Research Report
KTC-09-06/FR136-04-3F

KENTUCKY TRANSPORTATION CENTER

HIGHWAY-RAILWAY AT-GRADE CROSSING STRUCTURES: LONG-TERM SETTLEMENT MEASUREMENTS AND ASSESSMENTS

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Research Report

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Highway-Railway At-Grade Crossings:

Long-Term Settlement Measurements and Assessments

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ABSTRACT

The purpose of this research was to evaluate the long-term settlements for a wide variety of at-grade crossings. Twenty-four highway crossings were monitored 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 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.

Keywords: Highway-Railway At-Grade Crossings, Railroad Crossings, Crossing Settlement, Asphalt Trackbeds, Asphalt Railway Crossings, Top-of-Rail Settlement, Longitudinal Profile

May 2009

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No
KTC-09-06/FR 136-04-3F		

4. Title and Subtitle	5. Report Date
Highway-Railway At-Grade Crossings: Long-Term Settlement Measurements and Assessments	May 2009
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Jerry G. Rose, Mary G. Swiderski, Justin S. Anderson, and Lindsay A. Walker	*KTC-09-06*

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506-0281	
	11. Contract or Grant No. FRT 136

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Kentucky Transportation Cabinet 200 Mero Street Frankfort, KY 4062	Final Report – KTC -09-06 7/1/2004 – 6/30/09
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Kentucky Transportation Cabinet and the United States Department of Transportation, Federal Highway Administration

16. Abstract

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17. Key Words	18. Distribution Statement
Highway-Railway At-Grade Crossings, Railroad Crossings, Crossing Settlement, Asphalt Trackbeds, Asphalt Railway Crossings, Top-of-Rail Settlement, Longitudinal Profile	Unlimited, with the approval of the Kentucky Transportation Cabinet

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	30 w/o appendix	

Form DOT F 1700.7 (8-72)

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EXECUTIVE SUMMARY

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 for a wide variety of at-grade crossings. Twenty-four highway crossings were monitored 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.

CHAPTER 1. INTRODUCTION

1.1 DESCRIPTION

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 1.1.

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 subsequently 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.

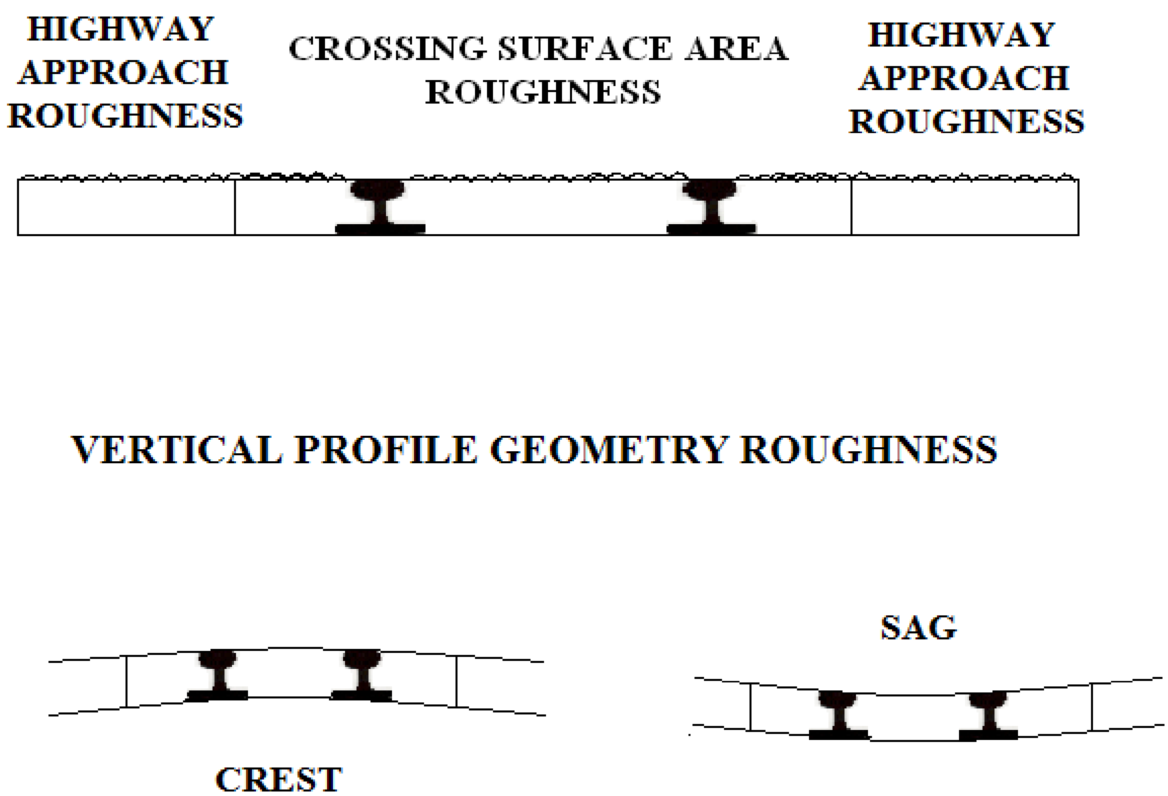


Figure 1.1 Primary contributors that affect the relative rideability of crossings.

1.2 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 (Michigan, 2003). 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 1.2. 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

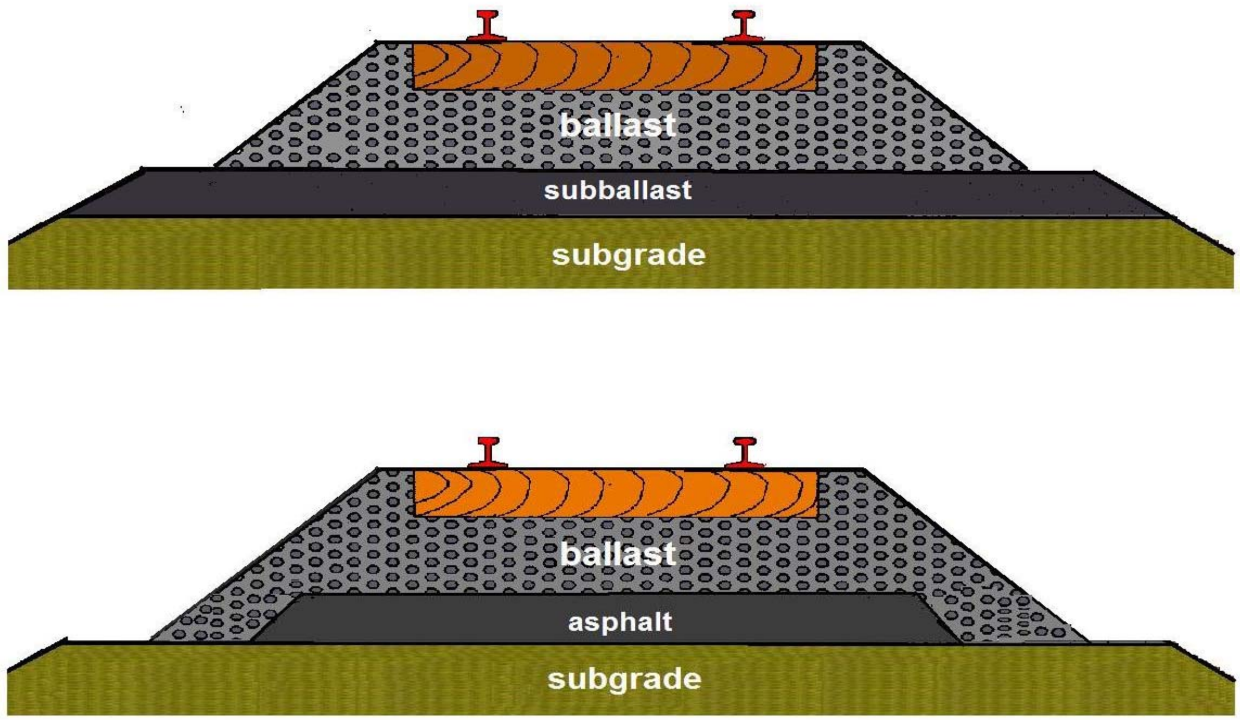


Figure 1.2 Cross-sectional views of all-granular and asphalt underlayment crossings.

