Turnout Rehabilitation with Bituminous Concrete Underlayments

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The importance of providing adequate trackbed support to maximize turnout life is emphasized. A relatively new procedure for construction and rehabilitation turnout trackbeds is described. The technique involves placing a subballast layer of bituminous (hot-mix asphalt) concrete below the ballast to provide proper support, impermeability, and positive drainage for the track structure. Design practices, installation procedures, 10-year performance evaluations, and economic studies are presented.

Turnouts represent one of the special trackwork components of the total railroad track system. Turnouts and other special trackwork, such as crossing diamonds, crossovers, interlockings, and highway crossings, typically require higher initial capital costs and higher maintenance costs to operate effectively than comparable regular two-rail trackbeds.

A recent study by a Roadmasters and Maintenance of Way Association of America Committee researching the economics of turnouts concluded the following (*1*):

> [T]he real economic benefits rest in the proper and timely maintenance of the turnout. Ignoring proper turnout maintenance contributes to accelerated wear to the turnout components and a significant reduction in normal serviceable life. It also leads to an increase in the premature replacement of various turnout components.

Obviously turnout maintenance involves not only maintaining the metal wearing surfaces and flangeways to the proper contour, smoothness, and adjustment, and the ties to proper spacing and condition, but also providing proper support for the metal and ties. This in turn provides a means to maintain proper geometric features for the turnout by reducing impact stresses and rapid deterioration and wear of the turnout components.

The selection of the support system depends on several factors. Lines having high-speed traffic and heavy tonnages and wheel loads require the highest quality geometric features for safe operations. Providing proper support is most important. Also, the poorer the quality of the underlying native materials and the more difficulty in obtaining adequate drainage, the more likely maintenance costs will accelerate unless proper roadway stabilization and drainage improvements are provided. The choice of an adequate quality ballast that does not deteriorate and degrade under traffic and weathering is important, particularly on lines that traverse poor quality subgrade materials combined with difficult drainage conditions.

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The conventional new trackbed support system consists of an open-graded crushed granular ballast material—typically crushed granite, basalt, or other hard, crushed aggregate. Underlying the ballast is a more dense-graded granular aggregate called a subballast. One or more layers of a geosynthetic may be used above or below the subballast.

Existing trackbeds typically do not have a well-defined layer of ballast. It generally transitions into a subballast. Thus, the relative and total thicknesses of the ballast and subballast vary from site to site, resulting in varying levels of support. Areas exhibiting poor quality subgrade materials and difficult drainage conditions provide less support for the track. Increased deflections of the track and increased relative movements between the rail, tie, and ballast interfaces cause the track components to deteriorate faster. Track geometry is adversely affected, and speeds must be reduced for safe operations.

A report presented at the 1991 American Railway Engineering Association (AREA) Technical Conference on the Economic Assessment of Increased Axle Loads Based on Heavy Axle Load Tests at the Association of American Railroads Transportation Test Center (*2*) indicated that when axle loads were increased from 33 to 39 tons, turnouts showed a much higher deterioration rate, which was reflected in higher routine maintenance requirements and in a shorter life for the major components of the turnout, and furthermore, turnout maintenance costs were substantially increased by heavier axle loads.

An ideal track support system provides a consistent support that is reasonably stiff, but has sufficient resiliency to absorb shocks and deflect slightly under loadings. This is particularly important at special trackworks where impact loadings are typically greater than along regular track. Because high and variable moisture contents of many subgrade and granular subballast materials will adversely affect their ability to provide a proper level of support, it is important that the track system provides adequate drainage to minimize the occurrence of high moisture levels in the subgrade and granular subballast.

HOT-MIX ASPHALT UNDERLAYMENTS

Recorded investigations involving the use of a layer of bituminous concrete, commonly known in the paving industry as hot-mix asphalt (HMA), within trackbeds began during the late 1960s (*3,4*) and continued sporadically during the 1970s. Concerted efforts began during the early 1980s, and today HMA underlayments are considered as an optional trackbed maintenance and construction technique. The AREA *Manual For Railway Engineering* (*5*) recently included a statement that "hot mix asphalt concretes have been used with success as a flexible stabilized roadbed."

During the 1980s significant research was funded by the National Asphalt Pavement Association and the Asphalt Institute to (a) evaluate the applicability of HMA trackbeds, (b) develop design criteria, (c) optimize field installation procedures, and (d) evaluate long-term maintenance costs and operating efficiency concerns based on the performance of in-service HMA trackbeds. Most of this effort has been carried out through the University of Kentucky with support from several railroad companies.

