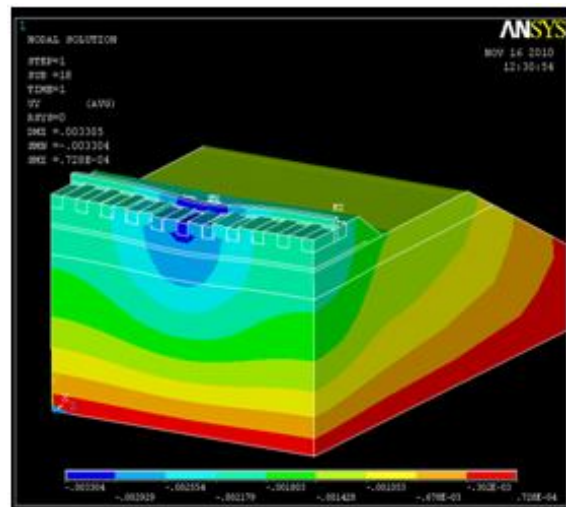


Figure 2. Ansys displacement results.

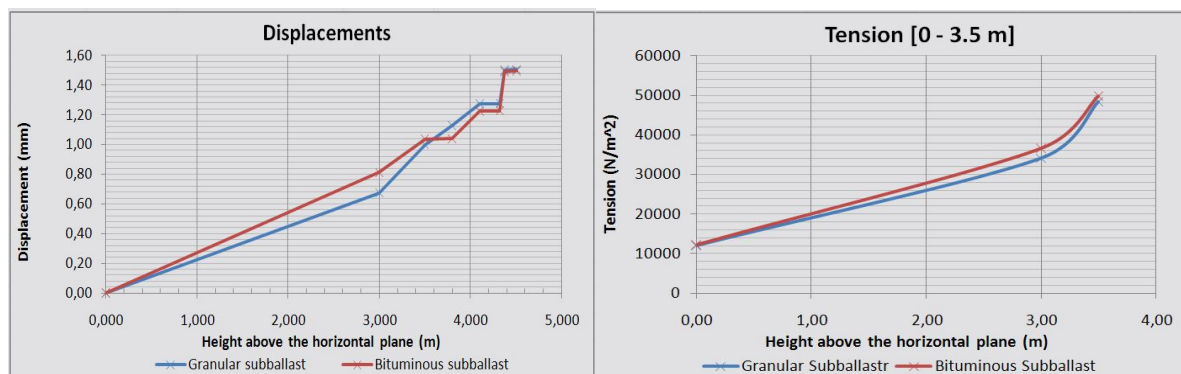


Figure 3. Comparative results from numerical analysis.

One of the most interesting conclusions obtained after analysis of the results shows that increasing sub-ballast thickness is more effective than using high modulus bituminous mixes. On the other hand, trackbed vertical stress levels on the asphalt layer under heavy tonnage railroad loadings are reduced to only a fraction of those imposed by high-pressure truck tires on highway pavements.

With respect to the practical experience gained in different countries, it should be highlighted that several countries are actively involved with the construction of new segments or complete rail lines with bituminous trackbeds. More specifically, the work developed over the early 1980's in the United States allowed the construction of asphalt trackbeds. It was primarily used for maintenance techniques and applications in existing tracks but when his behaviour was proved to be positive, the

use spread to new lines. Typically, the asphalt layer used is 15 cm thick and is topped with conventional ballast.

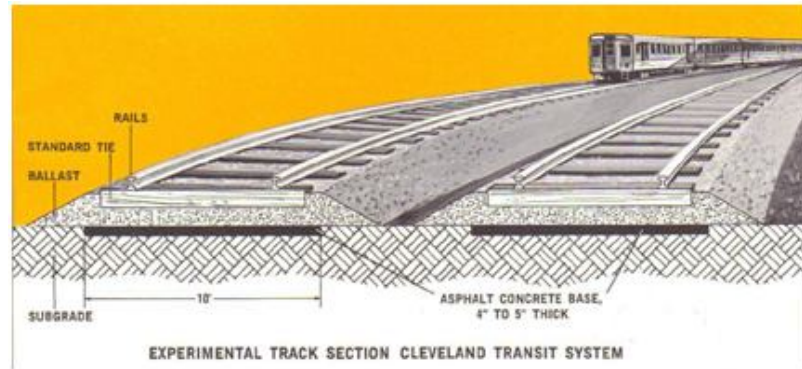


Figure 4. USA asphalt layer example [3].

Meanwhile, Japanese railways have used asphalt trackbeds solutions on certain test sections for their high-speed rail lines since the 1960's. However, it was not until the 1970's when asphalt trackbeds with ballast cover became a standard on newly constructed rail lines. The reason initially considered to use asphalt trackbeds was been to provide a firm support for the ballast and to reduce problems caused by track irregularities. For these reasons the first design was made of 5-cm thickness asphalt layer whose function was to make a waterproofing layer and facilitates drainage. The Japanese believe that this will reduce the load level on the subgrade to prevent subgrade deformation and reduce maintenance costs associated with ballast fouling from subgrade pumping. For performance-based design, track settlement and asphalt fatigue damage are the parameters to be considered.

