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UTILIZATION OF ASPHALT/BITUMINOUS LAYERS AND COATINGS IN RAILWAY TRACKBEDS – A COMPENDIUM OF INTERNATIONAL APPLICATIONS

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ABSTRACT

During the past thirty years the use of a layer(s) of hot-mix asphalt pavement within railway track structures has steadily increased until it is becoming a common consideration or practice for specific conditions and areas in several countries throughout the world. This practice augments, and for certain designs replace, the traditional granular support materials. It is considered to be a premium trackbed design. The primary documented benefits are to provide additional support to improve load distributing capabilities of the trackbed components, decrease load-induced subgrade pressures, improve and control drainage, insure maintenance of specified track geometric properties for heavy tonnage freight lines and high-speed passenger lines, and decrease subsequent expenditures for trackbed maintenance and component replacement costs. The asphalt layer is normally used in combination with traditional granular layers to achieve various configurations.

This paper presents a compendium of International Asphalt Trackbed Applications. The various factors are discussed that are considered in the design phases and subsequent performance-based tests and analyses. Illustrations include typical sectional views of the trackbed/roadbed components and thicknesses and photographs of construction and finished views for various asphalt trackbed applications in several countries. Following are brief accounts for selected significant international activities emphasizing high-speed and intercity passenger rail line applications.

In the **United States** the use of asphalt trackbeds has steadily grown since the early 1980's. It is primarily used for maintenance (cure-all) applications in existing tracks to improve trackbed performance and for new trackbed

construction where the projected superior performance of asphalt trackbeds can be justified economically. Typically the asphalt layer is 15 cm thick and is topped with conventional ballast. This application does not deviate significantly from typical designs, except the asphalt is substituted for a portion of the granular support materials.

Several other countries are actively involved with the construction of new segments or complete rail lines using asphalt (frequently termed – bituminous) trackbeds. For instance, **Japan** has used asphalt trackbeds on certain test sections for their high-speed rail lines since the 1960's, but since the 1970's asphalt trackbeds with ballast cover is a standard on newly constructed rail lines. The 5-cm thickness of asphalt primarily serves as a waterproofing layer and facilitates drainage. The Japanese believe that this will assist in reducing subsequent maintenance costs associated with ballast fouling from subgrade pumping. The Japanese have recently instigated a performance-rank design system. Asphalt trackbed designs are either required or are an option for the two premium trackbed performance ranks. **Italy** represents another country heavily involved with incorporating asphalt trackbeds in their rail lines. In the late 1970's Italy placed test sections of both asphalt and concrete on their original Rome to Florence high-speed line. From the Italian perspective the asphalt out-performed the other test sections, leading to standards requiring the use of asphalt trackbeds on all newly constructed high-speed passenger rail lines. The typical asphalt layer thickness is 12 cm.

Germany has focused on using asphalt for ballastless trackbed designs. The main asphalt track in use in Germany consists of concrete ties or slab track placed on a 26 to 30-cm thick layer of asphalt. Various designs are incorporated into

the system. Recently **France** installed a 3-km test section of asphalt on their Paris to Strasbourg Eastbound High-Speed Line. The French are currently observing the effects of high-speed trains traversing various test sections to determine how beneficial the use of asphalt trackbeds will be for future high-speed passenger lines. The sections are heavily instrumented for analyzing numerous trackbed induced effects on ride quality and other aspects.

Other countries, a recent addition includes Spain, are involved to varying degrees with the development of asphalt trackbed technology, particularly for high-speed and intercity passenger rail lines. Pertinent information and documentation of recent findings and results are included in the paper.

INTRODUCTION

From the austere beginning of the railway mode of transportation in the 1830s, the classic two parallel rails have been the identifying support and guiding mechanism for locomotives and trailing cars. Originally, the track consisted of small size rails attached to widely-spaced wood cross ties. As wheel loads, train frequencies and speeds increased, it soon became obvious that merely placing the rails and ties on the original/natural ground with little attention to the supporting materials would not suffice. The natural ground support varied considerably from one location to another resulting in undulating tracks. Ultimately, the ties became imbedded in the ground (soil) requiring considerable effort to adjust the profile and alignment of the track. These problems were exuberated for tracks traversing areas of poor quality soils (i.e., clays, peats, uniform silts, etc.) particularly during periods of prolonged precipitation and freezing/thawing conditions.

CLASSIC ALL-GRANULAR TRACKBED DEVELOPMENT

It became obvious that the quality of the support below the ties would have to be improved. Larger rail and larger ties more closely spaced provided some degree of improved load distribution. Further investigation revealed that a combination of natural mineral aggregate, stone, or rock was necessary and desired for placement around and under the ties to restrain excessive horizontal and vertical movements and displacements; thereby providing an improved track structure. Thus, the classic all-granular support trackbed began as a simple application of naturally occurring aggregate, stone, or rock, as structural support for the rail and ties. It was soon determined that this additive provided a track that was safe for higher speeds, provided for a smoother ride, minimized track maintenance activities, and ultimately resulted in an overall lower cost, increased track life, and a higher quality support structure. This material was termed “ballast.” Initially, little attention was given to the quality of the ballast material or to the actual quantity (mainly thickness under the ties) used for specific trackbed applications. Normally, naturally occurring aggregate materials from nearby sources were selected to minimize costs. However, these varied in their effectiveness

depending on their inherent strength and durability properties. Thus, the classic All-Granular trackbed configuration and structure evolved over the years as a reasonably simple structure.

As wheel loads, train frequencies, and speeds further increased attention was given to specifying larger rail size, selecting larger size ties that were spaced closer, and specifying a certain quality and width/thickness of ballast around and below the ties. The ultimate objectives were to reduce the imposed loadings to within the bearing capacity of the natural subgrade material, thereby providing uniformly strong support. Drainage was realized early-on as being very important, since most subgrade materials would lose considerable load-carrying capacity when they became wet or saturated. Thus draining surface water from within the track and directing water away from the track as expeditiously as possible were prime considerations.

The quality of the ballast was later given particular attention. The “ideal” ballast, and the one selected for the highest performance mainline tracks, was considered as “premium-grade” ballast. This required a crushed material composed of a hard, tough, and abrasion-resistant rock, thus the term “mainline” ballast, which would resist breakage, abrasion, and other forms of deterioration. In addition, the specified thickness of the premium ballast was increased to further distribute the imposed loadings. In order for the ballast to remain “workable,” so that track adjustments could be easily achieved to restore the required track geometry, it was necessarily composed of fairly large-size particles with a very small percentage of fine-sized particles. This type of particle grading is known as “open-graded” and even after the ballast obtains its maximum density; it still contains high voids content. Thereby it obtains maximum shear strength as a function of the interlocking of the crushed particles. The voids aid in draining water, and this size configuration is amenable to being adjustable when the track geometric features need to be restored.

However excessive fine particles can overfill the voids in the ballast and serve as lubricants forcing apart the large angular ballast particles. The fine particles can be 1) generated from ballast deterioration/breakdown due to loading-induced or other forms of deterioration, 2) the result of fines being “pumped” from the underlying subballast or soft subgrade, 3) dropped unintentionally from coal or grain cars, or 4) carried in by wind or washed in by water from the top. The result is a loss of internal friction, or shear strength, the main load distributing mechanism of ballast.

A further refinement of the support structure was the introduction of a specified thickness of “subballast” material between the ballast and subgrade. Typically this is a locally available aggregate material that has smaller top size than typical ballast and contains considerably more fine-sized

particles. It will compact to a very low void content with very low permeability. It is similar to the aggregate base material widely used for highway construction. Its main purposes are to provide support for the ballast, further distribute the loadings, and provide a certain level of waterproofing for the underlying subgrade. This improves the quality and load-carrying capability of the track structure. This trackbed design is known as “All-Granular” since no additional cementing or binding materials are incorporated in the various support materials and layers.

