
HOT MIX ASPHALT IN BALLASTED RAILWAY TRACK: INTERNATIONAL EXPERIENCE AND INFERENCES

LUV SEHGAL
Graduate Research Assistant, RailTEC, UIUC
AMIT GARG,
Graduate Research Assistant, RailTEC, UIUC and Chief Engineer, Indian Railways
VIJAY SEHGAL
Chief Administrative Officer (Construction), WCR
Dr WILLIAM BUTTLAR
Professor, Department of Civil and Environmental Engineering, UIUC

Executive Summary:

With the assumption that the conventional railway track structure with a concrete tie and rail web resting on 12 inches of ballast has reached a level which has matured beyond the possibility of any classical enrichment from research, a *de novo* look at the basic track structure has been a no go area. However, with unprecedented growth in speed and wheel loadings, the rail industry has to find new technologies to provide a stronger, safer and low maintenance structural solutions.

Asphalt, with its multi-faceted and adjustable behavior is perfectly suited to contribute towards the long standing problem of uneven stiffness of the granular sub ballast layer that a ballasted rail track is afflicted with. A lot of research and trials have been done in the European and Asian railways and a few instances of trial applications are available in the American Railways as well.

Bituminous sub ballast with optimum resilience has now proven to be an alternative to the conventional granular sub ballast. The results of a large number of studies reveal that the structural performance has improved when a 12 cm to 14 cm conventional bituminous subballast layer was used in lieu of granular layers.

This paper consolidates the knowledge available on the subject through an extensive literature review and attempts to establish that provision of an asphalt subbase layer below the ballast is not just a structural necessity for high speed railways but has the potential to replace the granular sub ballast in conventional railway track structure.

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1 Introduction:

Fifty years since the inauguration of the world's first high speed rail line between Tokyo and Osaka, Japan and more than 30 years after the building of the first European high speed (Paris to Lyon), high speed rail has proven to be one of the most competitive means of medium distance intercity transportation (1). Not only has the astounding advancements in traction systems like distributed traction motors, coach design like light aluminum coaches with vacuum suspension reducing the weight of the coaches by as much as 8 t, development of microprocessor based in cab signaling and now the Positive Train Control systems, improvement in track technology also has widely contributed to this marvel of technology which is superior in terms of environmental and ecological costs to all its competitors in its range of travel. With the assumption that the conventional railway track structure with a concrete tie and rail web resting on 12 inches of ballast has reached a level which has matured beyond the possibility of any classical enrichment from research, a de novo look at the basic track structure has been a no go area (2). However, with unprecedented growth in speed and wheel loadings, the rail industry has to find new technologies to provide a stronger, safer and low maintenance structural solutions.

1.1 Wither ballast?

From the structural point of view, the classical ballasted track configuration has been used with good results in almost all of the European high speed lines. However expected increase in volumes and speeds have led to increased maintenance costs of this structural configuration. As a consequence, recent railway research has focused upon developing low maintenance track structured for high speed lines. Findings of these studies have led to development and construction of new ballastless track structures on Japanese high speed lines and, more recently some links in European high speed network. Also of note is that the difference in cost of ballastless track and conventional track reduces in the tunnels and bridges and thus even in Europe, HSR in tunnels and bridges are laid on ballastless track. In Japan, the shinkansen slab track structure has been used in along almost all lines probably encouraged by the high number of tunnels and bridges along these lines. Geographical conditions and population densities in Japan may also have led to adoption of the viaduct route. Ref: Table 1.

When most of the track is built upon natural foundation, the high construction costs of slab tracks do not offset the benefits associated with low maintenance. Thus, ballasted tracks are still more cost effective for most European lines. Thus**, the goal is to develop intermediate solutions allowing for construction costs that fall in between those associated with conventional ballasted track and those with concrete slab tracks.** 50 years of HSR has shown that because of economic considerations, the ballastless concrete slab track structural has **not** become the *sin qua non* in modern high speed railways. Now that it is established that the ballast track structure cannot be done away with, it is essential that focus should be back on optimizing ballasted HSR track structure as a means to reduce operating costs without large increase in construction costs.

