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Design, Construction and Performance of Hot Mix Asphalt For Railway Trackbeds
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Introduction

The Asphalt Institute (AI) became interested in the use of hot mix asphalt (HMA) in railway trackbeds in the early 1960s. At that time, devices were designed and fabricated that could be placed on top of an HMA trackbed as a crib. The tie was to be placed in this crib. The track geometry could be adjusted for vertical and horizontal movements as required to maintain the proper track geometry. The idea was to have a full structural section composed of HMA only and was referred to as "overlayment".

In the late sixties, this idea fell by the wayside in favor of an HMA "underlayment" system that consisted of a layer of ballast on top of the HMA, which served as a sub-ballast. However the idea of placing the track directly on the HMA layer had not been completely abandoned at this time.

In 1969, the Santa Fe Railway placed a test section near Raton, New Mexico using these concepts. Three different thicknesses were placed with instrumentation. Pressure measurements were uniformly low for the three sections and readings were curtailed after two years. The test sections never showed any distress for the three levels of thickness. All the sections have performed well, and no maintenance has been required. The performance was questioned from two points of view: were the loads heavy enough, and were the subgrade and climatic conditions severe enough in New Mexico.

This line was constructed on a new location as a coal haul branch-line into the York Canyon Mine. Using a 214-m (700-ft) test section for each thickness, three levels of thickness were constructed: 63-mm (2.5), 127-mm (5-in.) and 190-mm (7.5-in.). Each section was placed 4.88-m (16-ft) wide and had 254-mm (10-in.) of ballast. The mix properties and gradation were similar to those used in subsequent test sections. In August 1983, several cores were removed from each section to determine the long-term aging properties of the mix. The mixture and recovered asphalt binder properties for these cores are shown in Table I. In 1979, weigh scales were installed which required the removal of some HMA underlayment. Some loose chunks of this compacted mat were picked up at the time these cores were taken. The increase in viscosity of the loose chunks compared to the other values shows the shielding effect of ballast on the aging properties of asphalt cement. The performance of this section has been excellent, based upon the condition surveys and track properties. (1) (5) The sections were sampled again in 1998 and recovered properties were fairly close to the values as shown in 1983. The penetration averaged 68 with a range of 61-77 and the average viscosity was 1361 P at 60 º C with a range of 1314-1477 P. It can be concluded that very little aging has occurred in the 29 years of service on these sections. This is basically what other sections are showing after several years of investigation. (5)

Table I- Recovered Mix and Asphalt Properties (RATON, NM)

Property	**Range for Sections**		**Loose Chunks**
	14 years	29 years	4 years exposure
Air Voids (%)	3.1 –4.7	0.9 – 4.2	---
Asphalt (%)	6.9 - 7.3	6.6 - 7.4	6.5
Max Aggr. Size, mm (in)	25 (1)	25 (1)	25 (1)
% Passing O.75 mm	9.3 - 10.1	8.8 – 10.4	10.3
Resilient Modulus MR			
Kpa @ 1Hz, 5ºC (x103)	--	3.3 – 5.26	--
Kpa @ 1Hz, 25ºC (x103)	--	1.2 – 4.0	--
Recovered Asphalt:			
Viscosity, 60o C,(P)	1060 –1610	1314 – 14 77	7525
Viscosity, 135oC,(cSt)	270 – 310	290 – 318	553
Pen, 25oC 100g., 5 sec	62 - 82	61 - 77	25

Note: 1 in. = 25.4-mm, 1 psi = 6.89 kpa

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Thickness Design For Trackbeds

The HMA trackbeds thickness design procedures, developed by the University of Kentucky (UK), are applicable for both underlayments and overlayments. (2) The computer software containing this program is referred to as KENTRACK. . For underlayment design, the trackbed model consists of three-layer elastic system, composed of: ballast, HMA, and subgrade.

It is recommended that the HMA mat extend 0.45 to 0.61 m (1.5 -2 ft.) beyond the tie ends. This normally requires that a 3.3 to 3.7 m (11-12-ft.) wide mat be placed on single-track installations. The mat will extend proportionally wider on turnouts, crossovers and other special trackworks.