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 deflection 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 for 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 (Rose & Tucker, 2002). 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 1.2 contains a typical view of a rail/highway crossing containing an asphalt underlayment.

1.3 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.

1.4 SCOPE

Detailed discussions of the "Fast Track Approach" and a "Cooperative Practice" utilizing asphalt underlayment trackbeds are contained in the first report of this series (Rose, et al. 1F, 2009).

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 crossing and approaches (AREMA, 2002) (AASHTO, 2001) (USDOT, 2007). Attempts to develop "Rideability" measures for crossings are described in the fourth report of this series (Rose, et al. 4F, 2009).

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.

CHAPTER 2. TOP-OF-RAIL PROFILE SETTLEMENT MEASUREMENTS

2.1 SITE SELECTION AND MEASUREMENT TECHNIQUE

Measuring top-of-rail elevations at various intervals is a technique to compare long-term performance of differing trackbed crossings. Generally, the largest rail settlement will occur immediately after construction, as the train vibrations consolidate the ballast and subgrade (Adwell, 2004).

Data was collected using conventional differential leveling. A surveyor's elevation rod and level instrument were used to measure settlement. An image of the process can be seen in Figure 2.1a. Measurements were taken on each rail at 10 ft (0.3 m) intervals for approximately 80 ft (24 m) on both approaches as well as through the crossing. At each station the rail was marked with paint to ensure the locations were consistent with previous measurements. There were approximately 20 measurement stations at each location. For a typical two-lane crossing the stationing was arranged so that the crossing surface was located between stations 9 and 13 and the asphalt underlayment extended from station 7 to 15. A longitudinal view of the crossing and approaches can be seen in Figure 2.1b. To determine the elevation of the rail, an arbitrary elevation of 100.00 ft was selected for a benchmark. The previously established benchmarks were used as a reference, and the level reading from these points were added to 100.00 ft to determine the height of the instrument. Next, the level reading of each station was subtracted from the height of instrument to determine top-of-rail elevation.

Twenty crossings were selected for long-term settlement measurements. Table 2.1 contains a listing of the various crossings relative to the CSX Transportation subdivisions. Also, provided are the railroad traffic, expressed as million gross tons per year, and the highway traffic, expressed as average daily traffic and percent trucks. All rail lines carry high tonnage except the one CSXT LH & STL subdivision line in Western Kentucky and the two Ann Arbor Railroad lines in Michigan. All other CSXT lines are in Eastern and Northeastern Kentucky. The highway traffic varies from very low to extremely heavy with several of the crossings carrying substantial percent trucks.

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 using conventional differential leveling procedures. 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 2.1c 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 minimal primarily serving local residential traffic with essentially no trucks.

Figure 2.1a Procedure for top-of-rail profile measurements.

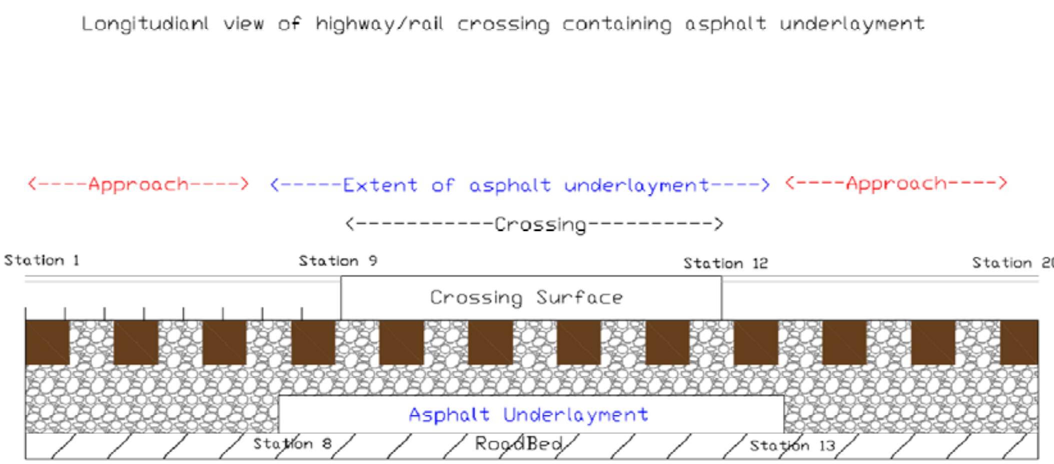


Figure 2.1b Locations for top-of-rail profile measurements.

Table 2.1 Traffic Information for Crossing used in Top-of-Rail Settlement Measurements

Crossing	MGT	Trains/Day	ADT	% Trucks
Cincinnati Subdivision				
Dam *	**38**		**25**	**0**
Fish Camp *	**38**		**25**	**0**
Flag Spring *	**38**		**500**	**1**
Union Street *	**38**		**200**	**1**
Cincinnati Subdivision				
Rt. 8 Concord	**38**		**200**	**5**
South Portsmouth	**38**		**300**	**1**
South Shore	**38**		**4120**	**3**
Vanceburg	**38**		**2220**	**2**
Rockhouse Subdivision				
Colson	**21**		**2800**	**24**
Indian Bottom Church	**21**		**2580**	**13**
No Name	**21**		**2580**	**13**
Old Letcher School	**21**		**2580**	**13**
Letcher School	**21**		**2580**	**13**
Thornton Gap	**21**		**2800**	**24**
LH&StL Subdivision				
US 60 Stanley	**8**		**4010**	**12**
Big Sandy/ Rockhouse Subdivisions				
KY Coal Terminal #1	**23**		**1500**	**85**
KY Coal Terminal #2	**23**		**1500**	**85**
KY 15 Isom	**21**		**9440**	**13**
KY Power-Louisa	**45**		**400**	**80**
Ann Arbor, MI				
Liberty Street	**1**	**2**	**11,200**	**0**
State Street	**1**	**2**	**25,560**	**9**
* Indicates no underlayment				
MGT - Million Gross Tons				
ADT-Average Daily Traffic				

Figure 2.1c Representative Cincinnati Subdivision crossing (Flag Spring) without underlayment.

The other 16 crossings contain asphalt underlayments. 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 2.1d. 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 2.1e. The three crossings on relatively light tonnage rail lines have very high highway traffic volumes. One of these is in Western Kentucky (see Figure 2.1f); 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 the 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 highway and heavy rail traffic. Settlement and deterioration of the crossings resulted in undesirable rideability features.

Figure 2.1d Representative Cincinnati Subdivision crossing (South Portsmouth) with underlayment.

The Top-of-Rail Settlement Measurement data was used to generate plots of rail elevation versus station number. These plots were generated in Microsoft Excel. Data collected from past measurements were plotted on the same graph to show a clear image of settlement of the rail in the crossing and approaches over time. Each line, representing one set of elevation points at a particular point of time, has two different line weights. The heavier line segment represents the asphalt underlayment location, which extends slightly beyond the crossing surface, and the lighter line segments correspond to the rail approaches. The graphs provide a visual depiction of the rail and crossing settlements with respect to time.

Detailed descriptions for the various crossings and plots of the Top-of-Rail Settlement Measurement data are contained in Appendix A (Swiderski, 2007). Summary information and data follows.