The classic investigation of the factors affecting the design of track structures and the resultant guidelines emanating from the study is the A.N. Talbot reports. These reprinted reports, based on research studies conducted from 1913 to 1942, contain empirical relationships for determining subgrade pressures and selecting ballast thicknesses (AREA, 1980). The reports were reasonably current for the time period, but mechanistic designs applicable for assessing a variety of trackbed designs have been developed during the past few years and currently have limited, but increasing utilization.

Figure 1 depicts the classic “All-Granular” trackbed design. For high-type trackbeds the quality of the materials and associated dimensions of the materials and layers are specifically selected and specified. It is assumed that proper attention is given to providing surface drainage to minimize the possibility of standing water seeping into the track structure, thus weakening the subballast or subgrade. The high-traffic mainline tracks require higher quality and thicker layers of ballast and subballast to resist the loadings and to effectively distribute the loadings to the underlying subgrade layer. Variations of this design has been common for the majority of the trackbed construction since the late 1800s and is currently the predominate design of railway track structures throughout the world. During the past 30 or so years, additional designs, incorporating Asphalt layers, have been gaining favor with designers and specifiers for specific applications in-lieu-of the classic All-Granular design.

ASPHALT TRACKBED DEVELOPMENT AND VARIATIONS

Since the early 1980s, the U.S. railroad industry has been selectively utilizing Hot-Mix Asphalt in the track structure as a support layer. Applications have been evaluated in other countries as well. The layer of asphalt, similar in composition to that commonly used for highway construction, distinguishes the track structure from the classic All-Granular trackbed. This development is in response to the impending challenges to provide higher quality and longer lasting track and support structures to accommodate the unprecedented growth in rail traffic volumes, revenue ton-miles, axle loadings, and tonnages being experienced throughout the world. Primary emphasis has been placed on developing and evaluating the

asphalt trackbed technology for Heavy-Tonnage Freight railroads in the United States and High-Speed Passenger railways in other countries.

Three basic types of asphalt trackbeds are being utilized. Two of them incorporate the traditional ballast layer as a portion of the support. The so-called “Asphalt Underlayment” trackbed is similar to the classic All-Granular trackbed; the sole difference being the substitution of the asphalt layer for the granular subballast layer. The typical cross-section is shown in Figure 2a. The “Asphalt Combination” trackbed includes both the asphalt layer and the granular subballast layer. The asphalt layer thickness may be lessened somewhat since a relatively thick subballast layer exists below. Figure 2b depicts this design.

The “Ballastless Asphalt Combination” trackbed consists of ties, or slab track, placed directly on a relatively thick layer of asphalt and a relatively thick underlying layer of granular subballast. These thickened sections compensate for the absence of the ballast layer. The exact design and configuration of the ties, monolithic or two-block, slab track if used, and profile of the asphalt surface varies significantly as a function of preferential specifications. The application of cribbing rock, or some other means, is necessary to restrain the ties from lateral and longitudinal movement. Figure 2c contains a generalized view of the “Ballastless” trackbed. Certain designs with unique features and configurations are typically covered by patents.

UNITED STATES ASPHALT TRACKBED APPLICATIONS

Since the deregulation of the U.S. freight railway industry in 1980, traffic volumes, revenue ton-miles, axle loadings, and tonnages have grown to unprecedented levels. This has prompted a continuation of and a recent resurgence of research to evaluate new technologies to provide higher quality and longer lasting track and support structures. Numerous capacity improvement projects are already in-service and many more are being planned, designed, and constructed to meet the increasing demands for efficient freight transport. These trends are expected to increase significantly as more reliance is placed on economical, fuel efficient, and environmentally friendly railway transportation.

In addition, increasing emphasis is being placed on expanding rail passenger lines within commuting distances to the larger urban areas of the U.S. Many of these projects are ongoing. However, the expected concentration of efforts will also include providing rapid rail (high speed) intercity passenger service, radiating out from the larger metro areas to connect cities within about 200 miles (322 km). This noble emphasis will entail larger investments in new trackage, designed and constructed to highest structural and geometric standards. This

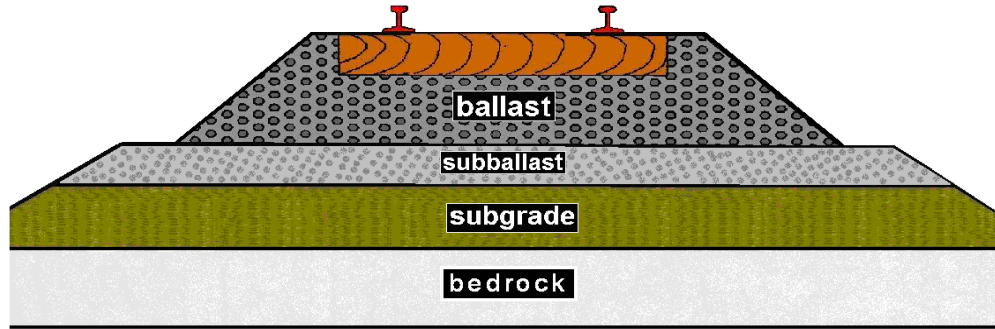


Figure 1. Classic All-Granular trackbed without asphalt layer

Asphalt
'Underlayment'

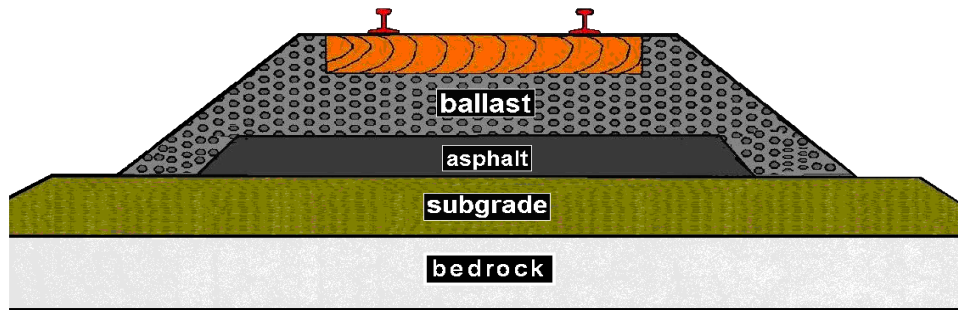


Figure 2a. Asphalt Underlayment trackbed without granular subballast layer

Asphalt
'Combination'

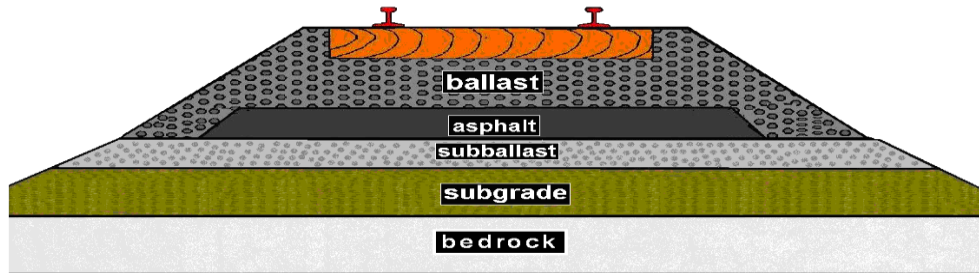


Figure 2b. Asphalt Combination trackbed containing both asphalt and subballast layers

'Ballastless'
Asphalt Combination

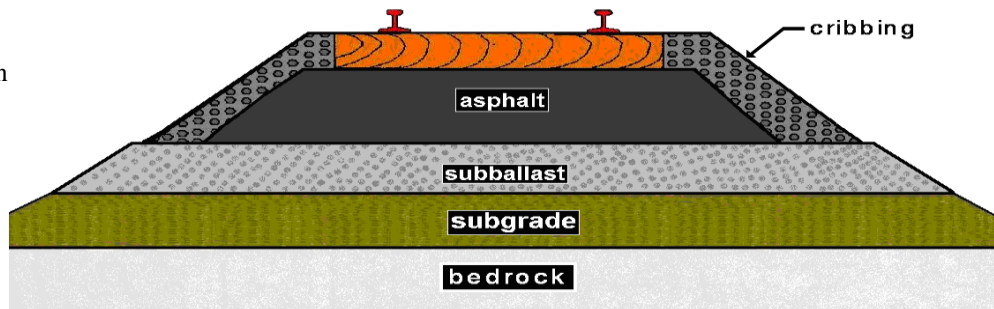


Figure 2c. Ballastless trackbed containing thickened asphalt and subballast layers

is necessary to provide a system that is capable of accommodating high-speeds while achieving safe operations and acceptable passenger comfort levels.