The thickness on the majority of the HMA trackbeds constructed to-date have been selected somewhat arbitrarily on the basis of traffic and underlying support (subgrade) conditions. These thicknesses were purposely varied on selected test installations to determine the minimum required thickness of underlayment. The methods are believed to be quite conservative and may be modified as deemed appropriate as more experience is gained through their use.

Table II shows the thicknesses of HMA and ballast for underlayments used in different categories of traffic and subgrade support. (3) For the design of underlayments the use of a minimum thickness of HMA is recommended; however, it is not considered practical or economical to place an HMA mat less than 75 mm (3 in) thick. The minimum thickness depends on the relative subgrade support; a poor subgrade requires a thicker HMA so that the bearing capacity of the subgrade is not exceeded. The minimum thickness is 75 mm (3 in) for excellent subgrade, 100 mm (4 in) for good or fair subgrade, and 150mm (6 in) for poor subgrade regardless of the traffic level.

The recommended minimum thickness of ballast is 125 mm (5 in) so that conventional roadbed maintenance equipment can be used when required for routine track adjustments. The required ballast thickness increases as the traffic level increases and as the subgrade support quality decreases. It can be seen from Table II that large ballast thicknesses are required for the combination of fair to poor subgrades and medium traffic.

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Table III shows the HMA thickness of overlayments for different categories of traffic and subgrade support. (3) The maximum thickness is limited to 457 mm (18 in). It can be seen from Table III that unless the subgrade classifies as good or excellent, it is not feasible to use overlayments and maintain reasonable HMA thicknesses.

The thickness designs reflected in the tables are based on the total number of load repetitions during the design life. It is recommended that for underlayments a design life of 30 years be used for fatigue cracking failure of the HMA mat. However, only ten years should be used for permanent deformation failure of the subgrade. The use of a shorter design life for permanent deformation is considered reasonable since any permanent deformation can be easily corrected by adjusting the ballast during routine surfacing maintenance. It is recommended that a design life of 30 years be used to simulate both fatigue cracking and permanent deformation failures of overlayment track support systems.

Design procedures contained in reference (2) can be utilized for selected non-standard cases of design lives, wheel loads, rail, ties, tie plates, ballast, climate and HMA. Also infinite combinations of train traffic and subgrade support can be evaluated. These procedures require use of numerous charts and require some simple calculations.

Based on over twenty years of measured performance by several railroad companies in both the US and Europe, this procedure has had great success. (4) During joint research by the AI and the UK in field trials, most of the mixtures that have been placed and evaluated have been plastic, low-modulus type mixtures. In this research, It should be noted that the open-graded unbound ballast layer is incapable of performing as a classical elastic layer. This occurs because the unbound layer is only able to provide a limited amount of shear resistance the rail, tie, ballast and HMA mat was considered as an elastic system. The ballast, being an open-graded unbound layer, would be incapable of performing as an elastic layer. As a result all stress transmitted to the HMA layer is applied predominately as shear with very little horizontal strain.

Using the elastic layer theory the design calculations of the subgrade stress indicate that, in most cases it appeared the subgrade stress was reduced to less than 100 kpa (14 psi). Instrumented test sections have been installed beneath sections of trackbed at the Transportation Technology Center Inc. (TTCI) at Pueblo, CO. The stress will be measured in both a soft subgrade and a normal condition under heavy loads up to 330 Million Gross met-tons (300 MGT).

Table II— Thickness Designs for HMA Underlayment Trackbeds (2)

Thickness of Ballast (TB) and HMA (TA) mm (in)

Train Traffic Million Gross Tons/year

Subgrade Support	Light 8 MGT/Y	Medium-Light 16 MGT/Y	Medium-Heavy 32 MGT/Y	Heavy 48MGT/Y
Excellent CBR = 20	TB = 125 (5)* TA = 75 (3)*	TB = 125 (5) TA = 75 (3)	TB = 150 (6) TA = 75 (3)	TB = 175 (7) TA = 75 (3)
Good CBR = 10	TB = 125 (5) TA = 100 (4)	TB = 125 (5) TA = 100 (4)	TB = 175 (7) TA = 100 (4)	TB = 225 (9) TA = 100 (4)
Fair CBR = 5	TB = 125 (5) TA = 100 (4)	TB = 200 (8) TA = 100 (4)	TB = 355 (14) TA = 100 (4)	TB = 460 (18) TA = 100 (4)
Poor CBR = 2	TB = 432 (17) TA = 150 (6)	TB = 610 (24) TA = 150 (6)	TB = NA TA = NA	TB = NA TA = NA