2.2 DATA ANALYSIS

2.2.1 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 2.2.1a and Figure 2.2.1a. 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 2.2.1b 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 2.2.1a and

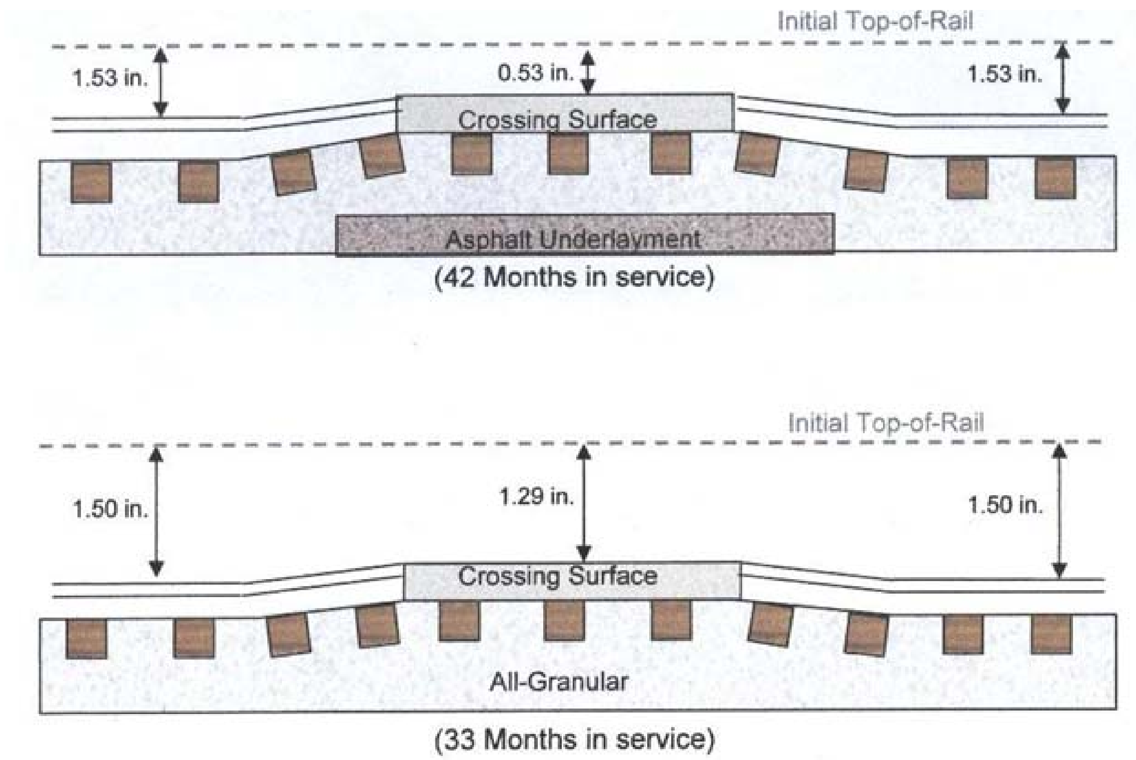
Figure 2.1e Representative Big Sandy Subdivision crossing (KY Coal Terminal) and Rockhouse Subdivision crossing (No Name, KY 7) both with underlayment.

Figure 2.1f US 60 (Stanley) crossing with underlayment.

TABLE 2.2.1a Average Approach/Crossing Settlements for Cincinnati Subdivision Crossings

Crossing	Average Approach Settlement	Average Crossing Settlement	Months in Service
Cincinnati Subdivision with No Asphalt Underlayment			
Dam	1.65 in.	1.25 in.	33
Fish Camp	1.46 in.	1.49 in.	33
Flag Spring	1.50 in.	1.28 in.	33
Union Street	1.40 in.	1.13 in.	33
AVERAGE (No Underlayment)	1.50 in.	1.29 in.	33
Cincinnati Subdivision with Asphalt Underlayment			
Rt. 8 Concord	1.28 in.	0.31 in.	40
South Portsmouth	1.65 in.	0.56 in.	42
South Shore	1.23 in.	0.20 in.	42
Vanceburg-Main Street	1.96 in.	1.04 in.	43
AVERAGE (With Underlayment)	1.53 in.	0.53 in.	42

1.0 in. = 25.4 mm



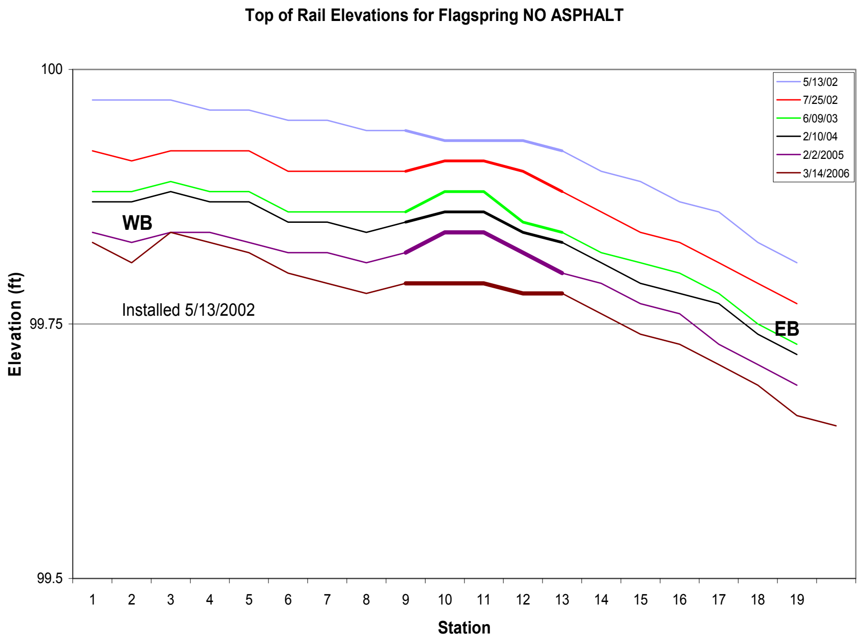
1.0 in. = 25.4 mm

Figure 2.2.1a Comparison of top-of-rail settlements for the eight Cincinnati Subdivision crossings.

Figure 2.2.1a. 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 2.2.1c 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.



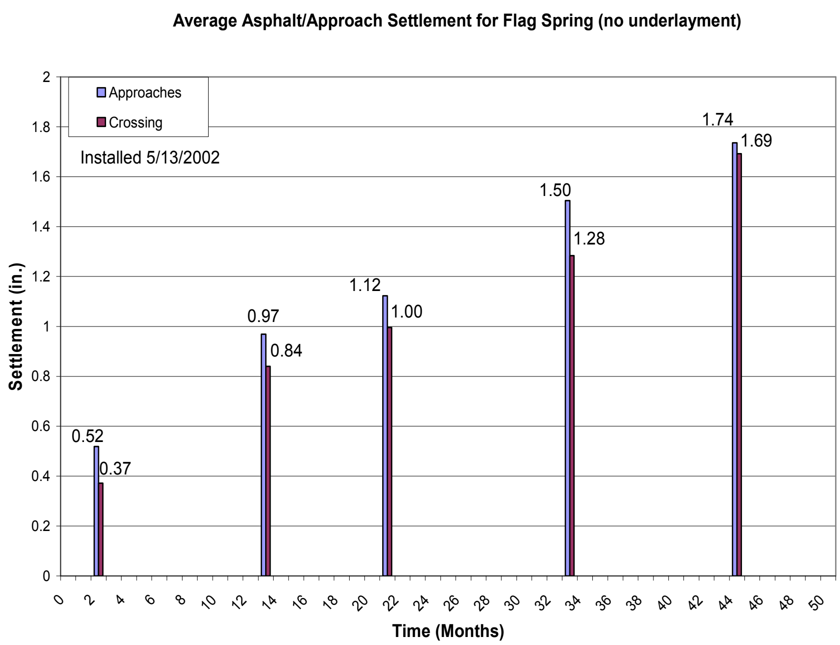


Figure 2.2.1b Representative Cincinnati Subdivision top-of-rail settlement data for Flag Spring crossing without underlayment.