Realizing in the early 1980s the impending challenges of providing higher quality and longer lasting track and support structures, several U.S. railroad companies and the asphalt paving industry developed designs and applications for using hot-mix asphalt within the track structure to replace a portion of the conventional granular material. Primary emphasis was initially directed to applications on the heavy-tonnage freight railroads for trackbed maintenance applications and as solutions for instability problems in existing trackbeds. These trackbed solutions included installing a layer of asphalt during the rehabilitation of turnouts, railroad crossings, bridge approaches, defect detectors, hump tracks, tunnel floors and approaches, and highway crossings, where conventional trackbed designs and support structures had not performed satisfactorily. These asphalt maintenance installations are in common use. Based on its superior performance as a maintenance solution, asphalt is now selectively considered as an option for new mainline tracks, yards, and terminal construction.

Typical Asphalt Trackbed Designs

The Asphalt Underlayment (Figure 2a), and to some extent the Asphalt Combination (Figure 2b), trackbed designs represent the bulk of asphalt utilization on U.S. railroads. The Ballastless (Figure 2c), trackbed design is not as readily adaptable to current U.S. railroad construction and maintenance practices as is the Ballasted designs. This discussion of U.S. practices relates to asphalt applications containing a ballast cover.

Asphalt underlayment design and construction standards for railways typically follow recommendations set forth by the Asphalt Institute (Asphalt Institute, 1998; Asphalt Institute 2007). The typical asphalt layer is approximately 3.7 m wide and is approximately 125 to 150 mm thick. For poor trackbed support conditions and high impact areas, a 200-mm thickness is commonly used. Thickness of the overlying ballast normally ranges from 200 to 300 mm.

The typical asphalt mixture specification is the prevailing dense-graded highway base mix in the area having a maximum aggregate size of 25 to 37.5 mm. This slight modification to the typical highway mix imparts ideal properties to the track structure. Normally the asphalt binder content is increased by 0.5% above that considered optimum for highway applications resulting in a low to medium modulus (plastic) mix, having design air voids of 1 to 3%. This mix is easier to densify to less than 5% in-place air voids and therefore facilitates adequate strength and an impermeable mat. Rutting of the plastic mix is not a concern in the trackbed since the pressures are applied through the ballast over a wide area. Bleeding and flushing are also of little concern since the

wheels do not come in direct contact with the asphalt layer and the temperature extremes are minimized in the insulated trackbed environment.

Typical Trackbed Installation Practices

The equipment required for installing the asphalt layer varies depending on the size of the installation. For short maintenance/rehabilitation projects, the asphalt is normally back-dumped on grade and spread with a trackhoe, small dozier, bobcat, etc. already on site, prior to compacting with a conventional vibratory roller. This process requires that the old track panel be removed. Thus the cost to place the asphalt is minimal, basically no more than placing conventional granular subballast. The cost of the asphalt material delivered to the job site adds a small percentage to the total track removal and replacement costs but is basically insignificant, since it replaces the granular subballast. The majority of the costs involve equipment, labor, and track materials. The added time to the track outage to place asphalt is insignificant, provided the track is to be removed and the underlying ballast/subballast replaced with new ballast.

For larger out-of-face projects, mainly new construction with a prepared subgrade, the asphalt is placed with conventional asphalt laydown (paving) equipment and compacted with large vibratory rollers. The procedure is similar to highway construction. The cost of the asphalt may be less than the cost of granular subballast if quality granular subballast has to be transported long distances due to insufficient quality or quantity in the immediate area. Normally, asphalt is compatible with a wide variety of aggregates. The thickness and width of the asphalt is less than that of granular subballast, thus about one-half or less material is required, which is also a cost advantage for asphalt. The asphalt can be placed with highway paving equipment as rapidly as highway paving with much less hand-work and concerns of smoothness.

Descriptions of Selected Projects

Santa Fe Railway (now part of BNSF) in the Kansas and Oklahoma areas, and a predecessor line to CSX Transportation, L&N Railroad/Seaboard System, in the Kentucky area, were the initial railways to become heavily involved with using asphalt underlayment. These initial installations were made during the early 1980s. These two large railways placed several hundred asphalt underlayments in the ensuing years and the numbers continue to increase each year.

The majority of the installations involved the rehabilitation of short trackbed sections which had historically required substantial maintenance. The predominance of these was at special trackworks—highway crossings, turnouts (switches), railway crossings, and crossovers, bridge approaches, and tunnel floors. Several large classification, automobile-unloading, intermodal, and bulk intermodal distribution yards had asphalt underlayment utilized to various extents.

Based on the improved performance of these early installations, countless railroads and rail agencies, including Short Lines and other Large-Size railroads, routinely specify Asphalt Underlayment or Asphalt Combination trackbeds when renewing special trackworks or chronic track instability sites. These include standard specifications for the materials and structure configuration. For instance, Norfolk Southern and CSX Transportation specify asphalt for all impact detectors; perhaps other railroads have similar specifications.

The largest open-track asphalt underlayment trackbed construction projects placed in service in the United States are on a portion of BNSF's high-speed, heavy-tonnage, and high-traffic transcontinental main line east of Amarillo, Texas, through the panhandles of Texas, Oklahoma, and southern Kansas. This largely single track line was selected for double-tracking to increase capacity. The ongoing project is being done in phases over a period of years.

The initial sub-projects specified an asphalt combination trackbed design. It had a 150-mm granular base, to provide a stable surface, topped with 100 mm asphalt layer, 300 mm of ballast, concrete ties, and 136 lb/yd (60 kg/m) rail. The granular base was deleted from succeeding projects and the asphalt layer was placed directly on the native soil subgrade. An initial 100 mm compacted lift of asphalt was placed followed by the final 50 mm. Densities and other asphalt and subgrade parameters were closely monitored.

Over 200 miles (322 km) of asphalt trackbed design have been placed during new track construction in the area (Lusting, 2007). Figures 3 and 4 show the placing of the asphalt and the track, respectively. Figure 5 is a cross-section of the asphalt trackbed standard design for the BNSF projects. This represents the norm for other U.S. railroads, although the asphalt layer is frequently increased for special trackwork

installations, particularly if trackbed instability in the area had been evident.

An example of a recent asphalt trackbed installation is the vertical clearance and highway/rail crossing elimination project on the UP/BNSF trackage through Wichita, Kansas. Approximately 2.5 miles (4.0 km) of trackage was elevated using granular fill. An asphalt combination trackbed was selected. Figure 6 shows the typical paving operation. Other examples of agencies adopting asphalt for trackbed construction include Hillsborough County, Florida, for all new or rehabilitated heavy traffic highway/railway at-grade crossings. Caltrains, in the San Francisco Bay Area, specifies asphalt for all at-grade crossing and other special trackwork.