HMA has been applied in hundreds of trackbeds during the past 11 years. The incidence appears to be increasing each year. It has been used in new construction installations such as passing siding extensions, new alignments, yards, terminals, and loading facilities. Wider use has been made at specific locations as a maintenance solution to specific trackbed instability problems in existing tracks. Typically the HMA serves to compensate for inadequate subgrade support and drainage conditions at sites where conventional maintenance and rehabilitation procedures have failed. Specific projects have included short sections of regular track, special trackworks (turnouts, crossings, hump tracks, and highway crossings), tunnel floors, bridge approaches, and loading facilities.

With the exception of a few initial test sites on low tonnage lines, almost all recent installations have been on high tonnage lines where attainment of high-quality support and adequate drainage are more critical. Exceptions are high-volume highway crossings intersecting lightly traveled branch or spur lines where the quality of the highway crossing is considered paramount. A paper presented at the 1991 TRB Annual Meeting (*6*) documents in detail the performance of several test trackbeds incorporating HMA.

TURNOUT DESIGN PRACTICES

A typical cross-sectional view of HMA underlayment trackbed is shown in Figure 1. The HMA mat is placed directly on new subgrade or on an existing roadbed. Most, if not all, turnout projects have involved rehabilitation of a turnout in an existing line. It may be desirable to undercut a particularly troublesome roadbed, but generally this has not been necessary. The increased level of support and enhanced drainage provisions of the HMA layer reduces the stresses to within acceptable limits for the underlying material.

A layer of ballast is placed between the top of the HMA mat and the ties. The HMA mat basically serves as a waterproofing subballast, in place of an open granular subballast, and does not require precise grade control because the layer of ballast serves as a leveling course.

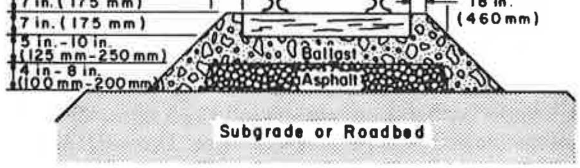

FIGURE 1 Typical HMA underlayment section.

The basic asphalt mix is fairly similar to that used for a conventional 37.5 mm (1.5 in.) maximum size dense-graded highway base. Highway base mixes have been used and are performing satisfactorily. However, it is possible to use a more plastic (low modulus), denser mix in trackbed applications to optimize certain mix properties. This is achieved by using a more dense aggregate grading and a higher than normal asphalt content. The low-void, high-asphalt-content mix is even more impermeable, compacts easier, and is more durable than a typical highway base mix. Details of the design are given elsewhere (*6*).

A rational and practical structural design procedure, KENTRACK, was developed during the early 1980s and later confirmed to be a reasonable, although conservative, procedure for HMA trackbeds. The design is based on two failure criteria: limiting the horizontal tensile strain (fatigue) at the bottom of the HMA and limiting the vertical compressive stress (permanent deformation) on the top of the subgrade. Charts were developed from the computer program to determine thicknesses of ballast and HMA as functions of subgrade support and the amount of train traffic. Discussions on the development and application of the KENTRACK charts for the thickness design of HMA trackbeds are presented elsewhere (*7,8*). Typical thicknesses are shown in Figure 1.

The recommended minimum ballast thickness is 125 mm (5 in.), so 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 level decreases. Typical ballast thicknesses range from 125 to 250 mm (5 to 10 in.), although greater thicknesses have been used.

HMA mat thicknesses range from 100 to 200 mm (4 to 8 in.). These thicknesses are sufficient to provide an impermeable mat. Increased load carrying capability can be more economically achieved by increasing ballast thickness.

The HMA mat should extend about 0.5 to 0.6 m (1.5 to 2.0 ft) beyond the ends of the ties, which requires a mat 3.4 to 3.7 m (11 to 12 ft) wide on single track installations. The mat will extend proportionally wider on turnouts or other special trackworks having longer ties. This will provide adequate width to achieve the desired waterproofing, support, and confinement properties of the HMA mat.