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.

2.2.2. Additional Underlayment Crossings

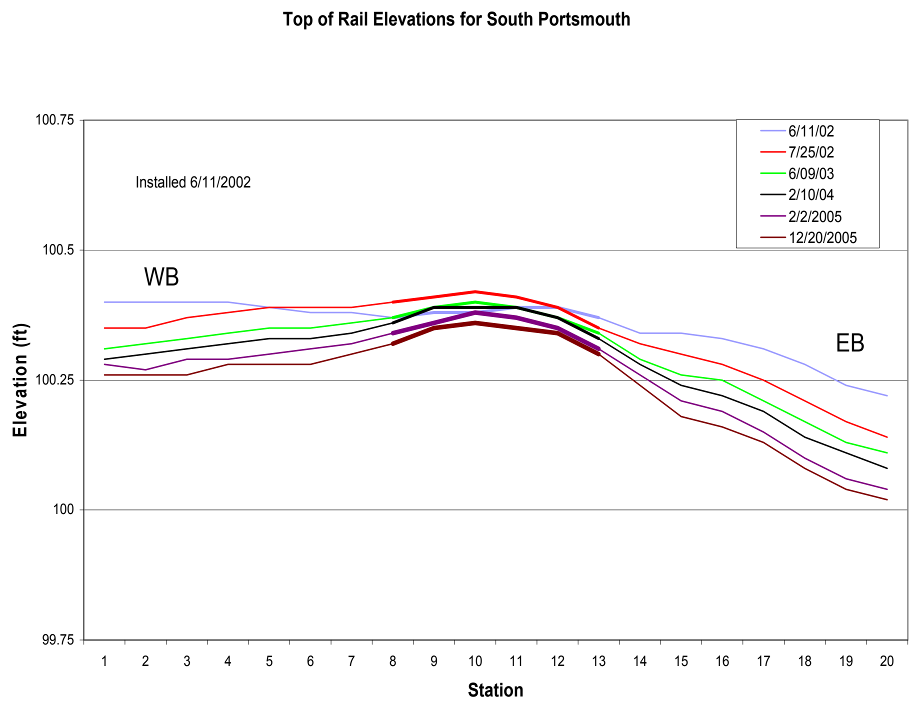
Twelve additional crossings underlain with asphalt were also monitored for top-of-rail settlement. Nine of these crossings are in Eastern Kentucky on CSX Transportation heavy tonnage rail lines. The highway traffic is significant and consists of substantial numbers of coal trucks on all of the crossings. 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 2.2.2a and data for a representative crossing is shown in Figure 2.2.2a. 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 2.2.2a and data for a representative crossing is shown in Figure 2.2.2b. The average settlements for the crossing areas and approaches respectively are less than the crossings previously discussed. However, the crossings had 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 2.2.2b contains settlement data for the asphalt/rubber seal US 60 Stanley Crossing in Western Kentucky. Measurements were taken periodically 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 2.2.2c shows the various top-of-rail profiles for the US 60 crossing since it was installed in 2002.

Table 2.2.2b 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 surface 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.



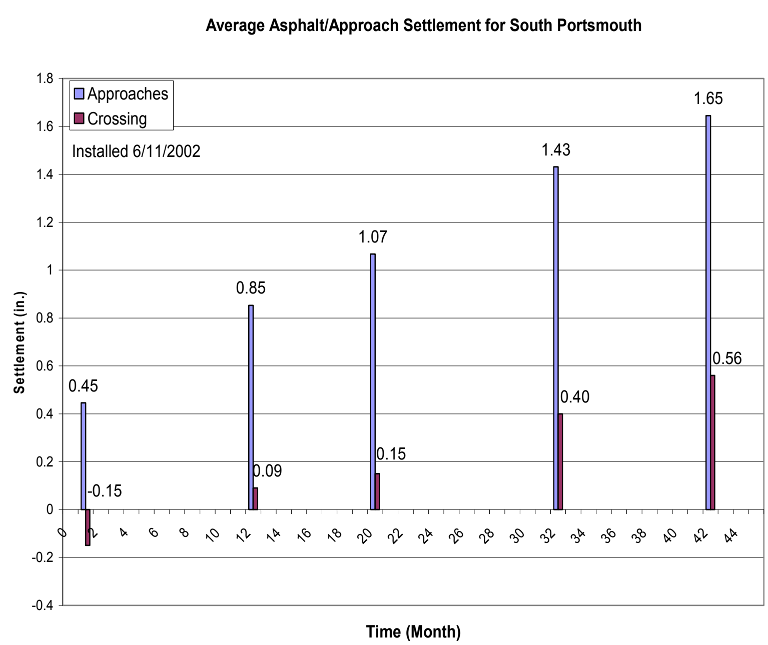


Figure 2.2.1c Representative Cincinnati Subdivision top-of-rail settlement data for South Portsmouth crossing with underlayment.

2.2.3 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 (Rosner, 2005).

The results from the 16 crossings containing underlayments were compared with the results from the four crossings containing 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 2.2.3a.

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.

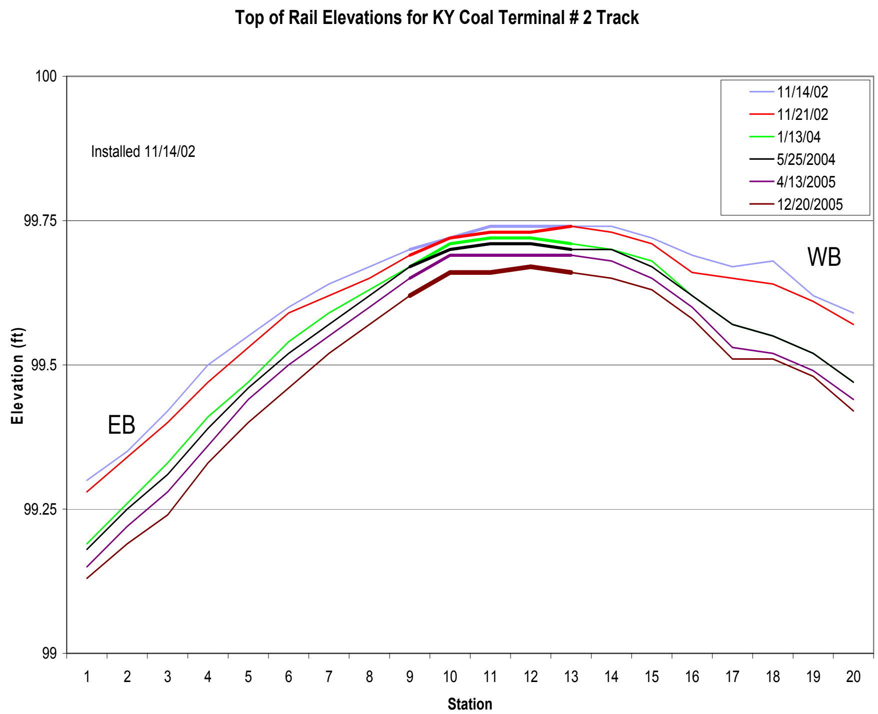
Thus, in each instance when an existing trackbed (without underlayment) was compared to an underlayment trackbed, the t-test indicated a significant difference in settlement measures. Conversely, in each instance when existing trackbeds (without underlayment) approaches or crossings were compared, the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

Detailed t-test data analyses for the Top-of-Rail Settlement Measurements are contained in Appendix C.