Tests and Evaluations of Asphalt Underlayment Trackbeds

Material Sampling and Core Drilling

Numerous in-service trackbeds have been subjected to materials sampling and core-drilling to ascertain the properties of the subgrade and asphalt materials. The primary purpose of these investigations was to assess if any weathering or deterioration of the materials was occurring in the trackbed environment which could adversely affect long-term performance (Rose and Lees, 2008). Summary discussions of the findings follow:

Material characterization evaluations were conducted on asphalt cores and subgrade/roadbed samples from eight asphalt trackbeds. The trackbeds were from 12 to 29 years old when tested and were distributed over five states. The inherent conditions varied significantly from site-to-site. These included asphalt thickness and composition, ballast thickness, trackbed support, and traffic. Previous characterization evaluations were available for the projects and the results were included for comparisons with recent evaluations (Rose, et al., 2000).



Figure 3. Placing Asphalt Underlayment on the BNSF Railway 'transcon' capacity improvement project



Figure 4. Placing the new track on the BNSF 'transcon' project prior to adding ballast and 'pulling the track up' to achieve the desired ballast thickness

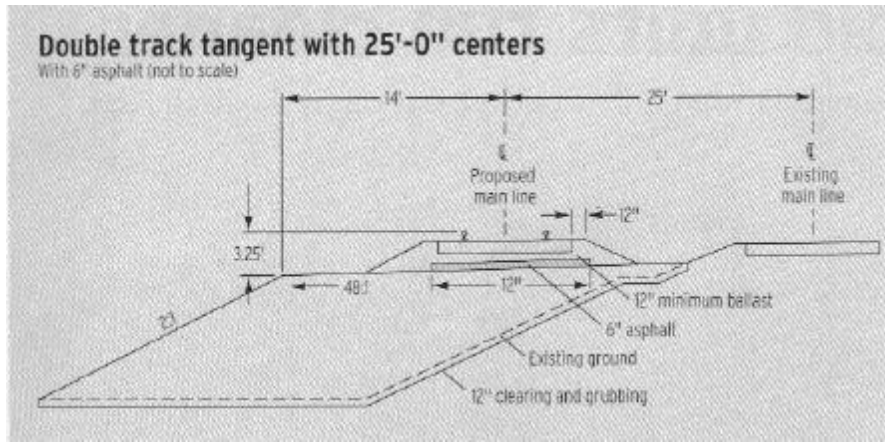


Figure 5. Typical Asphalt Underlayment track section on BNSF ‘transcon’ line



Figure 6. Placing Asphalt Underlayment on the Wichita, KS elevated track section for the mainlines of the BNSF and UP railways

The significant finding, relative to the materials (old roadbed/subgrade) directly under the asphalt layer, is that the in-situ moisture contents are very close to laboratory determined optimum values for maximum density of the respective materials. The asphalt layer is not performing as a membrane to collect and trap moisture, thus weakening support. Actually, since the in-situ moisture contents are at or near optimum for maximum density, the strengths and load carrying capacities of the underlying materials are also at or near optimum. Furthermore, average moisture contents remain essentially unchanged, at or near optimum, for the two projects from which previous data was available. For design purposes, it is reasonable to base strength or bearing capacity values at optimum conditions (moisture content and density) for the material under the asphalt layer. Using strength or bearing capacity values determined for the soaked condition, common for highway designs, is inappropriate for asphalt trackbed designs. The unsoaked, optimum moisture content condition is consistent with in-service trackbed conditions.

An equally significant finding, relative to the asphalt cores characterizations, is that the asphalt binders and asphalt mixes do not exhibit any indication of excessive hardening (brittleness), weathering, or deterioration even after many

years in the trackbed environment. This is considered to be primarily due to the insulative effects of the overlying ballast which protects the asphalt from excessive temperature extremes and oxidation and hardening of the asphalt binder. These factors will contribute to a long fatigue life for the asphalt layer. There is no indication that the asphalt layers are experiencing any loss of fatigue life based on resilient modulus test on the extracted cores.

The typical failure modes experienced by asphalt highway pavements are 1) rutting at high temperatures, 2) cracking and fatigue at low temperatures, 3) stripping/raveling under the suction of high tire pressures on wet pavements, and 4) progressive fatigue cracking due to inadequate subgrade support, generally augmented by high moisture and improper drainage. These conditions do not exist in asphalt railroad trackbeds. For example, the temperatures are not sufficiently high to promote rutting. Conversely, the temperatures are not sufficiently low to promote low temperature cracking and decreased fatigue life. The asphalt binder does not weather or harden excessively in the insulated trackbed environment which would have further negative influence on cracking and fatigue life. Obviously, the tendency to strip/ravel is essentially eliminated in the trackbed environment since there

is no rubber suction action. Also, the moisture contents of the underlying subgrade/roadbed support materials are maintained at or near optimum for maximum density and support strength.

Trackbed Pressure/Stress, Deflection, and Modulus Measurements

Trackbed pressure (stress) measurements have been obtained at prevailing speeds under heavy tonnage railroad loadings. Pressure measurements were recorded using hydraulic type earth pressure cells. These are imbedded in the track structure above and below the asphalt mat. Peak pressures occur directly below the tie/rail interface (Rose, et al., 2002).

Peak Dynamic vertical pressures imposed by typical 130 metric ton (1270 kN) locomotives range from 90 to 120 kPa on top of the asphalt mat. The average locomotive wheel load is 16 metric tons (160 kN). Pressures are reduced to 15 to 30 kPa under the 28 metric ton (275 kN) empty cars which have an average wheel load of 3.5 metric tons (35 kN). The beam action of the track, which distributes the concentrated wheel loadings over several ties and the confined, high modulus ballast layer, serve to effectively reduce the heavy wheel loadings.

By comparison, an 82 kg person will exert about 40 kPa pressure while standing on a level surface. Furthermore, typical tire pressures imposed on highway asphalt surfaces under loaded trucks range from 700 kPa to over 1400 kPa depending on the magnitude of loading and tire configurations. The trackbed pressures are further reduced to 35 to 50 kPa under the asphalt layer at the subgrade interface (Li, et al., 2001).

Dynamic track deflections have been recorded in conjunction with the pressure measurements using linear variable displacement transducers referenced to a fixed datum. Rail deflections under the 130 metric ton (1270 kN) locomotives and loaded cars average 6 mm for wood tie track and around 1 mm for concrete tie track. These are considered optimum for both track types.

Calculated dynamic track modulus (stiffness) values are in the 17 MPa range for wood tie track and around 52 MPa for concrete tie track. These are also considered optimum. The concrete tie track deflects much less than the wood tie track and is thus much stiffer. This increases pressure values within the ballast. The ballast must be properly supported from below so it can develop high shear strength to reduce the higher than normal imposed loading pressures. The high modulus asphalt layer provides increased support and confinement for the ballast in concrete tie track.

INTERNATIONAL ASPHALT TRACKBED APPLICATIONS

Italian Railway Asphalt Applications

The Italian State Railways has been active in the initial development and continued application of asphalt (bituminous) trackbeds for their extensive high-speed rail network. The Italian High-Speed Rail network consists of both an East-West and North-South line that currently extends 900 km and will soon reach more than 1,000 km. The original and most frequently trafficked high-speed line is the Rome to Florence line known as the “Direttissima”. Construction of this line began in the 1970s. During the construction the Italian Railway Company (Ferrovie dello Stato) determined that a minimum bearing capacity of 180 MPa was required to properly support the ballast for all high-speed lines. In order to achieve this requirement two materials were proposed as a support for the conventional track system --- a cement treated gravel and a bituminous mix. Comparing the two construction materials it was determined that a “high performance could be obtained with the new (bituminous) solution, together with the important savings in terms of crushed stone compared to the former solution. The long distance of transport of that material in those sections justified the bituminous subballast solution” (Teixeira, 2005). The Ferrovie dello Stato further decided to implement this new solution on all sections of the Rome to Florence line as long as the asphalt sublayer performed the following functions (Buonanno, 2000):

- Prevent rainwater from infiltrating the layers below the embankment
- Eliminate high stress loads and failures of the embankment
- Protect the upper part of the embankment from freeze/thaw action
- Gradually distribute static and dynamic stresses caused by trains
- Eliminate ballast fouling

The Italian High-Speed Railway cross sectional profile is shown in Figure 7. It is a multilayered system consisting of an embankment, supercompacted sublayer, asphalt subballast, ballast, ties, and rail. Construction practices for achieving this cross section places important emphasis on the placement of these layers in order to maintain proper geometrical alignment for high-speed rail operations. The bottom sections of the embankment consist of an anhydrous material that does not exceed 50 cm in thickness and has a minimum specified bearing capacity of 40 MPa. The material is compacted using static and vibratory compaction methods. The Italian quality control mandates that tests be conducted on 2,000 m² of the embankment to ensure proper compaction.

