Long-Term Performances of Rail/Highway At-Grade Crossings Containing Enhanced Trackbed Support

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ABSTRACT

Rail/Highway at-grade crossings supported on conventional all-granular trackbeds typically settle more rapidly than the highway and railway approaches to the crossing area. This is largely due to the added loadings in the jointly used (common) area. Normally these types of crossings must be renewed each time significant maintenance is performed on the track. In addition, a typical railroad track will consistently deflect about 0.25 in. (6.5 mm) in response to heavy rail loadings; whereas, the adjacent highway approaches will experience insignificant deflections in response to heavy truck loadings. These conflicting responses, due to dissimilar support, result in excessive deflections, rapid wear of the crossing components, and premature settlement and roughness of the crossing.

The purpose of this research was to evaluate the long-term settlements over a wide variety of at-grade crossings. As such, 24 highway crossings were used to determine the effects of enhanced support on minimizing long-term settlements of the crossing surfaces. Settlements of the rail and highway approaches to the crossing areas were compared to settlements of the common crossing areas over an average service period of three years.

Long-term settlements of crossings with traditional all-granular support materials were compared to crossings with enhanced support. The enhanced support was provided by substituting a layer of asphalt (termed underlayment) for the all-granular subballast layer. The asphalt was installed during the renewal of the crossings, which also involved concurrent installation of new track panels. The renewal process was “fast-tracked” so that the track would be back in service in four hours and the highway would be back in service in 8 to 12 hours depending on the extent of the approach installations. The enhanced support provided by the asphalt layer in combination with immediate compaction of the ballast precludes the need to facilitate compaction with train traffic over a period of days. Renewing a crossing can be accomplished in a single day with minimal closing of the crossing and attendant benefits to the traveling public. This involves a cooperative approach with the Railroad Company and Governmental Agency.

The trackbed crossings underlain with asphalt settled 41% of the amount for the all-granular supported trackbed crossings. In addition, the crossing areas underlain with asphalt settled 44% of the abutting all-granular supported track approaches. The statistical t-test validated the significance of the differential findings. Settlements of the all-granular track approaches to the crossings were statistically similar to each other and to the settlements of the all-granular crossing areas.
INTRODUCTION
It is common for motorists to encounter railroad/highway grade crossings that require speed reductions to safely and comfortably traverse the crossings. The smoothness or roughness of crossings can be the result of one or more of three primary contributors that ultimately affect the relative rideability and long-term performance of crossings. These are depicted in Figure 1.

The most likely contributor is the **roughness of the immediate crossing surface area**. This involves the width of the roadway and a length equivalent to the width of the trackbed, about 9 ft (2.7 m). The structural adequacy of the crossing and the quality of the materials and installation process will primarily affect this aspect. The information documented herein primarily relates to minimizing the effects of crossing surface area factors that adversely contribute to unacceptable settlement and subsequent roughness of the crossing surface area.

A second contributor is the **roughness of the highway approaches**. The length of the individual crossing approaches can vary from 0-100 ft (0-30.5 m) depending on the length of pavement disturbed during the crossing installation. It is highly dependent on the quality of the crossing installation and highway paving operations. Even though the crossing surface area may remain smooth, the effects of approaches can be detrimental to the smoothness of the crossing. The simple solution for restoring acceptable smoothness to the crossing may only consist of repaving the approaches. The railroad is basically unaffected by this activity. It may require milling the existing approaches so that a reasonable thickness of paving material can be placed to match the elevation of the crossing surface.

The third contributor relates to the **vertical profile geometry** of the highway relative to that of the intersecting railroad. This is specific to a particular crossing, and can vary from essentially no effect when the highway and railroad vertical profiles are flat and meet at the same elevation. However, it is common for the railroad elevation to be above or below that of the highway, thus a crest (hump) or sag (dip) respectively in the highway vertical profile. Both of these situations produce a “thrill bump” for the vehicle occupants – or roughness – even though the crossing surface area and highway approaches are smooth. It is common to increase the elevation of the approaches by adding thickness of the pavement near the crossing to minimize the effects of a crest vertical curve. Lowering the elevation of the railroad is another solution, but is very difficult to accomplish. Sag vertical curves are more difficult to address.

An additional situation that is difficult to address is when the highway is on a vertical grade and it intersects a railroad that is on a tangent, having no superelevation to match the vertical grade of the highway. This in effect creates a flat spot in the highway profile, inducing some measure of roughness, even though the crossing area may be very level and smooth.

In situations where the railroad and highway intersect on horizontal curves, the individual superelevations may not match resulting in a warp in the highway vertical profile. This is also difficult to address unless the superelevation can be adjusted. It adversely affects the smoothness of the crossing even though the crossing surface area and highway approaches may be smooth.