Note: * Minimum Ballast and HMA Thickness, Million Gross Tons per Year (MGTY), CBR—Subgrade California Bearing Ratio, 1 in. = 25.4 mm, 1 Ton = 0.9 metric-ton(MT), NA — Not an appropriate design, subgrade is too weak for loading

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Table III—Thickness Designs For HMA Overlayment Trackbeds (2)

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Excellent CBR = 20	150 (6)	250 (10)	330 (13)	355 (14)
Good CBR = 10	250 (10)	330 (13)	401 (16)	457 (18)
Fair CBR = 5	330 (13)	432 (17)	NA	NA
Poor CBR = 2	NA	NA	NA	NA

Note: NA — Not an appropriate design, subgrade is too weak for loading - Subgrade quality must be improved, MGT/Y— Million Gross Tons per Year, CBR—Subgrade California Bearing Ratio, 1 in. = 25.4 mm, 1Ton = 0.9 metric-ton

Construction of Full Scale Test sections

The two basic designs to be tested were the overlayment and the underlayment systems. In the overlayment system, the HMA is placed directly on the prepared subgrade. The rails and ties are then placed directly on the HMA mat. Ballast is normally placed in the tie cribbing and side areas. Other specific applications of overlayments require the HMA to be placed in the tie cribbing area and up to the top of the rail. The HMA mat performs as a sub-ballast in the underlayment system. The two designs are shown in Figures 1 and 2 respectively.

In 1979, a cooperative research program with the AI, the National Asphalt Pavement Association (NAPA), and the UK was initiated to place and monitor full-scale test sections. These sections were designed and placed over various types of soils and subgrade variations, traffic and climatic conditions. The plastic mixtures proved to be ideal for placing and yielding the uniform track modulus that was sought. Most of the test sections placed used the underlayment system.

The Marshall mix design criteria that was developed (based on 50-blows) is shown in Table IV. This mixture is consistent with a very low-voids highway base course mix. The gradation limits selected were those of a typical highway coarse aggregate dense -graded HMA base course. The grading limits for the master grading are shown in Table V. The coarse aggregate mixture was chosen as being a fairly stable plastic mixture, and was slightly impervious to air and water. The voids in this mixture are set at a very low limit, and yet, the mixture does not require an excessively high asphalt binder content to achieve the low voids. When the voids are low (1-3%), compaction is very easily attained. Compaction can be achieved with small rollers and minimum passes. Target compaction of around 95% maximum density is very important in achieving the desired long-term properties. Air voids of the in-place HMA mat is a factor in aging of the asphalt binder properties. If the mixture can resist air and water, the aging process is greatly reduced. The ballast, as shown in the previous discussion and Table I, provides additional resistance of aging to the asphalt binder properties. Other mixtures with similar volumetric properties would be expected to perform equally well.

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Table IV—Marshall Mix Design Criteria ASTM-1559

Property	**Range**
Compaction (blows)	50*
Stability	3375 KN (750 -lbs)
Flow	3.8-6.4 mm (0.15 – 0.25 in)
Percent Air Voids	1 - 3
Percent Voids Filled	80 - 90
In-place Density	92 - 98%*

* If Gyratory Shear compactor is used (50 gyrations)

**Percent maximum theoretical density based on ASTM D-2041

Table V- Gradation Range For Railway Mixtures

Sieve Size	**Percent Passing**
37.5 mm (1.5 in)	100
25.0 mm (1.0 in)	90 - 100
19.0 mm (3/4 in)	---
12.5 mm (1/2 in)	70 - 90
9.5 mm (3/8 in)	---
4.75mm (No. 4)	40-65
2.0 mm No. 10	25-45
0.42mm (No. 40)	10-26
0.18mm (No. 80)	6-18
0.75mm (No. 200)	3- 8
Percent AC-10, 20 or 30*	4- 7

* Based upon total weight of mixture

Special Applications For Overlayments

The overlayments systems have become increasingly important where environmental designs are required for loading areas of chemicals. Using this design concept, the HMA can encapsulate another material either hazardous or non-hazardous. Some materials may simply need to be controlled and disposed of in a proper and efficient manner if a spill occurred.