One of the countries with the widest experience incorporating asphalt trackbeds in their rail lines is Italy. Rome to Florence high-speed line was the first line where an asphalt layer was placed and then hundreds of kilometers have been built thereafter. The results obtained over time have been very satisfactory allowing the application of an asphalt sub-ballast layer in new Italian lines. In this case, the typical asphalt layer thickness is 12 cm with 30 cm of super compacted subgrade and 35 cm of ballast on top. The asphalt sub-ballast is placed using standard asphalt paving machines and then compacted using vibrating rollers to 98% of maximum density. It is noteworthy that asphalt sub-ballast layer introduced a remarkable improvement of the superstructure stability particularly at railway critical points such as switch points, expansion joints, level crossings and in areas between concrete structures (bridges) and embankments where dynamic forces are considerable. Finally, it is noteworthy the experience developed with polymer modified bitumen in asphalt mixes. This type of material has shown an important reduction of noise and vibration.



Figure 5. Aspect of asphalt trackbed for railway track [2].

Germany's rail network has undergone constant improvements, being the field of asphalt one of the most prominent and using several alternatives to conventional ballast design. Germans soon noted that wear and tear takes place more quickly than expected through stone displacement, breakage and abrasion because of the static and dynamic traffic loads applied on the railway ballast, thus requiring frequent maintenance. Around 25 years ago the asphalt base was used for the first time. Since then, a lot of different systems of the asphalt construction method have been approved by the DB AG, being Getrac method the most recent asphalt ballastless track system used.

Another country that has joined the experimentation and implementation of the use of bituminous sub-ballast is France who installed a 3-km test section of asphalt on line Paris-Strasbourg Eastbound. The main idea is to analyse the effects of high-speed trains passing through various test sections to determine the benefits of using asphalt trackbeds and the possibility of implementing them for future high-speed passenger lines. Those sections are completely instrumented to analyse and register numerous effects, parameters and other aspects, providing information for new designs and treatments.

Regarding the equipment and techniques required for installing the asphalt layer it can be stated that the procedures vary depending on the size of the installation and the type of treatment. It is noteworthy that the cost of placing the asphalt layer is similar to that of conventional granular subballast. Therefore, talking about short maintenance or/and rehabilitation operations, the asphalt is back-dumped on grade and spread with a trackhoe, small dozier, bobcat, etc. already on site, prior to compacting with a conventional vibratory roller.

With respect to new construction with a prepared subgrade, the asphalt layer is built with conventional asphalt paver and then compacted with conventional vibratory rollers, similar to highway construction, so there is no need for specific machinery.

4.- Advantages of bituminous sub-ballast

When comparing bituminous sub-ballast with all-granular solutions, the former can offer important advantages from the point of view of long term deterioration of the subgrade. The main features of the use of bituminous sub-ballast are:

- Distributed loads induced by rail cars, protect embankment both from water seepage and penetration of ballast items.
- It is not affected by freezing and is waterproof, allowing separate layers, and, therefore, prevent the migration of the material and thus the pollution of the railway ballast.
- It is a readily available product and production facilities are located throughout the country.
- It is quick and easy to lay with current construction methods, does not need a specialized technique. Stretches can be laid on a daily basis at a rate of production which halves construction times.
- It ensures that work vehicles can transit very soon after the ballast layer has been laid without inconvenience or consolidation time as with granular layers. A shorter construction times are achieved. There is no need to protect the finished surface by means of bitumen membranes or emulsion spray.
- It uses less granular material (which is costly as a result of the environmental problems involved in finding the natural aggregates and transporting them), allowing material savings of 40% compared to solutions that incorporate cement binders.
- It performs well with regard to wear and tear, since the stress-strain level is reduced compared to road layers.
- It adapts easily to any sagging in the platform and foundations without cracking, is suitable for irregular surfaces and nevertheless maintaining its ability to distribute stress underground, thereby protecting the platform and providing waterproofing.

- It can be paved at a precise tolerance due to its material characteristics.

Bituminous sub-ballast mix also has another important advantage, which is to be decisive for areas where there are nearby homes. The problem of vibrations and noise near urban areas are a relevant impact factor and can produce complaints from people. Bituminous mix attenuates solid-borne vibrations transmitted to the embankment and nearby structures and subsequently, distributes them throughout the area of concern. Other advantages of using a bituminous sub-ballast mix layer are related to the differential settlement of the track, particularly in singular points which cause many problems that require special attention. In fact, the use of stiffer materials as subballast can also reduce vertical stiffness variations on the track, reducing the magnitude of dynamic loads and, therefore, the need for action on the track.



Figure 6. Bridgeport, Alabama bridge approach [9].

Moreover, the benefits already attained may even be even increased by adding rubber granulates into the bituminous mix, because those improve their ability to dissipate energy and damp vibrations given the great propensity to dissipate energy of this kind of composite material. Some previous laboratory and small-scale tests have shown that rubber modified asphalt has high stiffness and high damping ratios compared with ballast, concrete, and conventional asphalt. These attenuation characteristics allow to reduce track and equipment maintenance costs, and improving the long-term performance of the track structure.