BACKGROUND
Deteriorating and rough crossing surfaces that have settled appreciably often result in undesirable driving conditions for both modes of transportation. Railroad and highway traffic volumes and axle loadings continue to increase so the frequency of encountering rough crossings will likely increase. The two modes require conflicting demands (1). The railroad roadbed and track system is designed to be flexible, deflecting about 0.25 in. (6.5 mm) under normal railroad traffic. This support is normally carried through the crossing. The highway pavement structure is
designed to be essentially rigid, deflecting a minuscule amount even under heavy trucks. The crossing (track) support is basically the track structure composed of granular (crushed aggregate or ballast) that may provide a different level of load-carrying capacity as the highway approaches. Thus the crossing area deflects excessively with subsequent permanent settlement. This results in rapid abrasion and wear of the crossing surface and support materials and the surface fails prematurely due to deterioration and settlement of the crossing.

The most common track (sub-structural) support for railroad/highway crossings consists of unbound granular materials as depicted in Figure 2. The upper portion is typically composed of open-graded, free-draining ballast size particles, generally sized from 3 in. (75 mm) to about 0.25 in. (6.5 mm). A granular layer composed of finer sized particles, or subballast, is below the ballast. The voids in the ballast layer can potentially provide a path for water to seep through and permeate the underlying subballast and possibly the subgrade. This can decrease the structural integrity of the support. The inherent lack of support for the highway vehicles in the track crossing area, can result in excessive deflections of the crossing. The excessive deflections combined with the lessening of the support strength due to the high moisture contents of the support materials produces permanent settlement of the crossing. This adversely affects the railroad and highway profiles in the immediate crossing area.

The ideal sub-structural support system for a rail/highway crossing:
- Provides adequate strength to resist the combined rail and highway loadings thus minimizing stresses on the underlying subgrade,
- Minimizes vertical deflections of the crossings due to rail and highway loadings so that the wear and deteriorations of the crossing components will be minimized, and
- Serves to waterproof the underlying subgrade so that its load carrying capability will not be sacrificed even for marginal quality subgrades.

Long-term consolidation or settlement of the crossing should be minimal providing for a smoother crossing with enhanced rideability characteristics for a longer period of time. The crossing will not have to be rehabilitated as frequently with attendant disruptions and expenses to the railroad company, governmental agency, and traveling public.

The use of a layer of hot mix asphalt within the track substructure, in lieu of conventional granular subballast, is widely utilized to provide ideal properties to the crossing (2). Literally thousands of crossings have been rehabilitated or initially constructed new using this procedure. The basic process involves removing the old crossing surface and track panel followed by excavating the underlying mixture of ballast, subballast, and subgrade to the required depth. These are replaced with a compacted layer of hot mix asphalt (termed asphalt underlayment), a compacted layer of ballast, a new track panel, and a new crossing surface. Figure 2 contains a typical view of a rail/highway crossing containing an asphalt underlayment.

OBJECTIVES
The primary objective of the research reported herein was to determine whether the enhanced support provided by the utilization of a layer of hot mix asphalt, in-lieu-of granular subballast, contributes to minimizing subsequent settlement while maintaining smooth crossing surfaces thereby extending acceptable performance life of crossings.

An ancillary objective was to document the development of a “fast-track” approach, made possible with immediate enhanced structural support, to quickly stabilize the track during installation thus vertically eliminating the need for “seasoning” the affected track, assuring minimal subsequent track settlement. The new crossing would be available for opening to traffic
soon after it was installed minimizing inconveniences to highway users and reducing train slow orders.

An additional objective was to optimize and categorize a cooperative practice whereby the affected railroad company and governmental (highway) agency would jointly participate in materials procurement, traffic control, and overall planning/management of the crossing installation/renewal process. This would inject certain economies by providing a high quality product in a timely fashion utilizing the inherent expertise of both the railroad company and the governmental agency. An additional benefit would be minimizing costly disruptions to the rail and highway traffic.

RIDEABILITY MEASURES FOR CROSSINGS
There are no widely used measures for quantitatively measuring the rideability of crossings. The American Railway Engineering and Maintenance-of-Way Association (AREMA) and the American Association of State Highway and Transportation Officials (AASHTO) have established recommended practices that are used as guides to establish policies and practices for the profile and alignment of crossings and approaches (3, 4).

These guidelines establish consistent geometric designs for railroad/highway grade crossings and approaches and help to eliminate roughness through a crossing, which directly affects the safety and reduces problems such as wear and tear or vehicle hang-up and high centering. The guidelines for the profile and alignment of crossings and approaches state that the highway must be level with the top of rails for 2 ft (0.6 m) outside of the rails. Additionally, the surface of the highway cannot be more than 3 in. (75 mm) higher or 6 in. (150 mm) lower than the top of nearest rail at a point 30 ft (9.1 m) from the rail, measured at right angle thereto, unless track superelevation dictates otherwise (5).