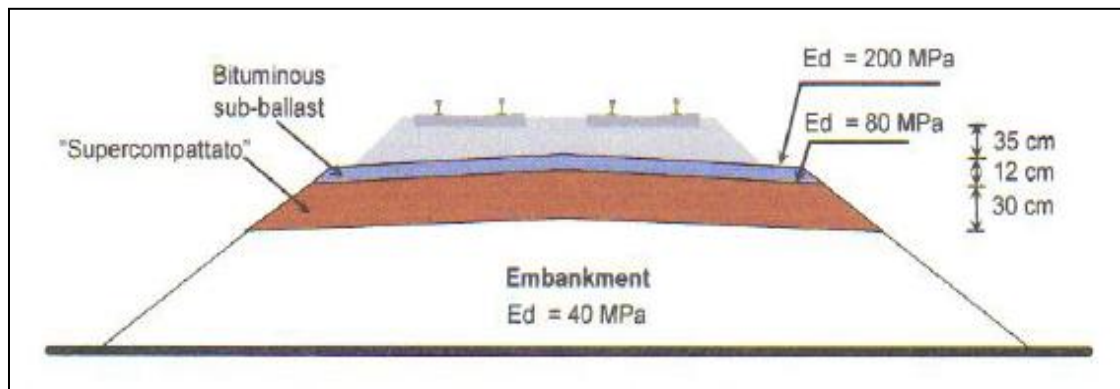


Figure 7. Italian High-Speed Railway Cross-Sectional Profile (Teixeira, 2005)

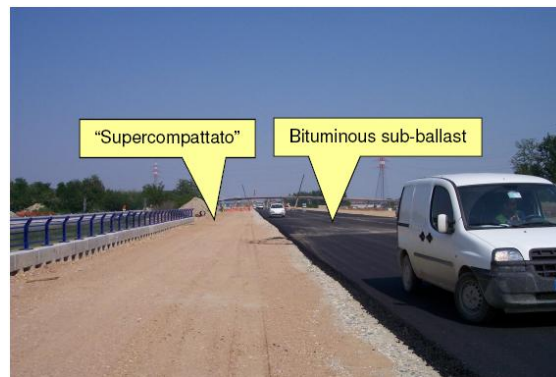


Figure 8. Constructed Supercompattato Layer and Asphalt Subballast (Teixeira, 2009)

The supercompacted (supercompattato) layer is then placed on the embankment with a finite thickness of 30 cm with a minimum subgrade modulus of 80 MPa (Figure 8). The supercompattato layer is a strong layer that has the ability to withstand the repeated loads placed upon it by the high-speed trains. The supercompattato layer also has the ability to serve as an impermeable layer to aid in intercepting and diverting surface water. The supercompattato layer consists of sand/gravel mixture and is placed with a cross slope of 3.5% (Policicchio, 2008).

The asphalt subballast layer, placed above the supercompattato layer, consists of an asphalt mixture with a maximum aggregate size of 0.25 cm and a finished thickness of 12 cm. It is applied over the entire track cross section, with a total width of around 14 m (Teixeira, 2009). The asphalt subballast must have a minimum modulus of 200 MPa in order to withstand repeated wheel loadings and to reduce stresses to the embankment. The asphalt subballast has the ability to distribute loads, provide an impermeable uniform drainage layer, and reduce the effects of freeze/thaw action (Policicchio, 2008). The asphalt subballast also provides several benefits, that the Ferrovie Dello Stato has taken advantage of, over the conventional granular subballast. These benefits include, but are not limited to (Teixeira, 2005):

- Increased safety and structural reliability due to increased modulus and uniformity
- Reduced life-cycle cost on the infrastructure from reduced subgrade fatigue
- Increased homogenization of the track bearing capacity on the longitudinal profile and better ballast confinement
- Reduced ballast fouling due to improved drainage
- Reduced vibration levels throughout the track therefore reducing noise
- Reduced thickness compared to a conventional granular design

The asphalt subballast is placed using standard asphalt paving machines (Figure 9) and then compacted using vibrating rollers to 98% of maximum density. The asphalt mixtures adhere to the Marshall design standards. Verification tests of the mixtures' adherence to specifications are performed every 10,000 m³. A verification of the dynamic response is conducted using a Falling Weight Deflectometer (Figure 10) with three tests for every 100 m (Brambati, 2007).



Figure 9. Placing of Asphalt Subballast (Teixeira, 2009)



Figure 10. Falling Weight Deflectometer (Teixeira, 2009)

The Italian railways soon determined that all new lines were to be constructed using this method and for nearly 20 years they have done so (Buonanno, 2000). In December 2009, with the completion of the North-South and East-West high speed passenger lines, the Italian High-Speed Network will consist of over 1,200 km of asphalt subballast (Teixeira, 2009).

Japanese Railway Asphalt Applications

The Japanese have widely used asphalt trackbeds in ballasted track for many years on both high-speed lines and regular lines. The primary focus of using asphalt trackbeds has been to provide a firm support for the ballast and to reduce track irregularities. This will reduce the load level on the subgrade to prevent subgrade deformation (Momoya and Sekine, 2007). The roadbed design methods are described in the “Design Standard for Railway Structures (Earth Structures).” In the January 2007 revision to this design standard, a performance-based revision was introduced. As the previous Design Standard for Railway Structures (Earth Structures) was based on specifications, the thickness of each layer of the roadbed was specifically defined (Momoya, 2007). A performance-based design standard was developed to account for this occurrence. The performance-based design standard considers the fatigue life of the track as affected by the number of passing trains. Therefore this design method allows designers to design asphalt trackbed thickness to satisfy roadbed performance requirements (Momoya, 2007). The

performance-based design procedure ranks or classifies three different standard track designs according to performance as follows:

- Performance Rank I: Concrete roadbed or asphalt roadbed for ballastless track
- Performance Rank II: Asphalt roadbed for ballasted track
- Performance Rank III: Crushed stone roadbed for ballasted track

The Performance Rank I track is a ballastless slab track that has either concrete or asphalt support with concrete ties directly fixed to the slab. It is considered the highest quality track. It is checked for track settlement, breakage of concrete reinforcement base, fatigue damage, cracking, contraction, and thermal stresses. Typical dimensions for the Performance Rank I asphalt ballastless track include:

- Width of slab: 2220 mm
- Thickness of concrete slab: 190 mm
- Thickness of asphalt-concrete base: 150 mm
- Thickness of well graded crushed stone layer: 150 mm

The Performance Rank II design is a ballasted track with a 50 mm thick asphalt layer. This design has been used for over 30 years in Japan due to the asphalt’s ability to distribute loads and facilitate drainage. For performance-based design, the settlement of the track and fatigue damage to the asphalt are the primary considerations. Performance Rank II is displayed in Figures 11 and 12 with the following dimensions:

- Thickness of ballast beneath tie: 250-300 mm
- Thickness of asphalt-concrete layer: 50 mm
- Thickness of well graded crushed stone layer: 150-600 mm

Performance Rank III is the typical design used in all-granular design. It is similar to typical all-granular trackbeds used in the United States.