There are two distinct approaches to enhancing ballasted track designs: (a) improving the track design as a whole, optimizing important parameters such as the track's vertical stiffness, and (b) improving both the design of the track structural components (e.g., developing new materials and shapes) and the bearing capacity of the track sub-structure (e.g., through treated soils and new materials such as sub-ballasts).

TABLE 1 Percentage of Tunnels and Viaducts on Selected Japanese and European High-Speed Lines

Railway line	% Tunnels	% Bridges or Viaducts	Total	Main Track Type (Ballasted or Slab)
Japanese high-speed lines				
Tokaido: Tokyo–Osaka (515 km)	13	33	46	Ballasted
Sanyo: Osaka–Hakata (554 km	51	38	89	Slab
Tohoku: Tokyo–Morioka (497 km)	24	71	95	Slab
Joetsu: Tokyo–Niigata (270 km)	40	60	100	Slab
European high-speed lines				
Paris–Lyon (480 km)	.8	.7	1.5	Ballasted
TGV Atlantique (280 km)	4.7	1.1	5.8	Ballasted
Valence–Marseille (295 km)	5.1	6.8	11.9	Ballasted
Hannover–Würzburg (326 km)	19.3	10.4	29.7	Ballasted
Köln–Frankfurt (177 km)	22.6	3.4	26	slab
Roma–Napoli (220 km)	11.4	15.9	27.3	Ballasted
Madrid–Sevilla (471 km)	1.9	3.4	5.3	Ballasted
Madrid–Lleida (481 km)	5.4	5.8	11.2	Ballasted

Railway research has shown that efforts in respect to optimization of track design for low maintenance will have two a pronged strategy**- 1**.**the importance of having a stiff subgrade** and **2**.reducing to the extent possible the stiffness of the rail pad or that of the rail–sleeper–ballast.
Teixeira and Lopez-Pita et al developed a method of evaluating the effects of track vertical stiffness on both maintenance costs and operational costs associated with energy consumption linked to traffic volume for a standard HSR track of 300kmph speed and 100 trains per day per track. The results showed that the optimum value of track vertical stiffness for these parameters lies between 70 -80 KN/mm. With a good track bed structure in place, the resulting optimal track pad stiffness would be 60 kN/mm. Even softer rail pads of stiffness 30kN/mm have been developed that enable rail rotation problems to be held to a tolerable level. Under tie pads between the tie and the ballast also allow high resilience and low maintenance (3) (14).

Finally, concerning track substructure design, increases in the bearing capacity requirements for high-speed lines led to the development of structural catalogues with increased subballast thicknesses in comparison with conventional tracks. Minimum bearing capacity in the range of 80 MPa to 120 MPa under the ballast layer are usually required. In almost all European high-speed ballasted tracks built to this point, granular-only materials (sand and gravel) have been used as a convention. It is only now, after years of research and experimentation that the unbound granular sub ballast is being progressively substituted with asphalt concrete layer as a layer of better stiffness and permeability characteristics. In some cases, the difficulties associated with meeting stiffness standards led to the use of cement-treated soils and cement- treated gravel instead of the traditional granular layers. In determining the feasibility of the bituminous subballast option, one should consider both (a) technical feasibility and design requirements to meet the standards for new high-speed lines and (b) the effectiveness of this type of ballast in reducing track maintenance needs.

1.2 Early improvements in track structure for HSR:
The initial HSR lines in Japan and Europe, the track design was based on improving traditional track structures. Essentially, most of the track structure was modified to meet high speed higher quality standards without overly increasing the track maintenance costs. Serious investments were made to both superstructures (rail, sleepers, ballast) and substructure (subballast and subgrade system). Use of UIC 60

rail, larger and heavier concrete sleepers, high quality ballast material with higher impact strength and introduction of a *different granular subballast layers* resulted in a level of structural functioning suitable for HSR traffic.