There are widely used standards to quantitatively measure roughness of highway pavements. Roughness is defined by AASHTO as the deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality (6). A standard scale of pavement roughness is known as the international roughness index (IRI). This scale was developed by the World Bank in the 1980s in order to create a consistent method of determining pavement roughness that could be utilized worldwide. IRI is calculated from a single longitudinal profile measured with a road profiler in both the inside and outside wheel paths of the pavement. The average of these two IRI statistics is reported as the roughness of the pavement section (7). The recommended units are meters per kilometer (m/km) or millimeters per meter (mm/m) and is based on the accumulated suspension (in., mm) divided by the traveled distance (mi/km).

These highway Inertial Profiles are designed to report average roughness data over substantial distances. Attempts to use these systems and isolate short (crossing) distances have not been totally successful (8, 9).

ASPHALT UNDERLAYERMENT TRACKBEDS
A typical asphalt underlayment replaces the subballast and a portion of the ballast in a typical trackbed. Asphalt by nature is considerably stiffer than the traditional granular material trackbed yet sufficiently resilient to support the highway and railway loadings, a combination which is ideal for both modes of transportation. The mixture most suitable for underlayments is basically a mix of paving grade asphalt binder (cement) and dense graded mineral aggregates similar to that used for highway pavement applications (2).
The benefits of this trackbed system have been documented (10, 11):

- A strengthened track support layer below the ballast to uniformly distribute reduced pressures to the roadbed and subgrade;
- A waterproofing layer and confinement to the underlying roadbed that provides consistent load-carrying capability for track structures, even on roadbeds of marginal quality;
- An impermeable layer to divert water to side ditches and essentially eliminate roadbed or subgrade moisture fluctuations, effectively improving and maintaining underlying support;
- A consistently high level of confinement for the ballast, so the ballast can develop high shear strength and distribute pressures uniformly;
- A resilient layer between the ballast and roadbed to reduce the likelihood of subgrade pumping without substantially increasing track stiffness; and
- An all-weather, uniformly stable surface for placing the ballast and track superstructure.

When replacing an existing crossing with an asphalt underlayment, the typical two-lane highway, single-track railroad crossing will be closed for four to five hours for train traffic and 8 to 12 hours for highway traffic. It is recommended that the following activities be conducted prior to rehabilitation (11):

- Notify the public and develop a plan for traffic diversion and detours,
- Obtain adequate outage (window of time),
- Cut rail and use joint bars to keep rail in service until work begins,
- Saw pavement approaches 7 ft (2.1 m) from both sides of rail to allow adequate room for excavation, and
- Store materials on-site, except for asphalt, in order to work as efficiently as possible.

Once the preparation has been completed, the process of installing the new underlayment can begin on the selected date. The following listing is the sequential activities:

- Remove the old crossing surface and excavate the trackbed to a depth of approximately 28 in. (700 mm).
- Compact subgrade with a vibratory roller if necessary.
- Dump and spread the asphalt. The width of the asphalt mat should extend 1.5 to 2 ft (0.45 to 0.60 m) beyond the ends of the ties. Generally a 12-ft (3.6 m) mat width is used. A minimum length of 25 to 100 ft (7.6 to 30.5 m) is recommended beyond the ends of the crossing to provide a transition zone. The asphalt mat is typically 6 in. (150 mm) thick.
- Compact the asphalt. A compaction level of 95% is preferred using a steel wheeled, vibratory type standard roller. It is also beneficial to leave a side slope allowing for drainage along the asphalt.
- Dump and spread the ballast. A thickness of 8 to 12 in. (200 to 300 mm) of ballast should be on top of the asphalt after compaction.
- Compact the ballast to stabilize the trackbed and minimize subsequent settlement.
- Position the prefabricated track panel on the compacted ballast.
- Bolt the new rail to the existing rail, welds can be made later.
- Add the cribbing ballast and additional ballast to fill in the cribs and allow for a track raise and adjustment.
• Surface, tamp, and broom the immediate crossing area.
• Install the crossing surface including the trenches along the track.
• Pave the highway approaches.

**IDEAL RAIL/HIGHWAY CROSSING RENEWAL PROCESS**

The goals for the ideal rail/highway crossing renewal process are to:

• Provide a quality, safe, cost effective rail/highway crossing that will remain stable, smooth and serviceable for both highway and rail traffic for a minimum of 15 years with minimal annual cost (minimizing costly disruptions for track and crossing maintenance),

• Accomplish the complete renewal (trackbed and crossing surface) in a minimum of time without significant disruption to rail and highway traffic (maximum four-hour train curfew and 8 to 12-hour highway closure), and

• Utilize a cooperative approach, involving both the railroad (and its contractor, if applicable) and the local governmental/highway agency, to provide an economical, quality product.