TABLE 2.2.2a Average Approach/Crossing Settlements for Eastern Kentucky Subdivision Crossings

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

1.0 in. = 25.4 mm



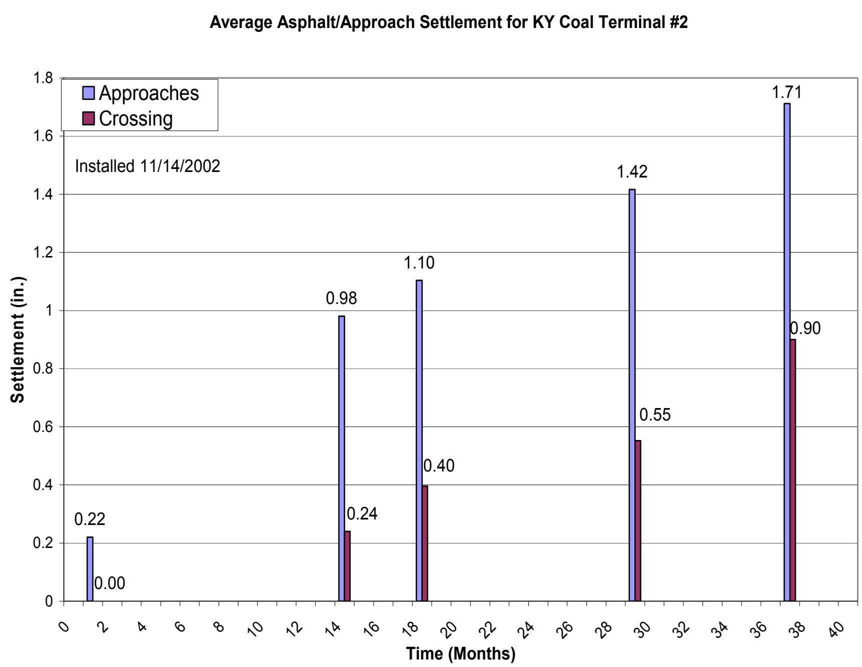
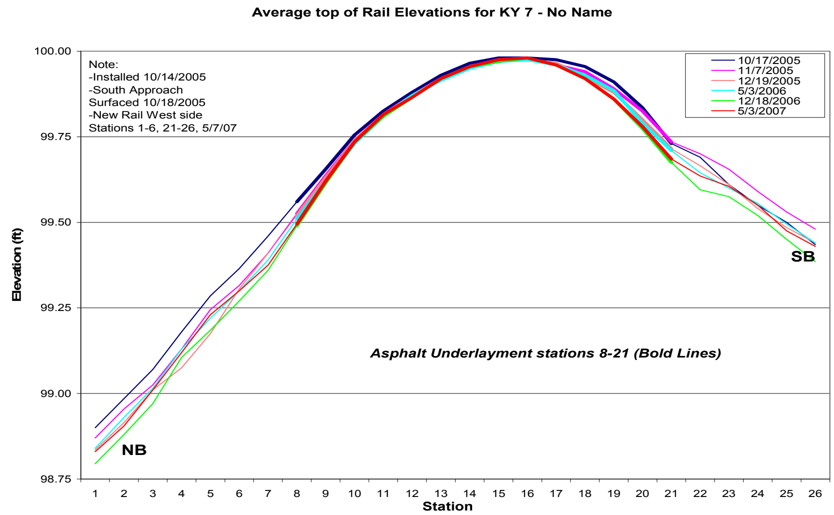


Figure 2.2.2a Representative Big Sandy Subdivision top-of-rail settlement data for KY Coal Terminal crossing with underlayment.



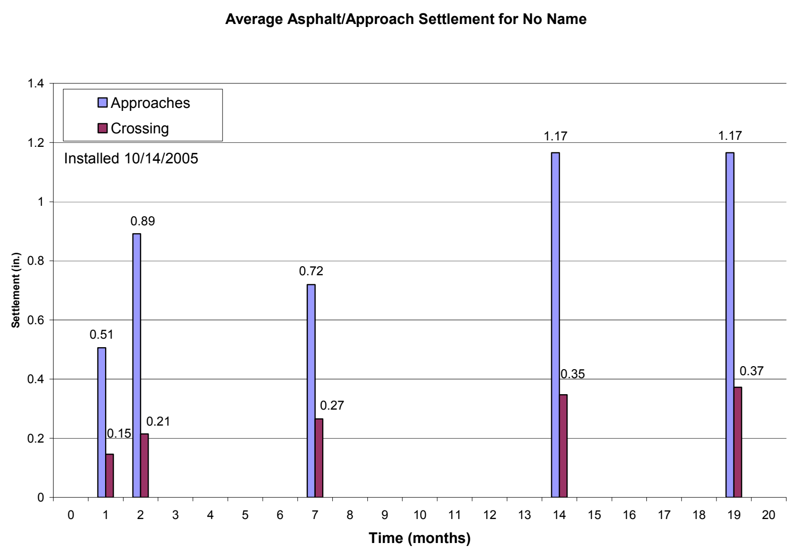
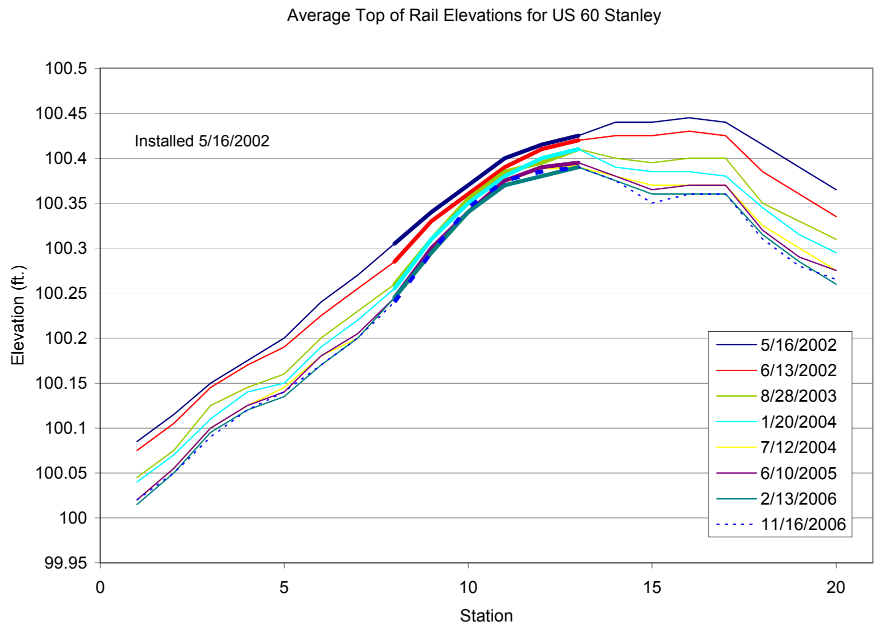


Figure 2.2.2b Representative Rockhouse Subdivision top-of-rail settlement data for No Name KY 7 crossing with underlayment.