Table 2: Track superstructure and their properties

Structural component	Conventional railway	High speed railway
Rails	UIC 60	UIC 60
Ties	CONCRETE 1615 Per km	CONCRETE 1587/1666 per km
Rail Pads: optimal railpad vertical stiffness (k pad)	30 kN/mm elastomeric pad	K pad≈60 kN/mm for elastomeric and thermoplastic pad

The high speed rail design is for a much lighter load of around 18.5t axle load whereas the conventional railway system moves axle loads for up to 32.5t. Use of HSR for freight traffic may lead to requirement of higher maintenance effort and reduction in quality of ride, sometimes close to threshold safety standards.

Track runs on both hard and soft soils. Retention of track parameters on hard soils is quite good. But the same is not the case with soft soils. The soft soils often results in twists beyond tolerance and becomes impediment to high speeds. Either progressive shear failure or excessive plastic deformation can cause the sub-grade to fail. These deformations in sub-grade lead to disturbance in track geometry. One more factor influencing the subgrade is dynamic amplification which can be well controlled if the ballast has inter-particle friction and is of uniform gradation. High-speed embankments need to be deeper, unyielding and more stable in comparison with conventional system. The existing weak soils must be replaced with well graded granular material with some fines. Rainy season coupled with drainage problems causes sub-grade to settle and that in turn leads to distortion of track. It is such a damaging factor that places emphasis on careful design of formation (4) (5).

Use of bituminous subballast layer as opposed to the typically used granular layer is discussed from this perspective. **Along with studying the various international practices of using the asphalt layer as an underlayment below the ballast, it would also be in order to compare the typical cross sections of the highway and railway pavement structure.** This comparison raises a few important observations:

2.0 A typical highway pavement structure:

A flexible pavement is normally modelled as a 3-layer structure with all asphalt materials combined into top layer (shown below in 2 separate layers for detailing), the sub-base as the second layer, and the subgrade as the third layer. The three layers are designed to have resilient modulus in decreasing order from the top i.e.; the asphalt layer has a higher subgrade modulus than the base layer which has a higher modulus than the subgrade soil, thus providing a gradual reduction in the subgrade modulus and the resultant stiffness.

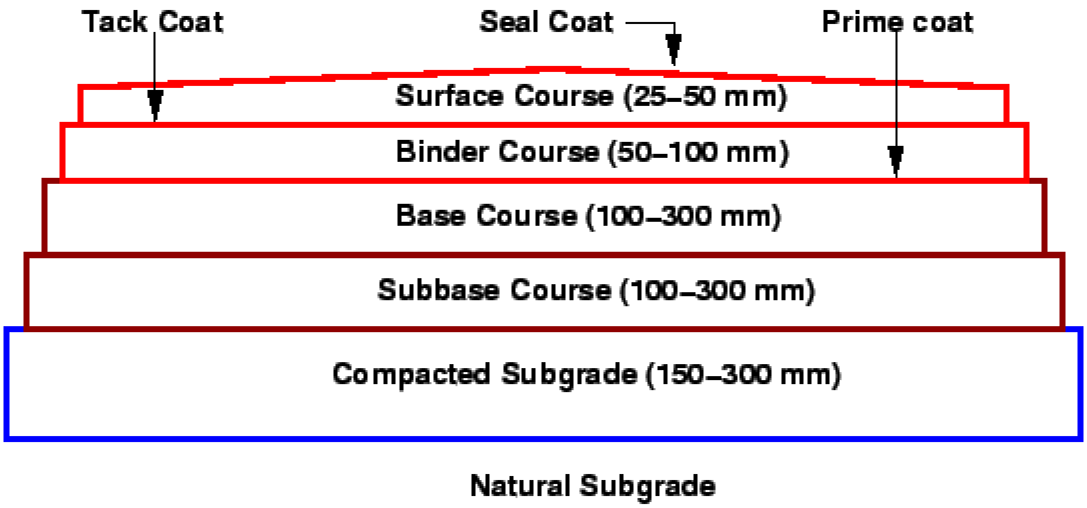


Fig. 1: Section of a typical highway pavement

Table 3: Layers of Highway pavement

Layer	Name	Thickness (inches)	Properties	Design parameters
1st/top Asphalt layer	Surface course/ Wearing layer	1-2		
2nd Asphalt layer	Binder Course/ Intermediate layer	4-6	High modulus, rut resistant to accommodate high compressive loads	Higher asphalt content than optimum for wearing surface layer
3rd/bottom Granular layer	Base course and sub-base course	10-20	Flexible, fatigue resistant	
These layers rest on the compacted subgrade. A properly designed intermediate and base layers can be expected to have design lives of 50 years, and thus can be considered as a perpetual or long-lasting pavement.				