French Railway Asphalt Trial Applications

The French high-speed rail network has currently more than 1,800 km of double track lines, all operating at maximum speeds of 300 km/hr. In 2009, the first section of the TGV-East line connecting Paris to Strasbourg reached speeds of 574 km/hr (357 mph) setting a new world record. On this line the French National Railway (SNCF) has developed a 3 km long test section that contained an asphalt subballast layer. SNCF Engineering is conducting laboratory and field tests to determine if an asphalt subballast should be considered as an acceptable alternative material for use on future high speed rail infrastructure projects (Rail and Recherche, 2005).

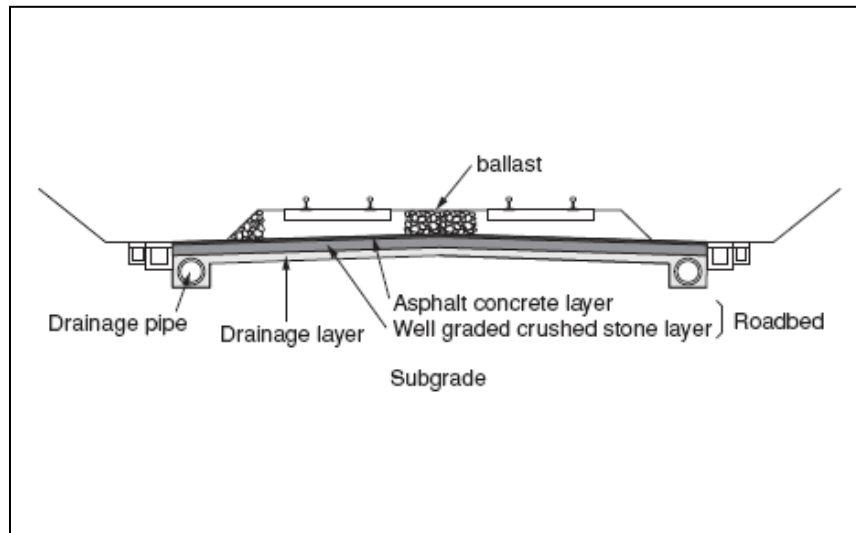


Figure 11: Performance Rank II Cross-Sectional Profile (Momoya, 2007)

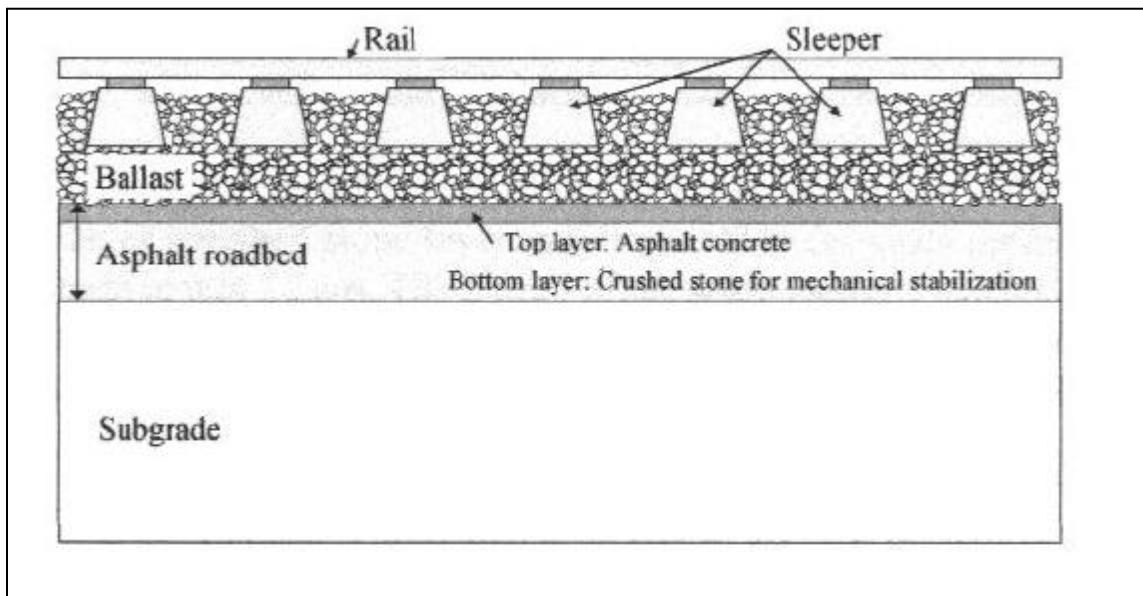


Figure 12: Performance Rank II Cross-Sectional Profile (Momoya and Sekine, 2007)

Figure 13 shows the comparison of the traditional all-granular profile used in the TGV-East line with the experimental asphalt subballast profile adopted in the 3 km test section. The traditional cross section consists of 30-cm thick ballast resting on a 20-cm thick subballast. The ballast and subballast rest on a 50-cm thick layer of limestone aggregate. In contrast the asphalt subballast cross section eliminates the 50-cm layer of limestone and replaces it with 14 cm of asphalt subballast as well as a 20-cm thick adjustment layer. This reduces the overall cross sectional thickness by 36 cm, which reduces the quantity of material by approximately 5,000 m³ per km of track (Bitume Info, 2005).

The test section was constructed by first compacting the 20-cm adjustment layer with an applied surface dressing

consisting of liquid bitumen proportioned 1.5 kg/m² and covered with fine gravels over the 14.50 m total width of the roadbed. The purpose of the surface dressing is to protect the adjustment layer from the construction vehicles as well as to improve surface drainage from inclement weather. The asphalt layer was then placed over a width of 10.70 m in two 5.35 m segments with a compaction requirement of 96%, as shown in Figure 14 (Faure, 2005). The asphalt layer was then coated with a single layer of liquid bitumen at a rate of 0.8 kg/m² and covered with fine gravels (Bitume Info, 2005).

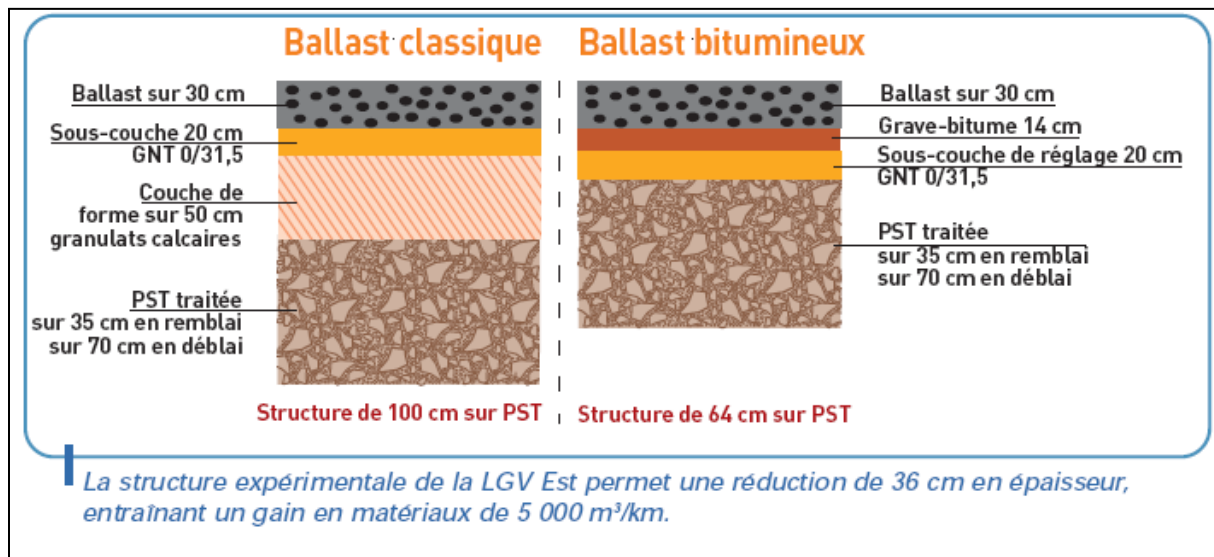


Figure 13. Traditional and Asphalt Cross Sections (Bitume Info, 2005)



Figure 14. Asphalt Placement and Compaction (Faure, 2005)

After installation of the asphalt test section it was determined by SNCF that tests and observations were to be conducted for four years after commissioning, to determine continuity of the asphalt layer, to evaluate the impact on maintenance, and to observe behavior during temperature changes. Various measurement sensors were placed to measure the temperature, pressure, and deformations of the base layer of asphalt. Temperature sensors continuously record the air temperature. Pressure sensors were placed on the asphalt test section and traditional sections to measure pressures on the subgrade. Strain gages embedded in the adjustment layer measure the deformations of the asphalt subballast. Both the strain gages and the pressure sensors are read twice a year. Accelerometers were also used to measure and compare the vertical accelerations of the conventional and asphalt structures

(Robinet, 2005). The line was commissioned in June 2007. SNCF placed a four year timeline for the tests and research evaluations, so the results from the tests are not expected until after June 2011. It is expected that if the test results are positive, asphalt subballast could be used on future projects.