TABLE 2.2.2b Average Approach/Crossing Settlements for US 60 and Ann Arbor Crossings

Crossing	Average Approach Settlement	Average Crossing Settlement	Months in Service
	LH&StL Subdivision		
US 60 Stanley (with Underlayment)	0.93 in.	0.45 in.	54
	Ann Arbor, Michigan		
Liberty Street	n/a	0.31 in.	23
State Street	n/a	0.31 in.	25
AVERAGE (with Underlayment)	n/a	0.31 in.	24

1.0 in. = 25.4 mm



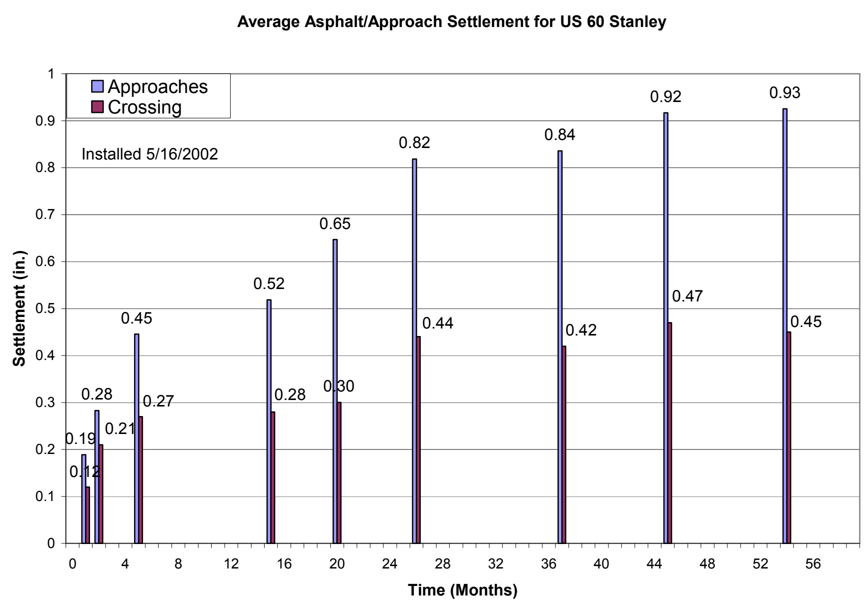


Figure 2.2.2c Representative LH & St. L Subdivision top-of-rail Settlement data for US 60 Stanley Crossing with underlayment.

TABLE 2.2.3a Results of t-Test for Top-of-Rail Settlements

All Twenty Crossings				
			t-statistic	Significant Difference?
Crossing Areas Without Underlayments	vs.	Crossing Areas With Underlayments	4.29	Yes
Approaches To Crossings With Underlayments	vs.	Crossing Areas With Underlayments	6.43	Yes
Approaches To Crossings Without Underlayments	vs.	Approaches To Crossings With Underlayments	0.62	No

Eight Cincinnati Subdivision Crossings				
			t-statistic	Significant Difference?
Crossing Areas Without Underlayments	vs.	Crossing Areas With Underlayments	3.78	Yes
Approaches To Crossings With Underlayments	vs.	Crossing Areas With Underlayments	3.96	Yes
Approaches To Crossings Without Underlayments	vs.	Approaches To Crossings With Underlayments	0.15	No
Approaches To Crossings Without Underlayments	vs.	Crossing Areas Without Underlayments	2.29	No

CHAPTER 3. LONGITUDINAL HIGHWAY PROFILE MEASUREMENTS

3.1 SITE SELECTION AND MEASUREMENT TECHNIQUE

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 3.1a). 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 3.1. 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 3.1b is a typical view of a crossing.

Detailed descriptions for the various crossings and plots of the Longitudinal Profile Measurement data are contained in Appendix B (Swiderski, 2007). Summary information and data follows.

3.2 DATA ANALYSIS

A characteristic longitudinal highway profile across the Rosemont Garden crossing is shown in Figure 3.2. 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 3.2 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.

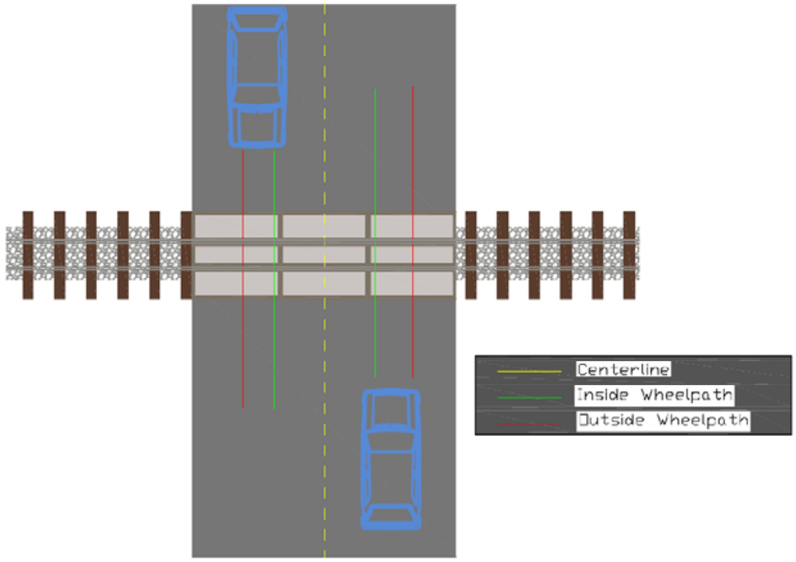


Figure 3.1a Procedure and locations for longitudinal highway profile measurements.

TABLE 3.1 Traffic Information Regarding Crossings

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

*Indicates Double Track

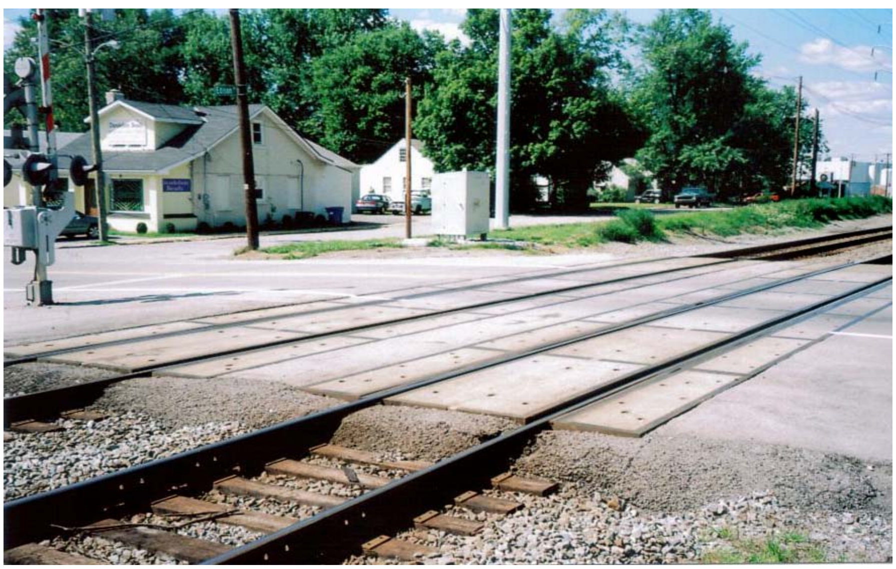


Figure 3.1b View of Rosemont Garden crossing.

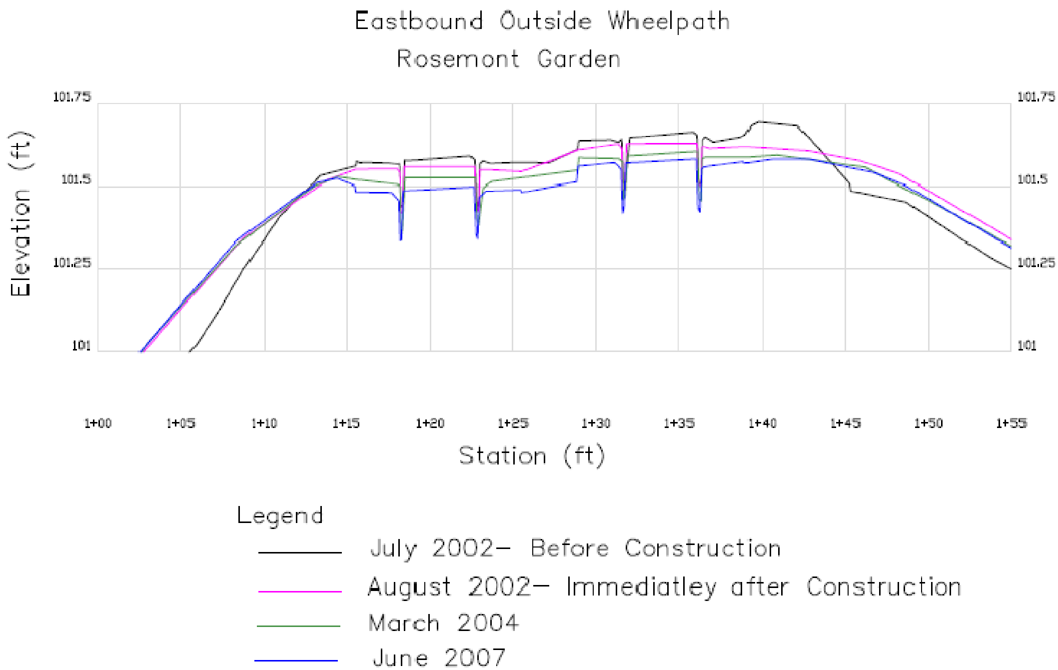


Figure 3.2 Characteristic pavement profile using total stationing.