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 enough to promote low temperature cracking and decreased fatigue life, nor do the asphalt binder 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.

2.1 A typical rail track with asphalt underlayment structure:
It is observed that the above configuration with a *stepped modulus pattern* is adopted with minor variations in almost all other countries except the USA where the base layer between the layer of asphalt and the

subgrade is conspicuous by its absence. The base layer comprises of roadbase material which is unbound and granular and consists of crushed rock/slag usually premixed with controlled amount of water sufficient for adequate compaction**.** This layer, typically 4 inches in thickness, ensures a flexible and fatigue resistant layer and provides a support of uniform stiffness to the layers above it.

The asphalt layer in the trackbed is somewhat synonymous with the base asphalt layer in the highway pavement design as explained above. It is protected from extreme environmental effects of sunlight, rainfall, and temperature due to the insulating effects of the overlying ballast and railway track. The wearing surface layer and intermediate layer of the perpetual highway pavement design provide similar insulation. In addition, the availability of oxygen is reduced which minimizes associated weathering and hardening of the asphalt binder. The HMA mix is designed similarly to the bottom layer of perpetual highway pavement. However it is important to note that the load on the base layer of a highway pavement is of the order of 3N/mm sq. whereas for a dedicated high speed railway, this load is only 0.8 N/mm sq., nearly a third in comparison (6).

Three basic types of asphalt trackbeds are being utilized all over the world:

1. The so-called a*sphalt Underlayment*" trackbed is similar to the classic All-Granular trackbed; the difference being the substitution of the asphalt layer for the granular subballast layer. The typical cross-section is shown below:

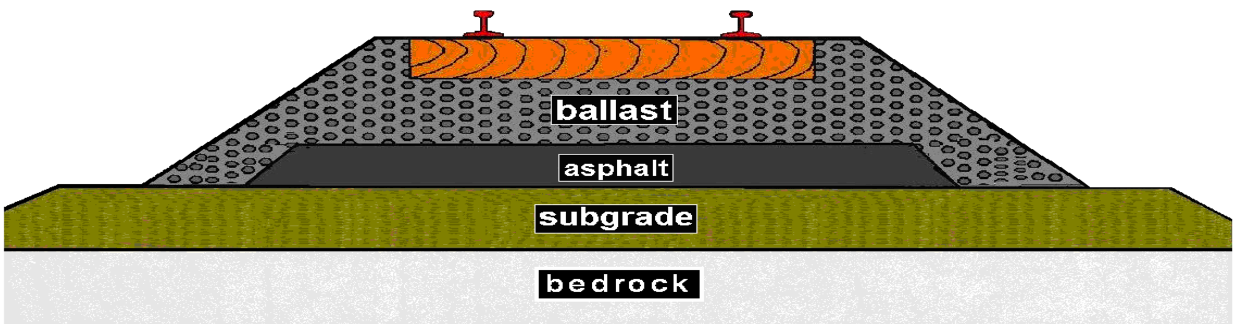


Fig 3: Asphalt Underlayment trackbed without granular subballast layer (common in USA)

2. 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. The figure below depicts this design.