TURNOUT REHABILITATION PROCEDURES

The primary use of HMA underlayments in turnouts is to rehabilitate turnouts that have exhibited poor performance when conventional procedures have been used, which has resulted in high maintenance costs and poor operating efficiency. Pumping of the fines (mud) from the underlying subgrade or old roadbed is the common condition (see Figure 2). Degradation of the ballast and wear of the ties are contributing factors. Geometry is adversely affected. Conventional in-place jacking and raking, plowing the mud from the shoulders, or adding a geotextile have not been successful in prohibiting the re-occurrence of mud pumping and contamination of the track.

The turnout must first be removed from the line. The contaminated mixture of mud, ballast, and old roadbed are excavated, typically dozed, to the desired grade, which ranges from 0.6 to 0.9 m (2 to 3 ft) below top-of-rail elevation, depending on the specified thicknesses of HMA and ballast.

FIGURE 2 Typical pumping turnout before placement of HMA underlayment.

The HMA is hauled by dump truck from a hot-mix plant and is either spread with a standard highway asphalt paver or dumped on the grade and spread with a dozer blade. Precise grade and thickness control of the HMA is more difficult when the mix is spread with a blade; however, time and costs are reduced if a paver and paving crew are not required. The blade spreading technique has been used for the majority of turnout rehabilitation projects. The railroad and contractor forces already on site handle the spreading and placing activities. It is desirable to slightly slope or crown the HMA mat to prevent ponding of water and facilitate drainage away from the roadbed. Installation of drainage pipe is normally not necessary. Figure 3 depicts a typical HMA placement.

The mix can generally be placed in a single lift up to 150 mm (6 in.) thick. Compaction should follow soon before the mix cools and stiffens, which would adversely affect the compaction effectiveness. A standard roller, preferably a steel-wheel vibratory type, is commonly used to obtain a well-compacted mat with minimum air voids.

The turnout can be immediately dragged back on or lifted on the hot HMA mat. Rubber-tired equipment will minimize scuffing of the hot mat. Sometimes it is preferred to place a layer of ballast on the HMA mat before repositioning the turnout. Ballast will slightly indent a hot HMA mat. This is not detrimental and may even be desired to increase the frictional resistance between the ballast and HMA mat. After the rails are joined, all or the remainder of the ballast is distributed. The turnout is pulled and surfaced to provide the specified ballast thickness below the ties and the required line and surface. Either Number 24 or Number 4 ballast is generally specified. It should provide a shoulder 0.30 to 0.45 m (1 to 1.5 ft) wide.

One hr or less is typically required to spread and compact the HMA mat for turnout rehabilitation. The time will be slightly longer if a paver is used to spread the mix.

PERFORMANCE

Four longer sections of HMA underlayment trackbeds were subjected to periodic instrumented tests and measurements during several years of weathering in the trackbed environment. Mat temperatures were monitored throughout the seasons, and HMA cores were taken for analysis of the recovered asphalt and properties of the mix. A detailed analysis, a summary of which follows, of the performance findings is presented elsewhere (*6*).

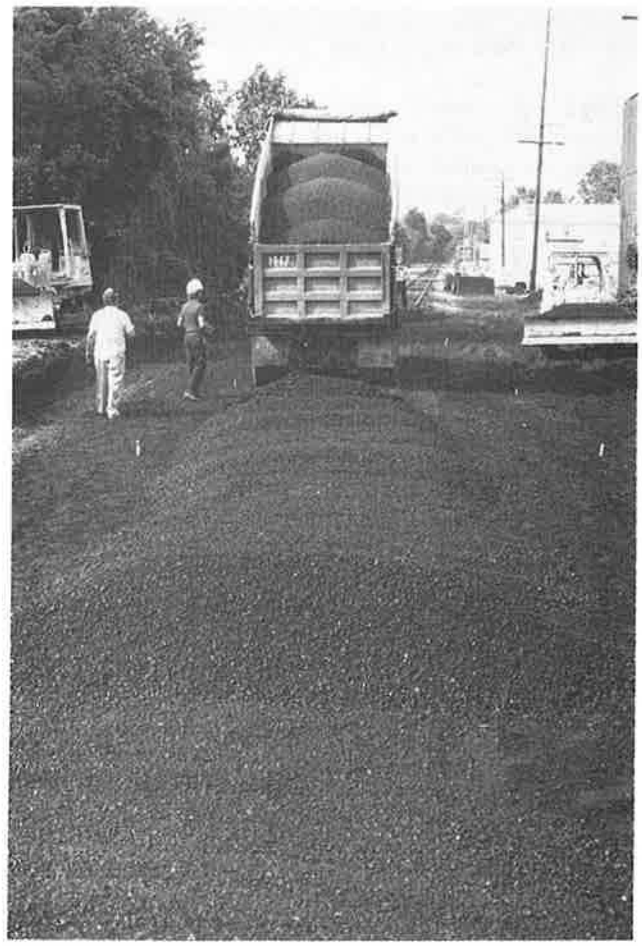

FIGURE 3 Placement of HMA with paver (*top*) and backdumping and spreading with dozer (*bottom*).