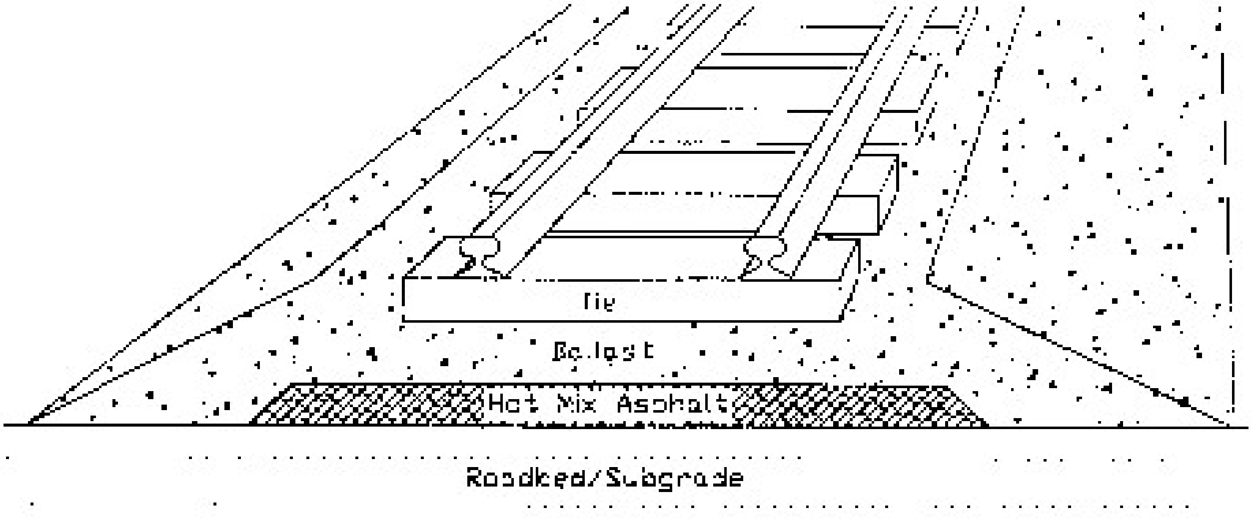

Figure I.—Underlayment

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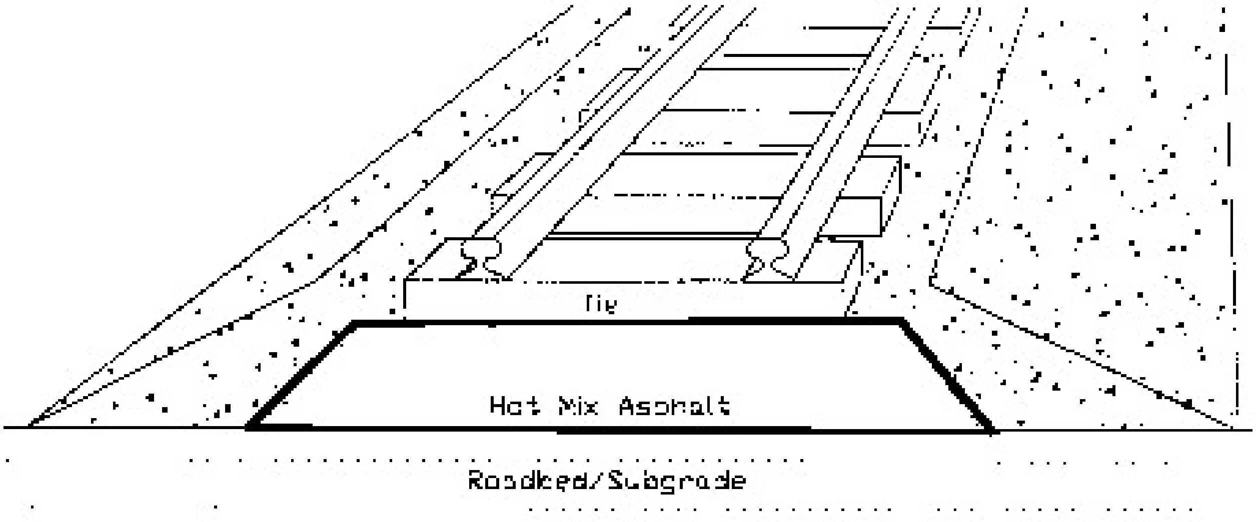