TABLE 3.2 Top-of-Rail Settlements Obtained From the Longitudinal Profile Measurements

Crossings	Waller Avenue		Rosemont Garden		Winchester*	Richmond**	
Settlement Intervals	2 years	5 years	2 years	5 years	3 years	3 years	6 years
Average Top-of-Rail Settlements	0.40 in.	0.73 in.	0.74 in.	1.19 in.	0.21 in.	0.34 in.	0.92 in.

*Initial Measurement 4 months after crossing installed.
**Initial Measurement 18 months after crossing installed.
1.0 in. = 25.4 mm

CHAPTER 4. CONCLUDING COMMENTS

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

Top-of-rail elevation changes (settlements) throughout the highway crossings and rail approaches were monitored for extended time intervals at 20 sites 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 during 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 governmental agency and railroad company to share responsibilities to enhance quality and minimize costs is readily apparent.

A more detailed discussion of the Findings and Conclusions for this research is contained in Appendix D.

REFERENCES

Adwell, J.C. (2004). *Performance Measures of Railroad/Highway At-Grade Crossings Utilizing Asphalt Underlayments.* MSCE Report, University of Kentucky, Department of Civil Engineering, May.

American Association of State Highway and Transportation Officials (2001). *A Policy on Geometric Design of Highways and Streets*. Fourth Edition.

American Railway Engineering Association (2002). *Highway-Railway Crossings. AREMA Manual for Railway Engineering.*

Michigan Grade Crossing Surface Repair Task Force Handbook (2003). Freight Services and Safety Division Local Grade Crossing Program Staff. Book 21, May.

Rose, J.G., et al. (2009). Highway-Railway At-Grade Crossing Structures: Optimum Design/Installation Practices and Management Program – An Overview. Research Report KTC-09-04/FR 136-04-1F, Kentucky Transportation Center, May.

Rose, J.G., et al. (2009). Highway-Railway At-Grade Crossings: Rideability Measurements and Assessments. Research Report KTC-09-07/FR 136-04-4F, Kentucky Transportation Center, May.

Rose, J.G., E.R. Brown, and M.L. Osborne (2000). *Asphalt Trackbed Technology Department: The First 20 Years.* Transportation Research Board Record, No. 1713.

Rose, J.G., M.G. Swiderski, and J.S. Anderson (2009). Long-Term Performances of Rail/Highway At-Grade Crossings Containing Enhanced Trackbed Support. Transportation Research Board 2009 Annual Meeting Compendium of Paper DVD, January, 38 pages.

Rose, J.G. and P.M. Tucker (2002). Quick-Fix, Fast-Track Road Crossing Renewals Using Panelized Asphalt Underlayment System. Proceedings of the American Railway Engineering and Maintenance-of-Way Association 2002 Annual Conference & Exposition, Washington, D.C., September.

Rosner, B. (2005). *Fundamentals of Biostatistics*, Sixth Edition.

Swiderski, M.G. (2007). *Long-Term Settlement and Profile Measurements of Rail/Highway Crossings.* MSCE Report, University of Kentucky, Department of Civil Engineering, December.

U.S. Department of Transportation (2007). Federal Highway Administration. *Railroad-Highway Grade Crossing Handbook.* Revised Second Edition, August.

Walker, L.A. (2002). *Evaluations of Hot-Mix Asphalt Underlayments in Railroad/Highway At-Grade Crossings.* MSCE Thesis, University of Kentucky, Department of Civil Engineering, December.

ACKNOWLEDGEMENTS

Several civil engineering graduate students contributed over the years to the data collection and analyses reported herein. These include:

Bei Su (MSCE 2003)
Joel Adwell (MSCE 2004)
Jitesh Gajera (MSCE 2005)
Jason Stith (MSCE 2005)
Aaron Renfro (MSCE 2008)

Mr. Paul M. Tucker of CSX Transportation was very supportive during the early stages of this project. Mr. Kristian Foondle of the Michigan Department of Transportation assisted. Numerous employees with the Kentucky Transportation Cabinet assisted during the various stages of crossing installations and subsequent data acquisition.

The Kentucky Transportation Cabinet and CSX Transportation provided financial support for this research. Steve Farmer served as the primary Study Advisory Chair for the KYTC.

APPENDIX A

Top-of-Rail Settlement Measurements

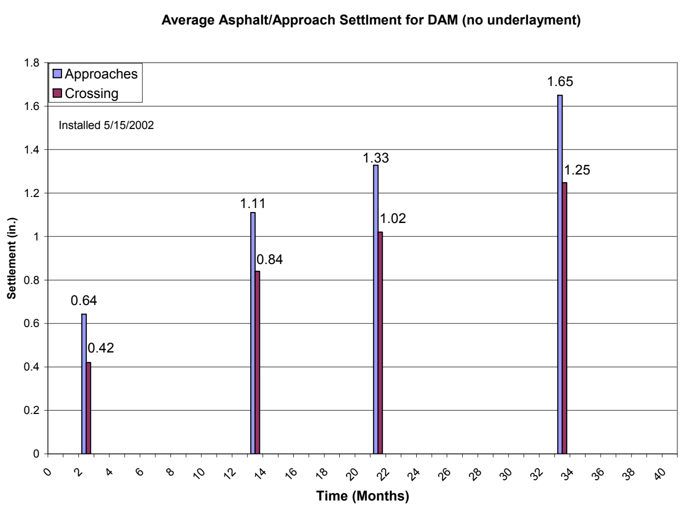
Results for Cincinnati Subdivision Crossings with No Underlayment

During a 2002 timbering and surfacing operation four crossings on the 38 MGT CSX Transportation Cincinnati Subdivision were rehabilitated with rubber seal and asphalt crossings, however no asphalt underlayment was incorporated. These four crossings retained a traditional trackbed and were merely "surfaced through" during the timbering and surfacing program. Top-of Rail settlements were monitored periodically in order to compare their performance with that of four other crossings utilizing an underlayment on the same line. Figures A.1 through A.4 contain the settlement data and plots.

Top-of-Rail Settlement Measurements were established at Dam and Fish Camp crossings, both are semi-private and carry very little highway traffic, each having approximately 25 Average Daily Traffic (ADT). Over 33 months of service, Dam approaches settled 1.65 in. and the crossing settled 1.25 in. and Fish Camp approaches settled 1.46 in. and the crossing settled 1.49 in. The Flag Spring and Union Street crossings are public crossings with a reasonable amount of traffic, averaging 500 and 200 ADT respectively. The Flag Street approaches and crossing settled 1.50 in. and 1.28 in. respectively. Union Street approaches settled 1.40 in. and the crossing settled 1.13 in. After an average of 33 months of service, the four crossing approaches with no underlayment settled an average of 1.50 in. and the crossing surface settled 1.29 in. All four crossings carry 38 MGT train traffic.