The importance of a planning meeting well in advance of the anticipated date for the renewal cannot be overemphasized. The railroad company and governmental/highway agency must address three primary issues:

• Select Date – This can have a major effect on minimizing disruption and inconveniences to rail and highway traffic. High volume rail lines having regularly scheduled trains must be reviewed to minimize the adverse effects of track closures. Certain times on certain days may have lighter volumes and the railroad can adjust schedules slightly. The highway volume and type of traffic coupled with the availability of alternate routes and detours will be important concerns. Site specific factors must be considered.

• Assign Responsibilities – These can be shared between the railroad company and governmental/highway agency to maximize the inherent expertise and economies of the two entities. The primary areas of responsibilities and the suggested responsibility party are:
  o Highway Closure and Traffic Control
    – Local highway/governmental agency
  o Public Announcements and Notification
    – Local highway/governmental agency
  o Obtain Railroad Curfew
    – Railroad company
  o Temporary Crossing Construction and Removal
    – Railroad company (or supervise)
  o Removal and Replacement of the Track and Crossing Surface
    – Railroad company (or its contractor)
  o Pave Asphalt Trenches and Approaches
    -- Local highway/governmental agency (or supervise)

• Share Cost – This may be predetermined as policies vary significantly due to specific governmental statutes and railroad company policies. However, a major objective is to extend available funds by assigning activities to the entity that can provide a quality product at the lowest cost. Normally, activities within the railroad right-of-
way must be conducted by, or under supervision of, the railroad company. Typical shared costs are:

- Removal and Installation of Track and Crossing Materials
  - Railroad company (may be reimbursed?)
- Traffic Control, Public Announcements, and Asphalt Paving
  - Local highway/governmental agency

CROSSING SETTLEMENT MEASURES

The two evaluations of the long-term performance of rail/highway crossings utilized elevation change (settlement) measurements along both the railroad – top-of-rail profiles and highway – longitudinal highway profiles. A summary treatise of the measurements and analyses follows. Detailed coverage can be found elsewhere (12, 13).

Top-of-Rail Profiles

Twenty crossings were selected. Elevations were established at 10 ft (3 m) intervals on both rails throughout the crossing and for typically 50 to 60 ft (15 to 18 m) along both track approaches. Initial measurements were taken immediately after the crossing was installed. Conventional differential leveling procedures were utilized (Figure 3). Based on established semi-permanent benchmarks, repeat profile measurements were taken periodically for three years or longer to assess the rate of and total settlement.

Four of the crossings contain typical all-granular support without asphalt underlayment. These crossings were rehabilitated during a tie renewal program. The crossing surfaces were removed in advance of the tie changeout equipment. Defective ties were replaced and new asphalt and rubber seal surfaces were installed. Figure 4 is a typical view of one of the crossings immediately after the surface was installed.

These four crossings are on the reasonably high-tonnage CSXT Cincinnati Subdivision mainline in Northeast Kentucky. However, the highway traffic is very low primarily serving local residential traffic with essentially no trucks.

The other 16 crossings contain asphalt underlayment. These are on three major and two minor rail mainlines. Four are located on the Cincinnati Subdivision. A representative crossing with underlayment is shown in Figure 5. Most of the others are located on heavy tonnage coal-hauling rail lines in Eastern Kentucky. These also accommodate high volumes of highway traffic and trucks. The combined rail and highway loadings on several of the crossings are considered to be the most severe in the state. A representative crossing is shown in Figure 6. The three crossings on relatively light tonnage rail lines have very high highway traffic volumes. One of these is in Western Kentucky (see Figure 7); the other two are in Michigan.

Prior to the study these 16 crossings were completely renewed. This implies that in addition to removing the old surface, the existing track panel and underlying ballast/subballast/subgrade materials were removed to provide space for an asphalt underlayment and ballast. A new track panel was installed and the track was surfaced and aligned prior to placing the crossing surface. Most of the new crossing surfaces are either pre-cast concrete or rubber seal/asphalt.

The primary reason for utilizing asphalt underlayments, during the replacement of these 16 crossing surfaces, was because the existing crossings had routinely not performed well under
the heavy rail and highway traffic. Settlement and deterioration of the crossings resulted in undesirable rideability features.