From the perspective of structural behaviour, it is noted that the bituminous sub-ballast may allow an important reduction in the seasonal vertical displacements, up to 50% or more under poor drainage conditions and not exist technical problem when replacing the ballast layer.

5.- Economical benefits.

Analyzed in economic terms the bituminous sub-ballast a number of conditions should be noted. Transport distance is a key factor in the cost of the granular sub-ballast, so it is necessary to take into account the availability of materials near the railway line in order to establish a comparison. Considering this fact, the cost of granular subballast, if quality granular subballast has to be transported a long distances, may exceed the cost of bituminous mix. Meanwhile, the bitumen cost was is the main cost factor of bituminous subballast and normally asphalt is compatible with a wide variety of aggregates.

Making an economic study, it can be determined that due to the dependence of granular material cost with distances from available quarry available, granular layer is more expensive than bituminous solution for transport distances above 60 to 80 km. This is a first approximation, but it is necessary to have updated data and costs to determine the distance from which a product is more advantageous

over the other. However, although for short distances the price of bituminous sub-ballast may be higher, the benefits it provides can be a key factor in determining its construction.

On the other hand, the thickness and width of the asphalt layer is normally less than that dimensions of granular subballast, which is also a cost advantage for asphalt. In addition it also provides a reduction of volume when applied. This reduction is estimated around a 200 m³/km/track because the waterproof characteristics of bituminous sub-ballast layer allows drainage with a track lateral slope less than that of granular sub-ballast, with the corresponding saving of material. Thus, the amount of ballast material saved may be equivalent to around 5% of the price of the bituminous sub-ballast layer.

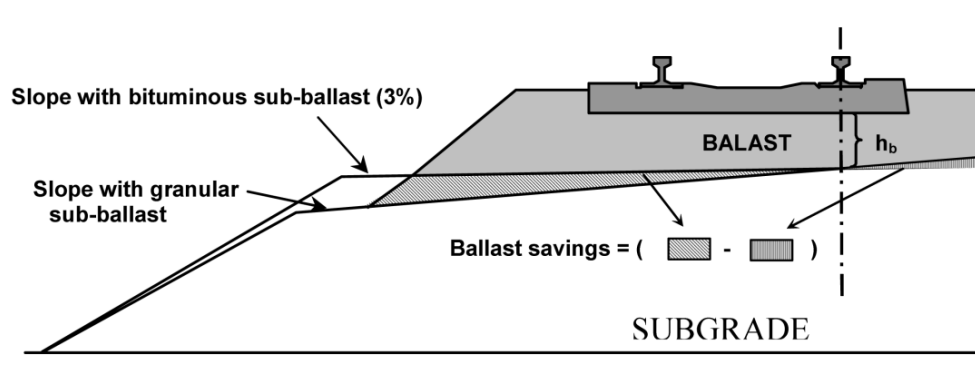


Figure 7. Schematic representation of the savings in ballast material [4].

6. Conclusions

The maximization of the use and service of the railway infrastructure, considering the development of society and future perspectives, seem to lead the conventional railway track with granular layers to exceed their structural capabilities, requiring higher maintenance needs. Nevertheless, the aim of this paper is to discuss the importance of a bituminous sub-ballast layer, and the possibilities that this solution offers.

During the last years the asphalt paving industry have developed designs and applications for using a layer of hot-mix asphalt within the track structure in lieu of conventional all-granular subballast. Properties, viability and benefits of the bituminous sub-ballast has been analysed and compared. One of the main characteristics is that it allows reducing overall cross-sectional thickness. From a theoretical design, with finite elements, the minimum thickness is between of 12 cm to 14 cm, in comparison with 30 cm of conventional granular layer. This thickness may be lower, depending on the characteristics of the asphalt mix used and the quality of support, allowing savings of a larger amount of material with the benefits that entailed.

Bituminous sub-ballast might bring relevant advantages among other aspects: subgrade protection and life cycle; track differential settlement and track dynamic performance, decreased abrasion, and increased life of the ballast, decreased wear and improved fatigue life of the ties, rail and reduced maintenance activities, among other relevant aspects. It is protected from extreme environmental effects of sunlight, rainfall, and temperature due to the insulating effects of the overlying ballast and railway track. It is found that the bituminous sub-ballast may allow an important reduction in the seasonal vertical displacements, up to 50% or more under poor drainage conditions.

An economical study (standard conditions applied) determines that the cost of the bituminous sub-ballast might be close to the cost of the granular solution. Depending on granular sub-ballast transport, bituminous sub-ballast can be a structural solution. Furthermore, it will be possible to outline and standardize building methods which will improve the performance of the entire railway structure. The construction of new rail lines represent ideal conditions since the exposed subgrade is available for placing the bituminous layer with conventional highway asphalt paving prior to placing the ballast.

The ongoing research and development of new techniques of maintenance for tracks with bituminous sub-ballast will encourage the addition of this solution to many railway lines in the close future, supported by a solid life-cycle costs analysis on the viability of this solution.

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