The range of temperature extremes in the HMA mat in the insulated trackbed environment was considerably less than is typical for HMA highway applications. Also less weathering and hardening of the HMA mixes and more consistent modulus values were noted for the HMA trackbed mixes than are typical for HMA highway mixes. No cracking or other distress was noted in any of the HMA mats.

Subgrade (roadbed) moisture contents under HMA mats were found to have stabilized at or near optimum values. This waterproofing effect provides uniformly strong subgrade support for the service life of the trackbed.

HMA trackbeds have maintained an optimum track stiffness with correspondingly less settlement and smaller deflections than normally obtained on conventional trackbeds. No significant changes in track geometry have been detected on the HMA underlayment trackbeds.

These performance evaluations were conducted on longer sections of track than is common for turnouts 30 to 90 m (100 to 300 ft) long. However, it is logical to assume similar test results would have been obtained for turnouts.

TURNOUT INSTALLATIONS

During the past several years numerous turnouts have been underlain with HMA and periodically observed. Possibly an even greater number of HMA crossing diamonds and road crossings are in service. Design and application considerations are similar.

The cost-effectiveness (or overall economics) of several HMA underlayment installations relative to costs associated with maintenance and operating efficiency before and after rehabilitation were investigated. The findings follow. Performance has been excellent for every HMA installation.

Ravenna, Kentucky

One of the first turnouts underlain with HMA was in 1981 on a Number 10 turnout on the L&N (now CSX) mainline through this East-Central Kentucky yard. An estimated 15 MGT of mostly 0.91-t (100-ton) coal trains use the mainline through the yard. The old turnout and contaminated ballast were removed as part of a general rehabilitation of the yard. An HMA mat 200 mm (8 in.) thick, 35.7 m (117 ft) long, and 4.3 to 7.3 m (14 to 24 ft) wide was placed on the old roadbed. After the preassembled new turnout was positioned on the HMA mat and joined to the mainline, 150 mm (6 in.) of ballast was unloaded and the track was pulled, aligned, and surfaced with conventional maintenance equipment.

Precise maintenance records were not available before 1981; however, the local maintenance crew indicated that the particular turnout had been a muddy spot for many years and had required a considerable number of raises, ballast, and tamping to keep the track in service. In the 10 years since it was rehabilitated, no maintenance has been required, and the turnout has remained high and dry with no fouling or settlement (Figure 4). The abutting track has performed poorly compared with the turnout. A skin lift was applied to the mainline during 1991.

FIGURE 4 CSX Ravenna Yard mainline HMA turnout after 10 years of service.

Flynn Yard Hump Track

An HMA underlayment was used by the Santa Fe in 1985 to rehabilitate the hump track and scale lead track (including four turnouts) at their 20 MGT Flynn Yard in Oklahoma City. This decision followed the favorable 3-year performance of a similar HMA underlayment on the trimlead track at the other end of the bowl. The original hump trackbed, built in 1981 and consisting of lime stabilized soil and ballast, had exhibited periodic major pumping and associated track irregularities. Cranes were used to remove the 183+ m (600+ ft) of line track and four turnouts. Next, the fouled ballast and lime-treated soil were excavated. An HMA mat 150 mm (6 in.) thick was placed in one lift (Figure 5) by means of a highway paving machine. The width and length of the mat varied from 3.7 to 16.5 m (12 to 54 ft) and 191 m (625 ft), respectively. Repositioning the original trackwork and applying 200 mm (8 in.) of ballast completed the installation. A recent view is shown in Figure 6.

Unfortunately, the track maintenance costs incurred on the hump between 1981 and 1985, before the HMA application, are not readily available. However, the magnitude was sufficient for the Santa Fe to essentially reconstruct the roadbed at tremendous cost. Two large mobile cranes, several pan scrapers, dozers, loaders, and the like were used during the 3-day main portion of the project.