**Cincinnati Subdivision Crossings**
Average settlements after 33 months for the four crossings that were rehabilitated without renewing the track and underlying material (no asphalt underlayment) are contained in Table 1 and Figure 8. Note that the average settlement for the track approaches was 1.50 in. (38.1 mm) and for the crossing area was 1.29 in. (32.8 mm). These values are reasonably close. The highway traffic is minimal for the asphalt/rubber seal surfaces on these four crossings. Figure 9 depicts typical top-of-rail settlements for a representative crossing. Measurements were taken at 10 ft (3.0 m) intervals for a total distance of 200 ft (61 m).

Average settlements after 42 months for the four crossings that had asphalt underlayments installed during the crossing renewals are also contained in Table 1 and Figure 8. Note that the average settlement for the track approaches was 1.53 in. (38.9 mm), practically the same as the average for the four non-asphalt underlayment crossings. This is expected since the existing trackbeds on the approaches are representative of old roadbed materials. Also, these crossings had been in service slightly longer, thus the slight increase in average settlement.

However, the significant measure is the settlement in the crossing areas over the underlayments. Note that this is only 0.53 in. (13.5 mm) or about one-third of the average approach settlements. This is obviously due to the effect of the enhanced support provided by the asphalt underlayment. The crossing surfaces are composed of both pre-cast concrete and timber to withstand the high traffic volumes.

Figure 10 depicts typical top-of-rail settlements for a representative crossing. The heavier line represents the crossing area underlain with asphalt. The lighter line represents the approaches without underlayment. It is obvious that the approaches have settled significantly more.

Comparing settlements within the crossing areas for the two types of crossing substructures indicates that the average underlayment crossing settlement of 0.53 in. (13.5 mm) was 41% of the average settlement for the typical trackbed of 1.29 in. (32.8 mm). In addition, the asphalt underlayment crossings had been in service 27% longer with substantially heavier highway traffic. The settlement rate over the asphalt underlayment crossing areas essentially ceases after three years.

**Additional Underlayment Crossings**
Twelve additional crossings underlain with asphalt were also monitored for top-of-rail settlement. Nine of these crossings are in Eastern Kentucky on CSX Transportation heavy tonnage rail lines. The highway traffic is significant and consists of substantial numbers of coal trucks on all of the crossings. These crossings represented severe tests for endurance. Five of the crossing surfaces are asphalt/rubber seal. The other four are pre-cast concrete. Average service life is 27 years.

Settlement data for these heavy traffic crossings is contained in Table 2 and data for a representative crossing is shown in Figure 11. The average approach settlement for the four Big Sandy/Rockhouse Subdivision concrete crossings was 1.58 in. (40.1 mm), similar to Cincinnati Subdivision crossing approaches. As expected, the average settlements within the crossing area was significantly less, averaging 0.84 in. (21.3 mm). These four crossings accommodate several hundred coal trucks each day. However, the highway crossing area has settled only 53% as much
as the approaches even with the added effects of the trucks. These crossings had been in service for 37 months when the last settlement data was obtained. Programmed tie renewal procedures have skipped over the crossings since the crossing areas had not deteriorated.

Similar data for the five Rockhouse Subdivision asphalt/rubber seal crossings is also presented in Table 2 and data for a representative crossing is shown in Figure 12. The average settlements for the crossing areas and approaches respectively are less than the crossings previously discussed. However, the crossings have been in service only 20 months. The crossing area average settlement of 0.52 in. (13.2 mm) is 44% of the average approach settlement of 1.18 in. (30.0 mm).

Table 3 contains settlement data for the asphalt/rubber seal US 60 Stanley Crossing in Western Kentucky. Measurements were taken on this crossing for 54 months after installation. This is a high speed, high volume highway. The train traffic on the CSXT mainline is moderate. The trend in settlement measurements is similar to previous documentation. The crossing area settlement of 0.45 in. (11.4 mm) is 48% of the 0.93 in. (23.6 mm) track approach settlement. Figure 13 shows the various top-of-rail profiles for the US 60 crossing since it was installed in 2002.

Table 3 also contains two-year crossing settlement data for two heavy highway traffic volume crossings on the light traffic Ann Arbor Railroad in Michigan. Measurements were only taken in the crossing areas. The two-year settlements of only 0.31 in. (7.9 mm) is likely attributable to the minor amount of train and truck traffic in Ann Arbor. It is included for comparison purposes.

Statistical Analyses of Top-of-Rail Settlements
The t-test was used to determine if the differences between Top-of-Rail Settlements results obtained at the crossings utilizing asphalt underlayments were significantly different from crossings which did not receive underlayments. The t-test is appropriate to use to determine if the means of two groups are statistically different from one another (14).