Spanish Railway Asphalt Trial Applications

The Spanish high-speed rail network currently consists of 1,600 km of double track lines operated at maximum speeds of 300 km/hr, with more than 2,000 km of new lines currently under construction and over 2,000km in the planning phase.

Following are the results of some technical and economical studies performed relative to using a bituminous subballast layer in-place of a granular subballast layer

(Teixeira et al. 2006; 2009). The Spanish Railways decided to test the use of this solution in trial sections located in the Madrid-Valladolid high-speed passenger line (already in commercial operation) and in the Barcelona-French border high-speed mixed traffic line, still under construction (Figure 15).

The structural design that supported the construction of these sections consists of a 12cm to 14cm layer of a bituminous subballast applied over a form layer with a minimum thickness of 30cm laying on top of a subgrade with a minimum bearing capacity of 80 MPa, as shown in Figure 16.

In the trial section between Sils and Riudellots of the Barcelona-French Border high-speed line, and due to

constraints related to the construction of the telecommunication cables gutter (channel), the bituminous layer does not cover the entire cross section, as it can be seen in Figure 17.

This 1 km trial section has been fully equipped with numerous extensometers, soil pressure cells, temperature sensors and soil humidity sensors and it will be monitored during 4 years in commercial operation under mixed traffic conditions (high-speed trainsets at 300 km/hr together with railway freight trains at maximum speeds of 120 km/hr). The results will later be used to support the validation of the use of this technical structure as one of the possible solutions for the more than 2,000 km of new high-speed lines still to be built in the next coming years in Spain.



Figure 15. Bituminous subballast sections built on the high-speed line Madrid-Valladolid, section between Segovia and Valdestillas (left) and on the high-speed line Barcelona-French Border, section Sils-Riudellots (right). Source: Teixeira (2009).

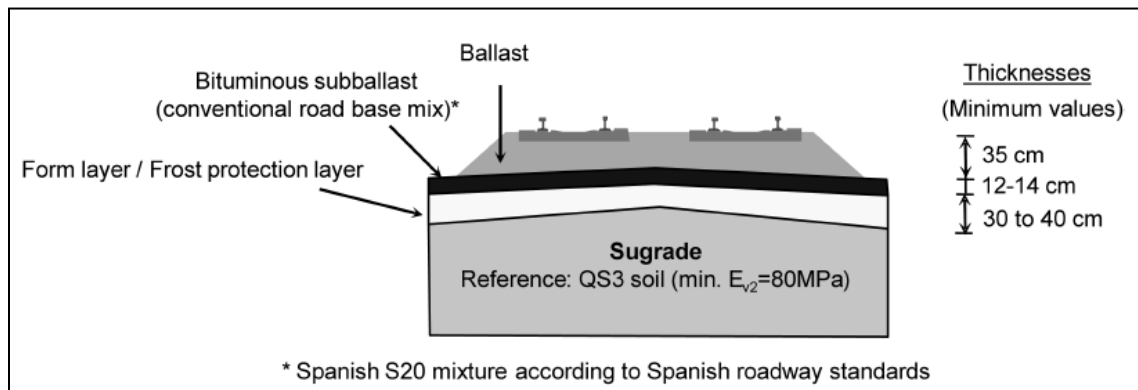


Figure 16. Track design with bituminous sub-ballast for Spanish high-speed lines standards. Source: Teixeira et al. (2009)

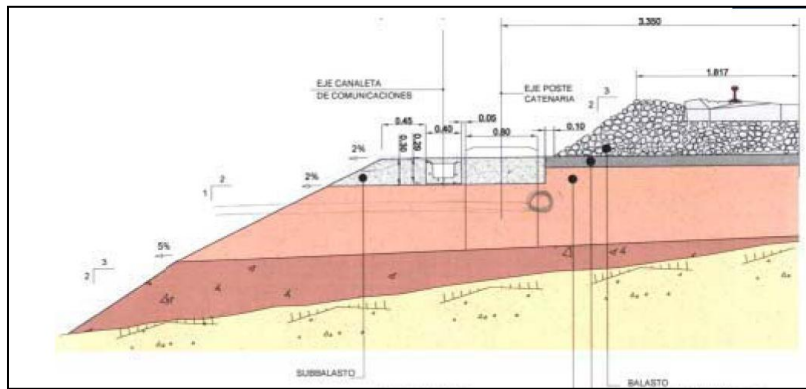


Figure 17. Cross section of the bituminous subballast section built in the high-speed line Barcelona-French Border, section Sils-Riudellots. Source: Teixeira (2009)

German Railway Asphalt Applications

Germany's rail network has undergone constant improvements in the past 30 years in order to keep and increase railway performance and market share. In some priority sections completely new high-speed lines have been built allowing maximum speeds of 250 km/hr in the 90s, and 300 km/hr on most recent lines.

Following the track infrastructure developments the German rail authority, Deutsche Bundesbahne (DB), determined that alternatives to conventional ballast track were necessary in order to lower maintenance costs and conserve natural resources. Eventually the "ballastless" slab was determined as a reasonable solution, particularly for the new German high-speed track designs. The aim of the ballastless slab is to have a track structure with good elasticity that is independent of the foundation stiffness. The initial asphalt ballastless track system used by Germany was constructed in the 1970s and since then there have been several other alternatives both for high-speed and conventional tracks, including asphalt ballastless track designs. The German Getrac is currently the most recent asphalt ballastless track system used (EAPA, 2003).

The German Getrac system includes an asphalt support layer with concrete ties anchored into the asphalt. The Getrac system consists of two different designs, A1 and A3. Figure 18 displays the typical cross sectional profile of the Getrac A1 on an embankment of modulus greater than or equal to 120 N/mm².

Both the Getrac A1 and A3 possess the same dimensions with the exceptions of the concrete cross tie and asphalt thickness. The Getrac A1 utilizes a 2.6 m long pre-stressed concrete tie that is considered a normal-width tie. The Getrac A3 uses a 2.4 m long pre-stressed tie that is slightly wider. Getrac A1 ties can be used when space restrictions don't exist, whereas the Getrac A3 design is used for narrow spaces such as existing tunnels. Furthermore the concrete ties used in Getrac A3 design have a larger bearing surface that reduces the unit

contact pressure between the tie and the asphalt, thus reducing the necessary thickness by 5 cm. This reduction in clearance height further enhances the capabilities of the Getrac A3 system for upgrading existing tunnels. In terms of savings, the Getrac system is an optimum alternative to manually increasing tunnel clearance height (Freudenstein, 2005). The asphalt supporting layer can be placed on a hydraulically bound layer (HBL or soil sublayer) but the overall thicknesses of the support is increased by 5 cm for both Getrac A1 and A3 design. The system displayed in Figure 19 could be used to lower material costs if a suitable HBL was readily available.