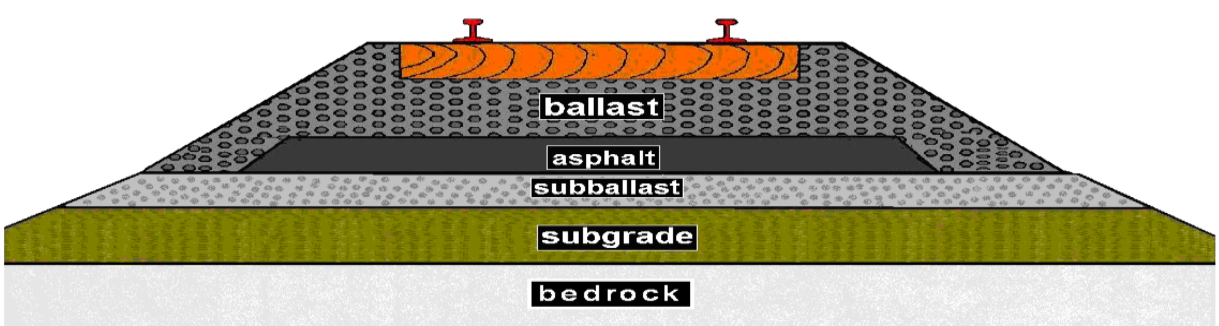


Fig 4: Asphalt Combination trackbed containing both asphalt and subballast layers (common in Europe and Asia)

3. 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 form lateral and longitudinal movement. The figure below contains a generalized view of the "Ballastless" trackbed.

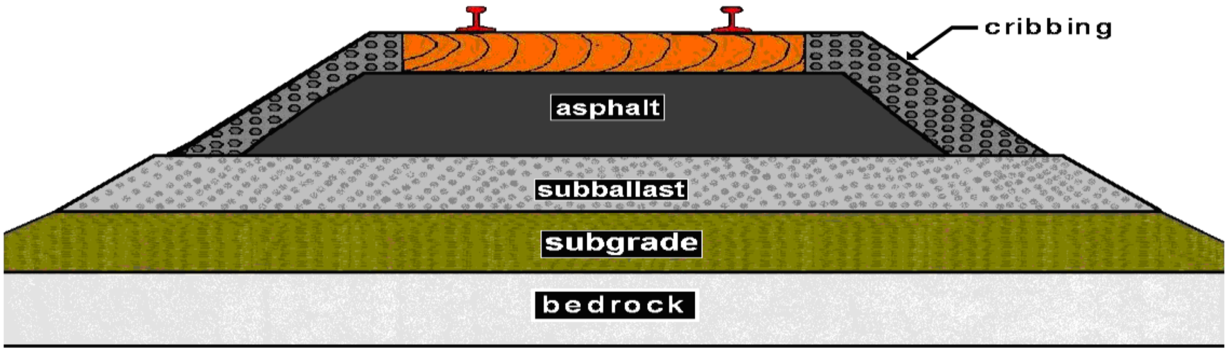


Fig 5: Ballastless trackbed containing thickened asphalt and subballast layers (used in Japan)

3.0 International design practices, applications, and performances of asphalt/ bituminous trackbed (7)(8)

Table 4: International practices

Country	Slab/ Ballasted	Layer 1	Layer 2	Layer 3	Layer 4
Japan	Slab & Ballasted	Slab thickness (19 cm), Ballast 30 cm)	Asphalt concrete slab (15 cm), Asphalt concrete (5 cm)	Crushed stone well graded (15 cm), crushed stone layer)15-60 cm)	subgrade
Italy	Ballasted	Ballast (35 cm)	Asphalt mix 12 cm, 200 MPa)	Supercompatto layer (30 cm, 80 MPa)	Subgrade (40 Mpa)
Spain	Ballasted	Ballast (35 cm)	Asphalt concrete (12-14 cm)	Frost protection layer (30-40 cm)	Subgrade (80 Mpa)
Germany	Ballasted slab		Asphalt Base (20 cm)	Asphalt base multilayer	Subbase (50-65 cm)
France	Ballasted	Ballast (30 cm)	Asphalt layer (14 cm)	Adjustment layer (20 cm)	Subgrade
USA	Ballasted	Ballast (20-30 cm)	Asphalt layer (12.5-15 cm)	No subballast	Subgrade
	Ballasted	Ballast (20-30 cm)	Asphalt layer (12.5-15 cm)	Sub ballast	Subgrade
India	Ballasted	Ballast (30 cm)	Blanket layer (upto 100 cm)	Sub ballast	Subgrade

3.2 Properties necessary for the railtrack underlayment:

To sustain railway loading, particularly HSR, asphalt mix provided in the as sub ballast or in sub ballast layer needs to have some physical and performance properties. Before design mix is done for HSR it is essential to understand the loading environment, deterioration conditions and failure mechanisms of asphalt layer, subjected to that particular loading. The superpave asphalt mix design practices have given the technology to select optimum material properties for the two underlying HW pavement layers meant to transfer load.