The results from the 16 crossings which received underlayments were compared with the results from the four crossings which contained all-granular trackbeds without underlayments. Additionally, the Cincinnati Subdivision was further evaluated for comparisons since this was the only subdivision that crossings with and without an underlayment were available for study. Seven t-test comparisons were made. The results are contained in Table 4.

Significant differences were apparent when comparing 1) crossing areas without underlayment to crossing areas with underlayment, and 2) approaches to crossings with underlayment to crossing areas with underlayment. Significant differences were not apparent when comparing 3) approaches to crossings without underlayment to approaches to crossings with underlayment, and 4) approaches to crossings without underlayment to crossing areas without underlayment.

Thus, in each instance when an existing trackbed (without underlayment) was compared to an underlayment trackbed, the t-test indicated a significant difference in settlement measures. Conversely, in each instance when existing trackbeds (without underlayment) approaches or crossings were compared, the data failed the t-test indicating no significant difference.

Longitudinal Highway Profiles
Four sites in Central Kentucky were selected; two very heavy traffic crossings on Norfolk Southern in Lexington and two heavy traffic crossings on CSX Transportation in nearby
Winchester and Richmond. These seven crossings (three are on double track) were completely removed and asphalt underlayments and new trackbed and crossing materials were utilized, similar to the rehabilitated Eastern Kentucky crossings described previously.

Elevations were established along the wheel paths on the highway approaches and across the crossings using Total Station measuring procedures (Figure 14). Measurements were taken prior to the rehabilitation activity, immediately after the crossing was installed, and at subsequent intervals afterwards for monitoring purposes. Special attention was also given for using the total station data to calculate Top-of-Rail Settlements.

Pertinent rail and highway traffic parameters are included in Table 5. The annual million gross tons rail traffic (MGT) and the average daily highway traffic (ADT) represent very high rail tonnage and highway traffic volumes. All seven crossing surfaces are pre-cast concrete. Figure 15 is a typical view of a crossing.

A characteristic longitudinal highway profile across the Rosemont Garden crossing is shown in Figure 16. Each profile represents a different period of time between settlement measurements. Note the existing hump on one of the highway approaches. This was milled off prior to placing the asphalt approaches for the new crossing. Also the thickness of the asphalt on the approaches, some distance from the crossing, was increased to reduce the approach gradient and improve crossing smoothness.

Table 6 contains average top-of-rail settlements obtained from the total station measurements. These vary somewhat, likely due to minor benchmark disturbances and the complexity of obtaining and reducing the data. However, the overall average settlement values are similar to those obtained from differential leveling top-of-rail measurements.

Programmed tie renewal (change-out) activities have occurred for trackage containing four of the crossings. The crossing areas were “skipped over” since they were still very smooth and serviceable.

**CONCLUDING COMMENTS**

The advantage of enhanced structural support, provided by asphalt underlayerment, was clearly demonstrated to minimize long-term settlement within the jointly used rail/highway crossing area.

Top-of-rail elevation changes (settlements) throughout rail/highway crossings and rail approaches were monitored for extended time intervals using conventional differential leveling techniques.

The 16 crossing areas underlain with asphalt carry considerably heavier highway traffic and truck loadings than the four all-granular supported crossings.

Long-term settlements, within the jointly used crossing areas, for the 16 crossings underlain with asphalt settled 41% of the amount for the four all-granular supported trackbed crossings. The significant difference was validated by the t-test.

In addition, the 16 crossing areas underlain with asphalt settled 44% of the abutting all-granular supported track approaches; this was also significantly different.

As expected, settlements for the 20 all-granular track approaches to the crossings were statistically similar to each other and to the settlements of the four all-granular crossing areas.

Long-term settlement measurements for four additional heavy traffic crossings, utilizing total stationing procedures along highway wheel paths, provided similar top-of-rail settlement data for assessment purposes prior to and after rehabilitation procedures.
All crossings underlain with asphalt have remained smooth and serviceable after the 3 to 4 years of monitoring. Most of the settlement occurs within the initial 2 to 3 years. Several of the heavy highway traffic crossings have been “skipped over” during subsequent tie-changeout programmed maintenance activities, with attendant minimization of traffic disruptions and crossing replacement costs.

The single-day (fast-track) crossing renewal process is feasible when enhanced structural support is provided. It permits immediate consolidation and compaction of the ballast and track minimizing subsequent significant settlement of the crossing. There is no need for train traffic to consolidate the ballast over a period of days, with attendant closure of the crossing to highway traffic.

The desirability of utilizing a cooperative approach between the railroad company and governmental agency to share responsibilities to enhance quality and minimize costs is readily apparent.