The cost of the HMA underlayment was minimal compared with the total project costs. Since 1985 the hump and scale lead trackage, including the turnouts, have required only one skin lift and have exhibited no settlement or pumping. Detailed data on long-term HMA mixture characterization and

FIGURE 5 Santa Fe Flynn Yard hump track with HMA in place.

trackbed performance testing for the Flynn Yard HMA projects are presented elsewhere (*6*).

Red River Army Depot

During 1985, HMA was utilized at this Texarkana, Texas, facility to demonstrate the applicability of the underlayment technique as a rehabilitation alternative on Army railroad track. Three tracks and three turnouts totaling 370 m (1,215 ft) at the locomotive maintenance shop yard were removed. A layer 100 mm (4 in.) thick was placed before the addition of 200 mm (8 in.) of ballast and replacement of the trackage. Particular attention was given to arranging the slope of the HMA mat to minimize leakage of water into the locomotive service pits. A contiguous area of 1,580 m^2 (17,000 ft^2) was paved to accommodate the multiple track configuration. The native soils in the area possess low-quality engineering characteristics.

An extensive evaluation of the design, construction, and initial performance of the installation was made by the U.S. Army Corps of Engineers Waterways Experiment Station, which culminated in a detailed report (*9*). Assuming no trackbed maintenance was required on the HMA section, the additional cost of using the HMA was estimated to yield a break-even point of 7.5 years, when the maintenance savings would exceed the higher initial cost. After 6.5 years, the HMA section has required no maintenance, and there is no indication if or when any maintenance will be required. The problem with leakage into the locomotive pit was also solved. An additional long-term benefit cited in the report was that the effects of the better drainage of the track structure would reduce tie decay, reduce track deterioration, and improve operating conditions. These conditions have been observed and further support the long-term economic benefits of HMA underlayments. A view of the yard is shown in Figure 7.

Falmouth, Kentucky

Two Number 10 turnouts at this town on the CSX Transportation single-track 40+ MGT mainline south of Cincinnati were rehabilitated in 1986 with underlayments to demonstrate the applicability of the technique under traffic. The turnouts had historically required periodic trackbed maintenance with accompanying slow orders. Two dozers and a loader were used to remove the old trackwork and excavate the fouled ballast and several layers of fabric. The HMA was back-dumped and spread with a dozer to a 125-mm (5-in.) thickness, 3.7- to 6.1-m (12- to 20-ft) width, and 46-m (150-ft) length. The dumping, spreading, and compacting of the HMA required less than 1.5 hr. The new trackwork was immediately dragged on the compacted HMA mat and joined to the existing track. Ballast totaling 125 mm (5 in.) thickness was dumped, and the turnouts were tamped and aligned.

The turnouts were rehabilitated on two separate days. A ten-hr curfew was in effect each day; however, only 8 hr was needed. The required track time could have been further reduced, if necessary, by employing larger equipment and

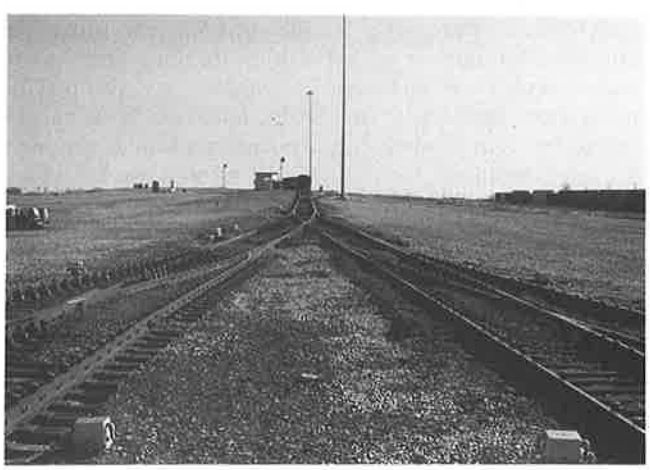

FIGURE 6 Santa Fe Flynn Yard HMA hump track after 7 years of service.