Following are the objectives required for an asphalt mix subjected to loading due to HSR.

a. Durability: In case of railway loading durability of asphalt mix should resist water coming down through ballast layer and coming up through mud pumping.
b. Temperature Resistance: In case of HSR, the asphalt layer will be present as underlayment, between ballast and subgrade. In this condition many layers above and below provide much lesser temperature variation as compared to other layers which are exposed to atmosphere.
c. High Modulus: HMA should not distort (rut) or deform (shove) under traffic loading. HMA deformation is related to various reasons It can be attained through use of angular aggregates, optimum binder content and specifying binder with minimum high temperature viscosity ensures higher modulus.
d. Fatigue Resistance: Though the load may not be of higher magnitude in case of HSR loading but still it can cause fatigue failures. The use of an asphalt binder with a lower stiffness will increase a mixture's fatigue life by providing greater flexibility.
e. Fine Graded: Open graded is more permeable and is used in surface courses. In track infrastructure, the position of asphalt layer requires more of drainage function, hence fine graded is an optimal choice (9).

HMA for railway trackbed is designed to be a medium modulus, flexible, low voids, fatigue resistant layer that will accommodate high tensile strains without cracking. It is concluded that the benefits impact favorably on achieving long-term, cost-efficient operations for the rail transportation system in the United States.

4.0 Superpave design for asphalt concrete for a typical railway underlayment for high-speed track:

Proposed inputs which can be adopted for a superpave HMA design:

1. Grade: Fine graded dense mix
2. Modulus: Low to Medium
3. Max size of aggregates: 25mm
4. Air voids: 1-3%

Table 5: Design parameters for superpave design for railway underlayment/ combination (11)(10)

Parameter Name	Parameter Values
Wheel Load (pound force)	Two@72000
Distance between Loads (inch)	70
Ballast Modulus (psi)	47000
Subballast Thickness (inch)	4
Subballast Modulus (psi)	20000
Poisson's Ratio for Subballast	0.35
Poisson's Ratio for HMA	0.45

Volume of Voids for HMA(%)	3
Temperature for HMA (°F)	50 (spring) 77 (summer)
Parameter Name	Parameter Values
	37 (autumn) 20 (winter)
HMA Modulus (psi)	698000 (spring) 372000 (summer) 1250000 (autumn) 2260000 (winter)
Subgrade Thickness (inch)	200
Poisson's Ratio for Subgrade	0.4
Poisson's Ratio for Bedrock	0.5
Traffic Volume (MGT)	32
Ballast Thickness (inch)	12 in
HMA Thickness (inch)	4-6
Subgrade Modulus (psi)	3000-15000