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<table>
<thead>
<tr>
<th>Crossing</th>
<th>Average Approach Settlement</th>
<th>Average Crossing Settlement</th>
<th>Months in Service</th>
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</tr>
<tr>
<td><strong>AVERAGE (No Underlayment)</strong></td>
<td>1.50 in.</td>
<td>1.29 in.</td>
<td>33</td>
</tr>
<tr>
<td><strong>Cincinnati Subdivision with Asphalt Underlayment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rt. 8 Concord</td>
<td>1.28 in.</td>
<td>0.31 in.</td>
<td>40</td>
</tr>
<tr>
<td>South Portsmouth</td>
<td>1.65 in.</td>
<td>0.56 in.</td>
<td>42</td>
</tr>
<tr>
<td>South Shore</td>
<td>1.23 in.</td>
<td>0.20 in.</td>
<td>42</td>
</tr>
<tr>
<td>Vanceburg-Main Street</td>
<td>1.96 in.</td>
<td>1.04 in.</td>
<td>43</td>
</tr>
<tr>
<td><strong>AVERAGE (With Underlayment)</strong></td>
<td>1.53 in.</td>
<td>0.53 in.</td>
<td>42</td>
</tr>
</tbody>
</table>

1.0 in. = 25.4 mm
**TABLE 2 Average Approach/Crossing Settlements for Eastern Kentucky Subdivision Crossings**

<table>
<thead>
<tr>
<th>Crossing</th>
<th>Average Approach Settlement</th>
<th>Average Crossing Settlement</th>
<th>Months in Service</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rockhouse Subdivision</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colson</td>
<td>1.30 in.</td>
<td>0.81 in.</td>
<td>22</td>
</tr>
<tr>
<td>Indian Bottom Church</td>
<td>1.52 in.</td>
<td>0.96 in.</td>
<td>19</td>
</tr>
<tr>
<td>No Name</td>
<td>1.17 in.</td>
<td>0.37 in.</td>
<td>19</td>
</tr>
<tr>
<td>Old Letcher School</td>
<td>1.16 in.</td>
<td>0.20 in.</td>
<td>18</td>
</tr>
<tr>
<td>Letcher School</td>
<td>0.76 in.</td>
<td>0.25 in.</td>
<td>21</td>
</tr>
<tr>
<td><strong>AVERAGE (with Underlayment)</strong></td>
<td>1.18 in.</td>
<td>0.52 in.</td>
<td>20</td>
</tr>
<tr>
<td><strong>Big Sandy/Rockhouse Subdivisions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KY Coal Terminal #1 Track</td>
<td>1.16 in.</td>
<td>0.68 in.</td>
<td>37</td>
</tr>
<tr>
<td>KY Coal Terminal #2 Track</td>
<td>1.71 in.</td>
<td>0.90 in.</td>
<td>37</td>
</tr>
<tr>
<td>KY 15 Isom</td>
<td>2.10 in.</td>
<td>1.17 in.</td>
<td>37</td>
</tr>
<tr>
<td>KY Power-Louisa</td>
<td>1.35 in.</td>
<td>0.59 in.</td>
<td>37</td>
</tr>
<tr>
<td><strong>AVERAGE (with Underlayment)</strong></td>
<td>1.58 in.</td>
<td>0.84 in.</td>
<td>37</td>
</tr>
</tbody>
</table>

1.0 in. = 25.4 mm
<table>
<thead>
<tr>
<th>Crossing</th>
<th>Average Approach Settlement</th>
<th>Average Crossing Settlement</th>
<th>Months in Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH&amp;StL Subdivision</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 60 Stanley (with Underlayment)</td>
<td>0.93 in.</td>
<td>0.45 in.</td>
<td>54</td>
</tr>
<tr>
<td>Ann Arbor, Michigan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liberty Street</td>
<td>n/a</td>
<td>0.31 in.</td>
<td>23</td>
</tr>
<tr>
<td>State Street</td>
<td>n/a</td>
<td>0.31 in.</td>
<td>25</td>
</tr>
<tr>
<td>AVERAGE (with Underlayment)</td>
<td>n/a</td>
<td>0.31 in.</td>
<td>24</td>
</tr>
<tr>
<td>1.0 in. = 25.4 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 4 Results of t-Test for Top-of-Rail Settlements