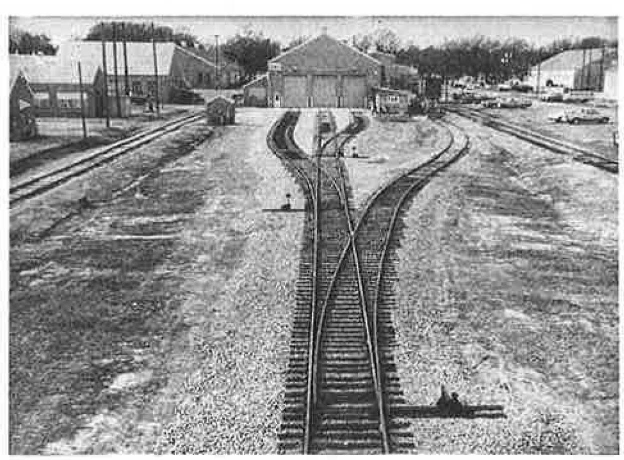

FIGURE 7 Red River Army Depot HMA locomotive maintenance shop yard.

TABLE 1 FALMOUTH REHABILITATION COST PER TURNOUT

Item	Cost
New turnout (metal and ties)	$13,000
Remove old turnout, excavate and place new turnout	
Section gang, 6 workers for 1 day	1,118
Welding gang, 2 workers for 1 day	412
Equipment rental	520
Welds (4 @ $250)	1,000
Surfacing gang for 10 hr	1,174
Tamper	727
Regulator	1,269
Ballast, 200 mm (8 in.)	750
HMA, 125 mm (5 in.), 65 t (72 tons)	2,350
Total	$22,320

NOTE: HMA cost $= \frac{2,350}{22,320} \times 100 = 10.5$ percent.

performing certain preparatory work before cutting the rail.

Detailed costs were maintained for each turnout rehabilitation project. The average cost for a turnout is presented in Table 1. The HMA represented 10.5 percent of the project costs. However, had HMA not been used, a granular subballast layer and geotextile would have been used in its place. Thus, the effective increase in the cost of the HMA was reduced to $1,450, or 6.9 percent, as noted in Table 2.

The affected area was undercut and a geotextile installed in 1982. This proved ineffective. Information gathered from two former roadmasters and the present roadmaster revealed that during the 12 years preceding the HMA applications, the turnouts had required frequent maintenance for adequate geometry for safe operations. On average, portions of the turnouts were raised and tamped at 3-month intervals. Ballast was dropped with mechanized raising and surfacing once a year. The average annual cost for these routine maintenance operations, excluding the 1982 undercutting and geotextile installations, was $2,650 per turnout, as noted here.

Hand raising and tamping four times a year:
5-person crew × ½ day × $175/person/day × 4 times/year = $1,750

Mechanized surfacing once a year:
(½ car of ballast × $800/car × 1 time/year = 400) + (1 tamper/regulator/operator × $1,000/day × ½ day × 1 time/year = 500) = $2,650 total per turnout per year

During the 5.5 years since the turnouts were underlain with HMA no trackbed maintenance has been needed or applied. The effective HMA cost of $1,450 was recovered during the first 6 months. Total savings for the following 5 years is $2,650 × 5, or $13,250 per turnout. In addition, traffic interruptions due to maintenance curfews and slow orders have been eliminated, which has provided additional savings. The excellent performance of the turnouts is depicted in Figure 8.

TABLE 2 FALMOUTH EFFECTIVE HMA COST PER TURNOUT

Item	Cost
Actual HMA cost	$2,350
Minus subballast cost (est.)	−450
Minus geotextile cost (est.)	−450
Effective HMA cost	$1,450

NOTE: $\frac{1,450}{20,870} \times 100 = 6.9$ percent, where 20,870 is the estimated rehabilitation cost without HMA.

Livingston, Kentucky

This represents a more recent (1988) HMA turnout rehabilitation project on which the costs and performance have been closely monitored. Included in the 90-m (300-ft) -long section on the CSX 50 MGT single-track mainline in southeast Kentucky were a Number 10 turnout for the Livingston sidetrack and the approach to north end of the Rockcastle River bridge. The turnout and bridge approach had required periodic trackbed maintenance for several years. A geotextile had been placed previously under the turnout, but had not rectified the chronic pumping and instability problems. It was decided to remove the badly deteriorated turnout and underlying materials and replace them with an HMA underlayment and new ballast and turnout.

The track was out of service for 8 hr. Dozers were used to remove the track and excavate 330 mm (13 in.) below bottom of ties. The 109 t (120 tons) of HMA was backdumped on the grade, spread with the dozers, and compacted to a 125-mm (5-in.) thickness in 45 min. A 200-mm (8-in.) thickness of granite ballast and a new wood tie turnout were installed along with the existing track panels (Figure 9).