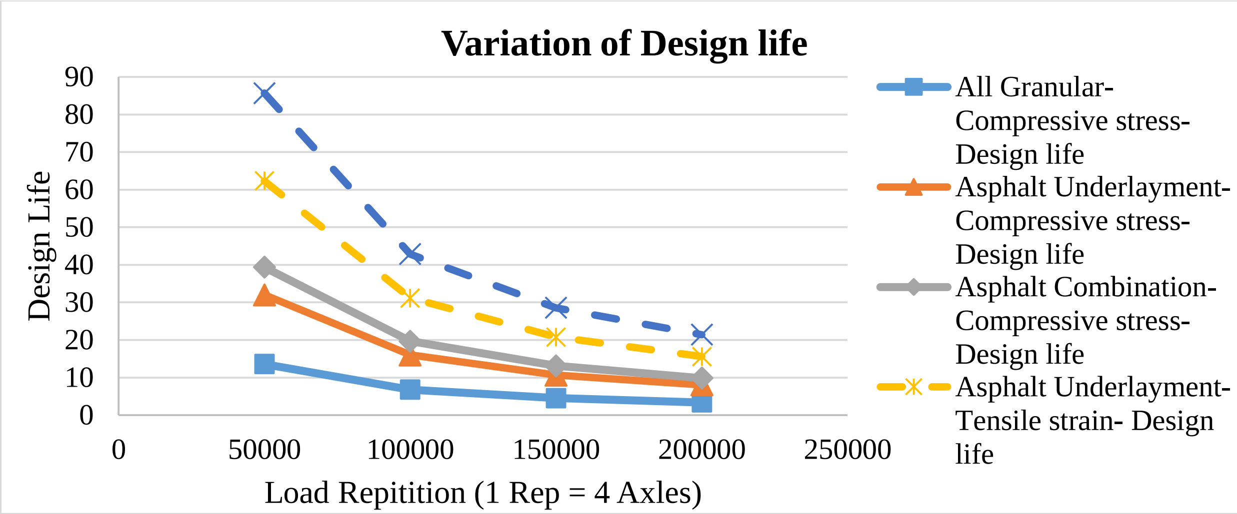
5.0 KENTRAL 4.0 Analysis

The KENTRACK program is a finite element based railway trackbed structural design program that analyzes trackbeds having various combinations of all-granular and asphalt-bound layered support. It is applicable for:

1. Calculating compressive stresses at the top of subgrade, indicative of potential long-term trackbed settlement failure.
2. For trackbeds containing asphalt layer, for calculating tensile strains at the bottom of the asphalt layer, indicative of potential fatigue cracking.
3. Predicting trackbed service lives considering that variances in subgrade modulus and axle loads and the incorporation of a layer of asphalt within the track structure have significant effects on subgrade vertical compressive stresses (12).

Component layers of typical trackbed support systems are analyzed while predicting the significance of layer thicknesses and material properties on design and performance. The effect of various material parameters and loading magnitudes on trackbed design and evaluation are determined and predicted by the computer program. The results are preliminary in nature and may need refinement in terms of data inputs for a conclusive inference. However, they indicate that the presence of sub ballast below the asphalt layer has a very positive effect on the life of the asphalt layer and also the subgrade.

Load Repitition	All Granular		Underlayment				Combination			
	Compressive Stress	Design Life	Compressive Stress	Design Life	Tensile Strain	Design Life	Compressive Stress	Design Life	Tensile Strain	Design Life
	MPa	Years	MPa	Years	10^-5	Years	MPa	Years	10^-5	Years
50000	-0.0747	13.6	-0.0604	32.02	8.35	62.34	-0.06	39.37	9.36	85.691
100000	-0.0747	6.805	-0.0606	16.01	8.37	31.17	-0.062	19.68	9.37	42.845
150000	-0.0749	4.54	-0.0607	10.67	8.4	20.78	-0.064	13.125	9.39	28.56
200000	-0.0752	3.403	-0.061	8.05	8.53	5.58	-0.065	9.84	9.42	21.42



Further conclusions arrived at from the technical papers and analysis from KENTRAK for different cases which were a part of this study are:

1. Increasing the upper grade brings decreases subgrade compressive stresses and asphalt tensile strains in both trackbeds that utilize asphalt. As expected, the service lives of subgrade and asphalt layers are increased. These changing trends are opposite to varying the lower grade. When the lower grade increases, increases in subgrade compressive stresses and asphalt tensile strains lead to a reduction in the subgrade and asphalt tensile strains lead to a reduction in the subgrade and asphalt service lives. Varying the lower asphalt binder grade has a more significant effect on the service lives than varying the upper grade.
2. The subgrade compressive stresses and asphalt tensile strains are reduced when the asphalt layer thickness increases. Meanwhile, the associated service lives are increased greatly. The service life of the trackbed is determined by the minimum service life of the subgrade layer and the asphalt layer.
3. The tensile strain decreases as the subgrade modulus increases. For the low subgrade moduli, the subgrade cannot adequately support the asphalt layer.
4. Increase in the thickness of ballast decreases the subgrade compressive stress, which also leads to an increase in subgrade service life. Additionally, asphalt tensile strains are reduced.
5. Substituting concrete ties for wood ties provides a reduction in subgrade compressive stress and asphalt tensile strain for asphalt trackbeds. The subgrade compressive stress is reduced by as much as about 10 percent and the asphalt strain is reduced by 25 percent. As a result, the service lives of subgrade and asphalt are increased significantly using concrete ties.
6. Increasing axle load will increase subgrade compressive stresses and asphalt tensile strains if an asphalt layer is included. As expected, service lives of subgrade and asphalt layer decrease. Overall, the subgrade compressive stresses and asphalt tensile strains are increased by 20 percent in asphalt underlayment trackbed but the service lives of the subgrade and asphalt are reduced greatly, about 50 percent, when axle loads increase from 33 tons to 39 tons. Axle loads have significant effect on the service lives of trackbeds. Heavy haul lines require a strong trackbed foundation support due to increases in subgrade compressive stress and asphalt tensile strain in asphalt trackbeds. Therefore, controlling the magnitude of axle load is beneficial for trackbed service life (13)(14).