Figure II. —Overlayment

Figure III shows an example of a special application of the overlayment design. This is a railway ballast washing and loading rack. The facility washes and loads approximately fifty ballast cars, three times a week. The fifty cars are pushed through the ballast washing and loading area using an end-loader. Prior to paving the area with an asphalt overlayment, track maintenance was almost a daily event. The overlayment was designed with a drain pad sloped away from the track area into a settling pond. Fines that are washed from the ballast material are pushed toward and washed into the pond area on a regular basis. The fines are pulled from the pond into an area where they are allowed to dry and sold as another construction material. The facility has a service record of over twelve years of good performance. Tailings that were washed from the ballast as it is being loaded on the rail cars destroyed the trackbed, requiring almost daily maintenance. The washings also created an environmental problem for both the on-site property as well as the adjacent property. The asphalt overlayment was brought to the top of the rail to provide positive drainage to the settlement pond. Figure IV depicts the type sludge and water deposited onto the asphalt overlayment surface.

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Figure III. — Construction of Overlayment

Construction of the overlayment in the critical area of washings is shown in the Figure III. The residue from the washing was also contaminating the adjoining property area, which lead to complaints form property owners. The paved surface area drains to the left in the photo into the settling pond, which is cleaned as required.

Other overlayment systems have been installed as a track structure and soil encapsulation for chemical materials. These hazardous materials are not necessarily always in a liquid form. They can be heavy metals as zinc, lead or other undesirable contaminates or simply fertilizer type materials. Anything that may be considered as a pollutant of the ground water table should be a consideration for encapsulation. When overlayments are designed for holding ponds involving hazardous materials, the slope must be designed to get the spill into the holding area immediately. Depending upon the type chemical being handled, a sealer may be required on the asphalt-lined holding pond area.

Figure IV. —Special Overlayment Design

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The cost analysis shown in Table IV compares two equal designs for a given condition. The unit items will vary with project locations and material supplies. Although the designs are considered equal structurally, the underlayment designs have out-performed the conventional design in every test, under all conditions. There were many advantages of the underlayment found after the analysis of the performance began to be studied in-depth. For example, it was reported that the track geometry seems to hold much better than that for conventional track systems on the curves. In coring the underlayment, it was found that the ballast keyed into the plastic mixture in the early traffic loadings. Although this was an important finding for the researchers, it wasn't anticipated in the initial design phase.

In all test sections placed in a corrective situation, the additional cost over in excess of the conventional construction was recovered in less than seven years, and in many cases, in less than six months. Most of the underlayment sections have never required any maintenance. In some areas of heavy and concentrated traffic, such as double diamond crossings, the upper level of ballast has been replaced prior to the replacement of the hardware. In heavy traffic designs, such as double diamond crossings, the underlayment have extended the life of the hardware 50-100 percent, which represents considerable savings. (1)

It is difficult to make track construction and re-construction cost estimates that may apply across the nation. Materials cost vary considerably, depending on availability and site access. It is obvious that to place HMA on an existing trackbed, access by haul trucks to the site is essential. In many areas, HMA delivery may be limited due to the length and time of haul due to temperature loss of the mixture. Ballast is currently being shipped to site and placed on the trackbed by conventional railway construction equipment. In comparing the differential cost, the initial cost is not the major factor. The future cost of repairs and maintenance are what makes the HMA underlayments most attractive. An attempt to compare two sections of conventional and HMA underlayments is made in Table VI. In the control test sections, a geotextile fabric was placed on the prepared subgrade. Fabric is not used in asphalt underlayment or overlayment systems.