The significance of the Getrac design is the ability of the track structure to maintain proper geometric alignment, critical for high speed passenger operations. The Getrac system is able to maintain track alignment by the use of high strength concrete anchor blocks (Figure 20) that elastically attach the concrete ties to the asphalt supporting layer. These anchor blocks are designed so that the longitudinal and lateral forces are transferred to the asphalt layer without displacement of the concrete ties, eliminating the need for ballast.

Other advantages of the Getrac system are its easy and quick installation, long term stability of track geometry, long life-cycles with reduced maintenance, and fast track renewal after train accidents (Freudenstein, 2007). Due to these benefits, the German Getrac system has been heavily used in the upgrading of existing tunnels for use in high speed rail operations. This is mainly due to the cost-effectiveness of the Getrac A3 system and its ability to reduce cross sectional thickness and overall width of the track. An example project is the 120-year old Brandleite tunnel that was upgraded in 2005 using Getrac A3 designs. The Getrac installation at Brandleite consisted of removing the existing track structure, refilling subbase embankment, paving asphalt (Figure 21), drilling holes for anchor blocks, positioning of concrete ties (Figure 22), and installation of concrete anchor blocks. The finished product is displayed in Figure 23.

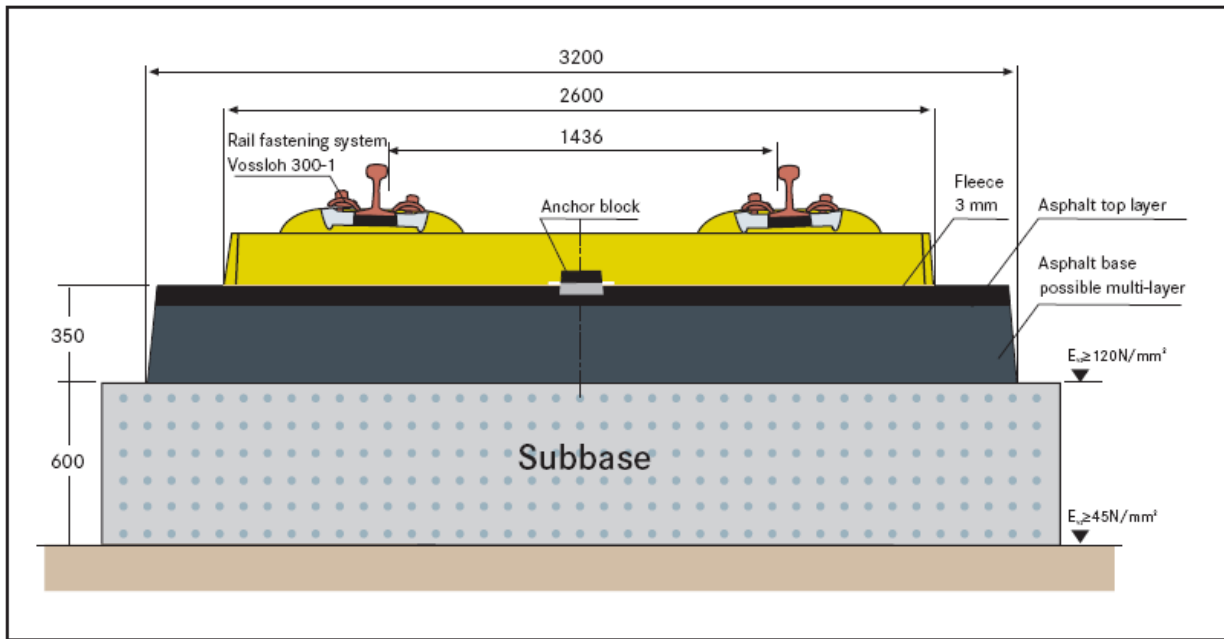


Figure 18. German Getrac A1 Cross Sectional Profile

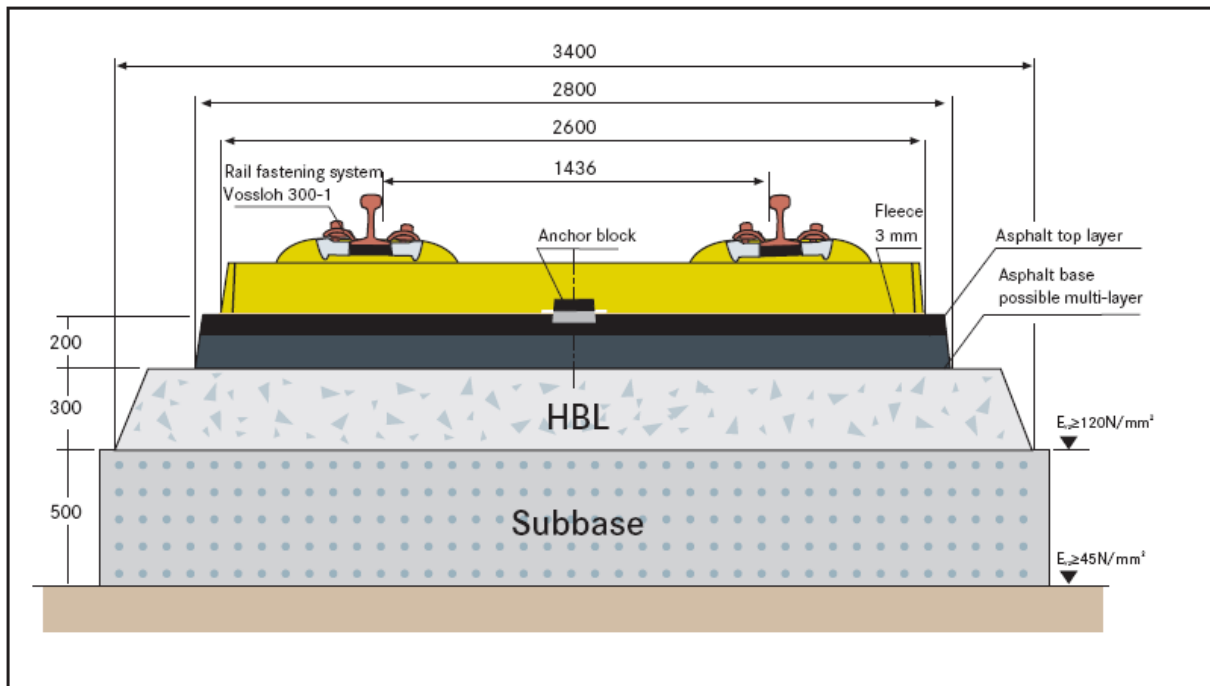


Figure 19. Getrac A1 Cross Sectional Profile with Hydraulically Bound Layer



Figure 20. Concrete Anchor Blocks (Rail.One, 2008)



Figure 21. Paving with Asphalt



Figure 22. Installation of Concrete Ties

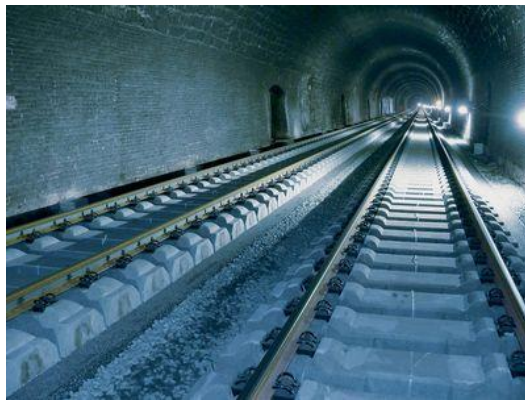


Figure 23. Finished Getrac A3 Track at Brandleite Tunnel

CLOSURE

This paper describes current practices for the utilization of asphalt/bituminous railway trackbeds in the United States and five foreign countries. The contents are by no means all-encompassing, but rather represent typical activities over a span of the past thirty years. It is likely that additional countries are involved with this technology to varying extents, but are not reported herein due to lack of information in the literature sources reviewed by the authors.

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