6.0 Financial Analysis:

Studies have revealed that the quality function of track follows the formula

$$Q(t) = Q_0 \text{ x } e^{bxt}$$

Thus the actual quality Q (t) corresponds to the initial quality Q0 multiplied with e powered by the rate of deterioration b over the elapsed time t. The b-rates allow calculating the differences in tamping cycles and the differences in service lives of track with and without asphalt layers. The reduction of the b-rate from 0.09 to 0.06 is relevant, as it increases the leveling-lining-tamping (LLT) cycle from 3 to 5 years, equal to 67% based on the identical threshold value. Based on the relation between LLT cycle and service life, the increase of service life is 17% (7).

Comparative cost analysis of introduction of asphalt concrete and base WMM layer (wet mix macadam comprising of crushed stones of specified grades) replacing the top unbound coarse granular subgrade layer in a typical railway bank with a granular unbound layer of 1m below the ballast is as follows:

Assuming that the calculations may vary depending upon the country, costs, distances etc., it is evident that the financial consequence (as an initial capex) of introducing this change is negligible, if at all.

However as stated earlier, the increase in life cycle of the asset, reduced maintenance of track, better performance standards of rolling stock etc. are all collateral benefits which need to be quantified and accounted for (12).

7 Conclusions:

The study of the profound literature available on the subject as well as the international practices in detail and also with insightful inputs from concept leaders like Jerry Rose have led us to the following **conclusions:**

1. Along with establishing the benefits of using the bituminous subballast layer on high speed tracks, this paper also emphasizes that it can be used very profitably on conventional track as well and has the potential to be a standard component of the track structure with a minimum thickness of 12 to 14 cm as an alternative to the typical granular layers being used at present. The literature available on the subject provides adequate evidence that applying bituminous subballast layer leads to improvements in high speed track performance enabling low levels of track settlement and better track bearing capacities.
2. Effect of sub ballast is related to a) the vertical stresses in ballast as an indicator of the possible track settlement b) tensile strains on the sub ballast itself as an indicator of service life and c) vertical stresses on subgrade as an indicator of the long-term performance of the subgrade.
3. Kentrack, the validated track numerical model which works on the elastic multilayer theory can be used to predict the design life of the subgrade and the asphalt sub ballast layer considering the variance in dynamic loads and climatic conditions.
4. Asphalt can replace the all-granular subballast completely, but the improved subgrade should be high quality. Most agencies prefer, on new construction, to place a minimum thickness of a granular subballast prior to placing the asphalt. The European countries specify the modulus values for all of the layers and base the design on that for choosing thicknesses, similar to how the pavements are designed.
5. There is a scope for further study in this field for designing an asphalt layer specifically for conventional railways using superpave performance grading system. Studies have noted that even highway superpave mix designs have worked well as they weather at a very slow rate in the insulated environment, both from temperature and sunlight, in the trackbed environment. It will be useful to define their relationship through a study. It is also observed that Korea and Japan and also European countries are ahead of the US/India, at present in terms of accumulated wisdom in this field and are therefore ahead in finding appropriate use of the asphalt layer as a standard structural component.

6. The actual cost effectiveness can be derived by doing ling term performance tests of the alternative options or doing a detailed LCCA. This can be attempted in one of the European Railway systems (Spanish or French) who have used the asphalt layer in longer stretches for their high speed tracks constructed recently.

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