Table 3 provides a comparison of the actual costs for the HMA underlayment on 90 m (300 ft) of track and turnout and estimated costs for conventional rehabilitation using additional ballast and geotextile. The HMA basically replaced 100 mm (4 in.) of ballast and a geotextile. No additional labor or equipment costs were assigned directly for placing the HMA because the labor and equipment were on-site and it would have taken as long, if not longer, to place the extra ballast and geotextile.

The HMA was delivered and dumped for $28/ton, for a total cost of $3,360. This represented 7.1 percent of the total project cost of $46,935. However, the increased cost of using HMA over that of conventional materials and design was only $1,160, or 2.5 percent, as indicated in Table 3.

The turnout and bridge approach track sections had been undercut and a geotextile installed in 1983. This proved ineffective. Information gathered from the local roadmaster, maintenance crew, and retired roadmaster revealed that for many years the turnout and bridge approach areas had required frequent maintenance to maintain adequate geometry for safe operations. On average, the turnout was raised and tamped at 2-month intervals. Ballast was dropped with mechanized raising and surfacing at 6-month intervals. The average annual cost for these routine maintenance operations was $4,425, as noted here.

Hand raising and tamping every 2 months:
5-person crew × ½ day × $175/person/day × 6 times/year = $2,625

Mechanized surfacing every 6 months:
(½ car of ballast × $800/car × 2 times/year = 800) + (1 tamper/regulator/operator × $1,000/day × ½ day × 2 times/year = 1,000) = $4,425 total per turnout per year