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Table VI - New Track Construction Cost Per Track Mile

Materials/Methods	**Conventional**	**HMA Underlayment**
New 132-lb Carbon Rail	$130,000	$130,000
New Wood Ties, 3200	100,000	100,000
Other Track Materials	50,000	50,000
Surface & Align, 2 lifts	10,000	10,000
150mm(6-in) Subballast	34,000	----
100mm (4-in) HMA	----	59,200
200mm (8-in) Ballast	24,000	24,000
612 g/m2(18-oz) Geotextile	15,800	-----
Total Cost	$363,000	$372,700

1 lb/yd = 0.5 kg/m, 1 in = 25.4 mm, 1 oz/yd2 = 34 g/m2,
1 ft = 0.305 m, and 1 ton = 910 kg

Evaluation Of Performance

Track geometry and wear on hardware were measured to assess the overall performance of the trackbed. Other observations were: 1) the ballast fouled from the top rather than the bottom due to fines created around the crib areas, 2) the ballast was self-cleaned where rainfall was sufficient 3) the ballast keyed into the plastic mixture providing a stable alignment on horizontal curves, and 4) the HMA underlayment provides a uniform track modulus and waterproofs the subgrade, providing a uniform modulus for the design period. Maintenance has been very minimal, and no slow orders have been issued where HMA underlayment or overlayments were used.

Repeated testing and evaluation of the track geometry, that is vertical and horizontal alignment, has shown excellent results of the designs. The subgrade has also undergone extensive testing to track moisture contents and density conditions. Twenty years of testing indicates that the moisture has remained within ± 2% of optima for the underlayment systems. (1,5) In view of this relative constant moisture content, consideration should be given to designing on the CBR at optima moisture rather than a soaked CBR, which the current procedure uses. This would drastically reduce the thickness as shown in Tables II and III.

The extended life of hardware was evident especially in areas of high maintenance and heavy loads, such as double diamond crossings. The underlayments extended the life of this type hardware as much as 50-100%. (5) When replacing these type facilities, it was found that the top 200mm (8 in) of approximately 400-600 mm (16-24 in) ballast was all that was repaired or replaced below the hardware.

Many miles of heavy, high-speed, transcontinental trackbeds are being constructed with this method, and double tracking is being done using these techniques. Based on the joint research and measured performance by the UK and AI, the following advantages for HMA are realized:

Short Term Benefits

The advantages of a quality roadbed structure with regard to out-of-face and spot maintenance costs are grouped as follows:

- Decreased ballast applications and surfacing cycles
- Decreased tie and plate wear
- Decreased rail and other track materials wear and fatigue
- Decreased special track-work replacements
- Decreased ballast cleaning and replacement

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Long Term Operating Costs

Maintaining a quality roadbed structure will reduce operating costs by improving the operating efficiency of train movements. Favorable test data and results of performance evaluations obtained to date indicate HMA track-beds will reduce track maintenance costs. The advantages include:

- Increased speed and safety of operations due to good track geometry
- Decreased train resistance and fuel consumption
- Decreased rolling stock wear and repair
- Increased tonnage ratings for similar motive power
- Decreased operational interference's from maintenance activities
- Decreased number of slow orders and other restrictions

The HMA track-beds, which have been subjected to periodic track geometry tests, have not exhibited any degradation of track geometry parameters. Obviously, no slow orders or operational interference from maintenance activities have existed since no maintenance has been required.

Conclusions

The primary benefits of the HMA layer are to improve load distribution to the subgrade, waterproof and confine the subgrade, and confine the ballast, thus providing consistent, load-carrying capability. The waterproofing effects are particularly important since the impermeable HMA mat essentially eliminates sub-grade moisture fluctuations, which effectively improves and maintains the underlying support. Additionally, the resilient HMA mat provides a positive separation of ballast from the subgrade and thereby eliminates subgrade pumping without substantially increasing the stiffness of the track-bed. The resultant stable trackbed has the potential to provide increased operating efficiency and decreased maintenance costs, which should result in long-term economic benefits for the railroad and rail transit industries.

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