<table>
<thead>
<tr>
<th></th>
<th>t-statistic</th>
<th>Significant Difference?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Twenty Crossings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossing Areas Without Underlayments vs. Crossing Areas With Underlayments</td>
<td>4.29</td>
<td>Yes</td>
</tr>
<tr>
<td>Approaches To Crossings With Underlayments vs. Crossing Areas With Underlayments</td>
<td>6.43</td>
<td>Yes</td>
</tr>
<tr>
<td>Approaches To Crossings Without Underlayments vs. Approaches To Crossings With Underlayments</td>
<td>0.62</td>
<td>No</td>
</tr>
<tr>
<td><strong>Eight Cincinnati Subdivision Crossings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossing Areas Without Underlayments vs. Crossing Areas With Underlayments</td>
<td>3.78</td>
<td>Yes</td>
</tr>
<tr>
<td>Approaches To Crossings With Underlayments vs. Crossing Areas With Underlayments</td>
<td>3.96</td>
<td>Yes</td>
</tr>
<tr>
<td>Approaches To Crossings Without Underlayments vs. Approaches To Crossings With Underlayments</td>
<td>0.15</td>
<td>No</td>
</tr>
<tr>
<td>Approaches To Crossings Without Underlayments vs. Crossing Areas Without Underlayments</td>
<td>2.29</td>
<td>No</td>
</tr>
</tbody>
</table>
**TABLE 5 Traffic Information Regarding Crossings**

<table>
<thead>
<tr>
<th>Highway Crossing</th>
<th>ADT</th>
<th>% Trucks</th>
<th>Railroad</th>
<th>MGT</th>
<th>Trains/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waller*</td>
<td>15,600</td>
<td>1</td>
<td>NS</td>
<td>76</td>
<td>40-45</td>
</tr>
<tr>
<td>Rosemont Garden*</td>
<td>8,780</td>
<td>1</td>
<td>NS</td>
<td>76</td>
<td>40-45</td>
</tr>
<tr>
<td>Winchester*</td>
<td>11,650</td>
<td>3</td>
<td>CSXT</td>
<td>34</td>
<td>15-20</td>
</tr>
<tr>
<td>Richmond</td>
<td>15,530</td>
<td>11</td>
<td>CSXT</td>
<td>51</td>
<td>20-25</td>
</tr>
</tbody>
</table>

*Indicates Double Track
<table>
<thead>
<tr>
<th>Crossings</th>
<th>Waller Avenue</th>
<th>Rosemont Garden</th>
<th>Winchester*</th>
<th>Richmond**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settlement Intervals</td>
<td>2 years</td>
<td>5 years</td>
<td>2 years</td>
<td>5 years</td>
</tr>
<tr>
<td>Average Top-of-Rail Settlements</td>
<td>0.40 in.</td>
<td>0.73 in.</td>
<td>0.74 in.</td>
<td>1.19 in.</td>
</tr>
</tbody>
</table>

*Initial Measurement 4 months after crossing installed.
**Initial Measurement 18 months after crossing installed.

1.0 in. = 25.4 mm
Figure 1 Primary contributors affecting the relative rideability of crossings.
Figure 2 Cross-sectional views of all-granular and asphalt underlayment crossings.
Figure 3 Procedure and locations for top-of-rail profile measurements.
Figure 4 Representative Cincinnati Subdivision crossing (Flag Spring) without underlayment.
Figure 5 Representative Cincinnati Subdivision crossing (South Portsmouth) with underlayment.
Figure 6 Representative Big Sandy Subdivision crossing (KY Coal Terminal) and Rockhouse Subdivision crossing (No Name, KY 7) both with underlayment.
Figure 7 US 60 (Stanley) crossing with underlayment.
Figure 8 Comparison of top-of-rail settlements for the eight Cincinnati Subdivision crossings.
Figure 9 Representative Cincinnati Subdivision top-of-rail settlement data for Flag Spring crossing without underlayment.
Figure 10 Representative Cincinnati Subdivision top-of-rail settlement data for South Portsmouth crossing with underlayment.
Figure 11 Representative Big Sandy Subdivision top-of-rail settlement data for KY Coal Terminal crossing with underlayment.
Figure 12 Representative Rockhouse Subdivision top-of-rail settlement data for No Name KY 7 crossing with underlayment.
Average Top of Rail Elevations for US 60 Stanley

Station | Elevation (ft.)
--- | ---
0 | 99.95
5 | 100.05
10 | 100.1
15 | 100.15
20 | 100.2
25 | 100.25
30 | 100.3
35 | 100.35
40 | 100.4
45 | 100.45
60 | 100.5

Average Asphalt/Approach Settlement for US 60 Stanley

Time (Months) | Settlement (in.)
--- | ---
0 | 0.28
4 | 0.30
8 | 0.21
12 | 0.27
16 | 0.28
20 | 0.30
24 | 0.28
28 | 0.27
32 | 0.28
36 | 0.65
40 | 0.82
44 | 0.84
48 | 0.92
52 | 0.93
56 | 0.45
Figure 13 Top-of rail settlement data for US 60 Stanley crossing with underlayment.

Figure 14 Procedure and locations for longitudinal highway profile measurements.
Figure 15 View of Rosemont Garden crossing.
Figure 16 Characteristic pavement profiles using total stationing.