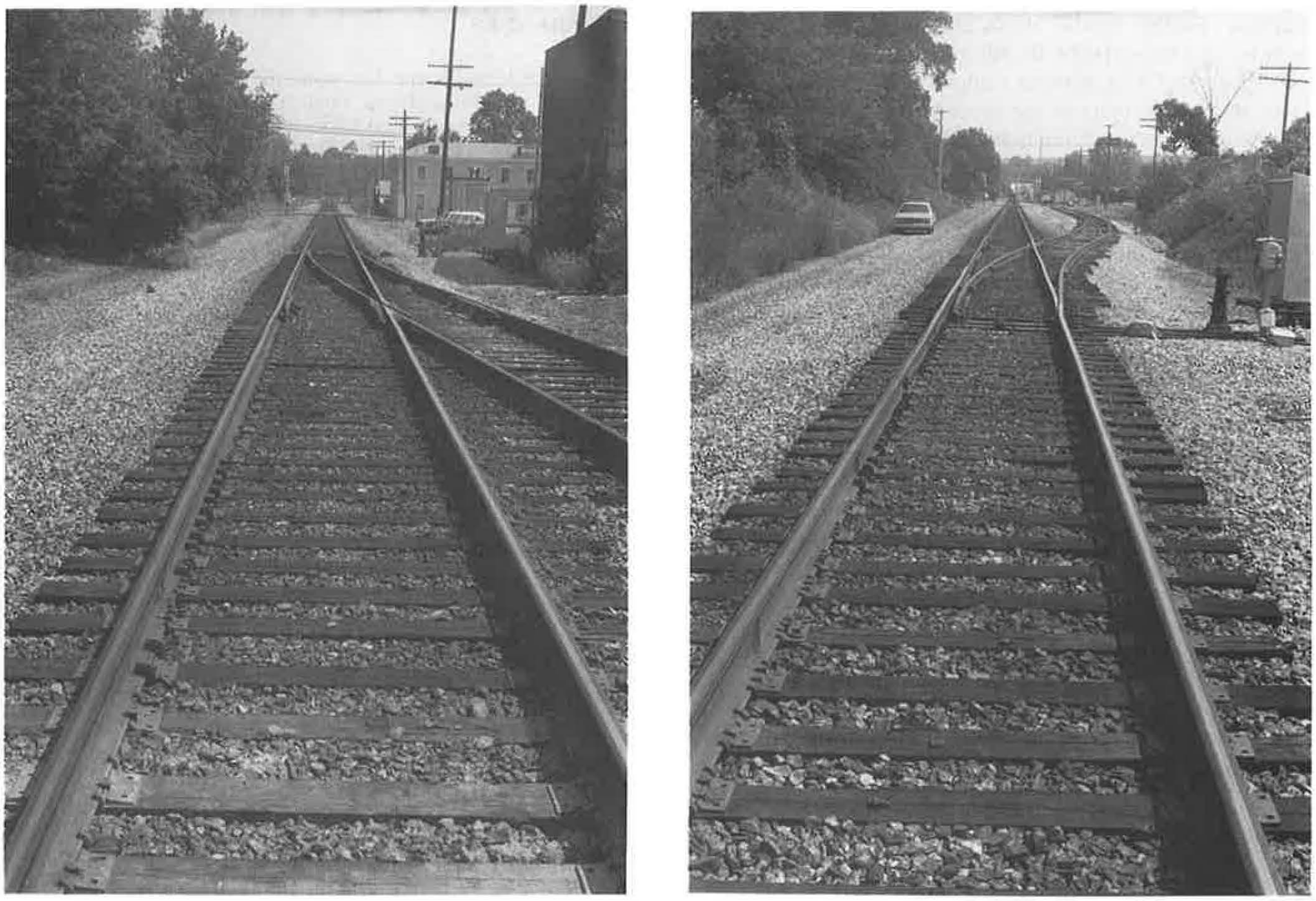

FIGURE 8 CSX Falmouth, Kentucky, mainline HMA turnouts north (*left*) and south (*right*).

The increased cost for the HMA, $1,160, was recovered during the first 3 months by maintenance savings on the turnout alone. During the following 1.5 years no maintenance was required, resulting in a savings of $6,637. During 1990 the wood tie trackage in the area, including the turnout, was replaced with concrete ties. Obviously, the section was surfaced following the concrete tie installation. No maintenance has been required since, and the geometry has remained essentially perfect.

FIGURE 9 CSX Livingston, Kentucky, mainline HMA turnout and bridge approach installation.

CLOSURE

HMA has been successfully used to rehabilitate numerous special trackworks, including turnouts, where conventional maintenance and rehabilitation procedures had not been successful. Performances of all monitored HMA turnout projects have been excellent. No ballast fouling, settlement, or other trackbed deterioration has been observed.

Typically the old turnout and fouled ballast and subballast are removed before placing the layer of HMA and new ballast. The additional time required to spread and compact the HMA is minimal, provided reasonable access for truck delivery is

TABLE 3 NUMBER 10 TURNOUT AND 90 m (300 ft) OF TRACK REHABILITATION AND RENEWAL COSTS, LIVINGSTON, KENTUCKY, 1988

Items	Conventional (Estimated)	HMA Underlayment (Actual)
New Turnout (Metal & Ties)	$16,775	$16,775
Remove Old Turnout, Track & Excavation	11,310	11,310
Replace New Turnout & Track	5,220	5,220
Welds	570	570
Surface & Align	1,000	1,000
18-oz Geotextile	900	–
Ballast & Unloading	(12 in.) 10,000	(8-in.) 8,700
5-in. HMA 120 tons @ $28/ton	--	3,360
Total	$45,775	$46,935
	$\frac{3,360}{46,935} \times 100 = 7.1\%$	$\frac{1,160}{45,775} \times 100 = 2.5\%$

Note: 1 in. = 25.4 mm, 1 oz/sq yd = 34 g/m², 1 ton = 0.91 t available. Further modifications and optimization of equipment for delivering HMA by rail to remote locations and for spreading the HMA without removing the turnout will enhance the acceptability of the procedure. The increased cost of using HMA is small and is typically recovered in less than a year through reductions in trackbed maintenance costs and improved train operating efficiency.

The primary benefits of the HMA layer are to improve load distributions to the subgrade, waterproof and stabilize the moisture content and strength of the subgrade, confine and thereby improve the load-carrying capacity of the ballast, and provide an impermeable layer to separate ballast from intermingling with subgrade. The resilient HMA mat eliminates subgrade pumping and does not substantially increase the stiffness of the trackbed.

To date the studies have mainly concentrated on evaluating ballast, HMA, and subgrade performance for HMA underlayment installations. The consistent high-quality support features of the HMA underlayment system should also enhance the performance of the turnout components (metal, ties, and fastenings) by reducing deflections and impact forces that adversely affect the fatigue, wear, and ultimately the life of the components. These factors will become more significant as wheel loads, tonnages, and speeds increase on the mainline routes. Reduced maintenance expenditures and increased operating efficiency are important goals for a profitable, competitive railroad system.

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