Top-of-Rail Settlements

Dam (No Underlayment)



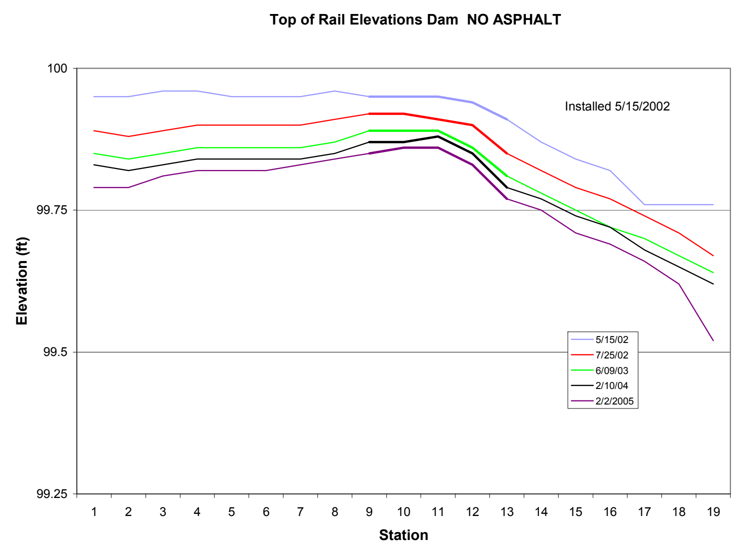


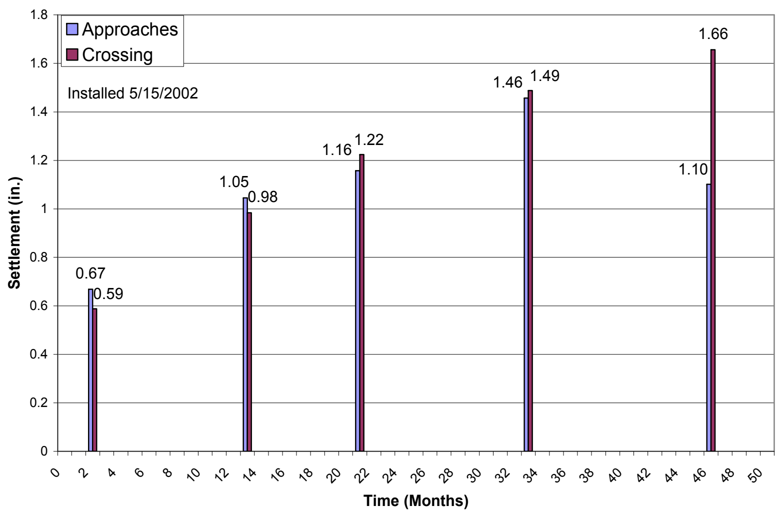
Figure A.1

Top-of-Rail Settlements

Fish Camp (No Underlayment)

(46 month data inconclusive due to a track surfacing affecting the elevation datum)

Average Asphalt/Approach Settlement for Fish Camp (no underlayment)



Top of Rail Elevations for Fish Camp NO ASPHALT

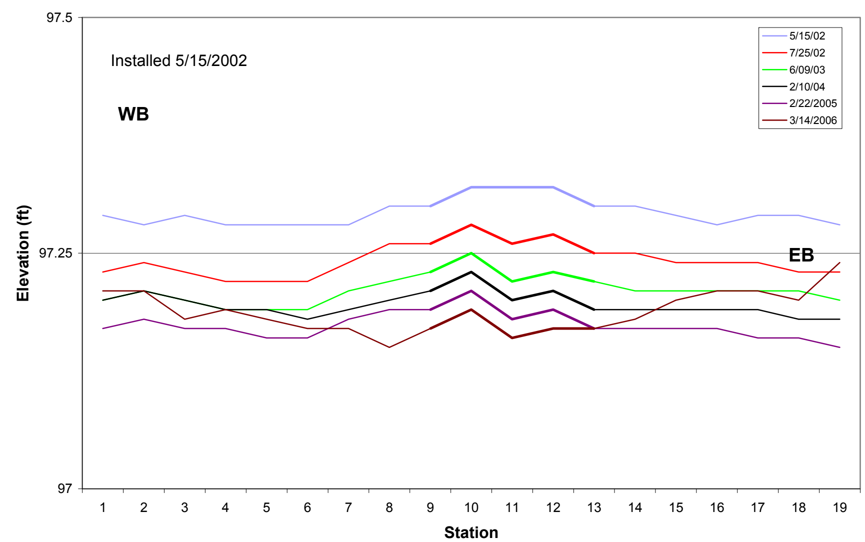


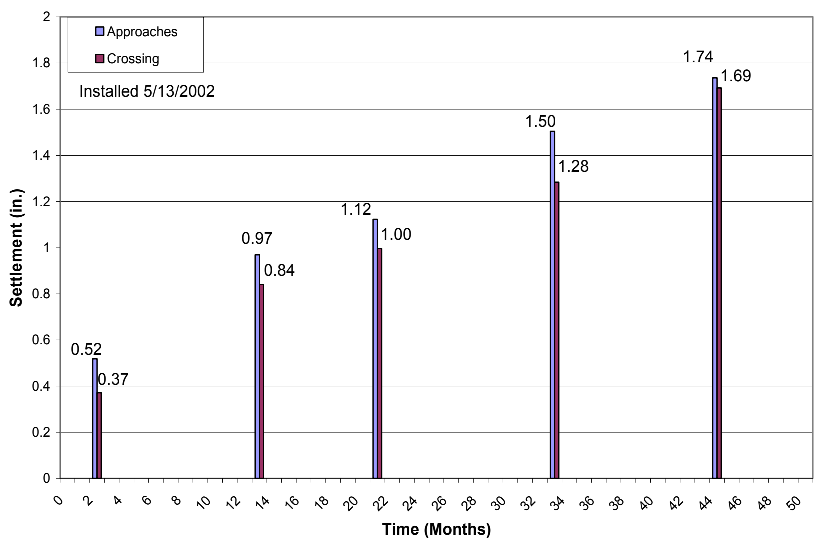
Figure A.2

Top-of-Rail Settlements

Flag Spring (No Underlayment)

(Only used 33 month data to be consistent with the other three non-underlayment crossings)

Average Asphalt/Approach Settlement for Flag Spring (no underlayment)



Top of Rail Elevations for Flagspring NO ASPHALT

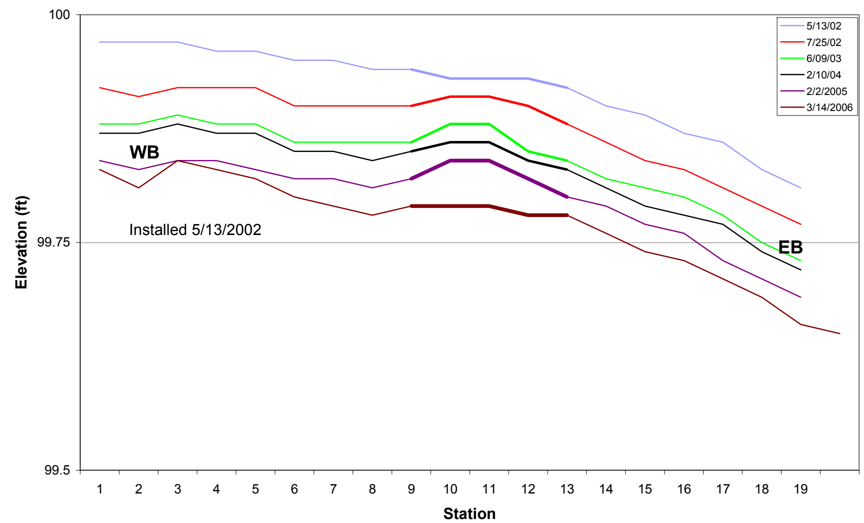


Figure A.3

Top-of-Rail Settlements

Union Street (No Underlayment)

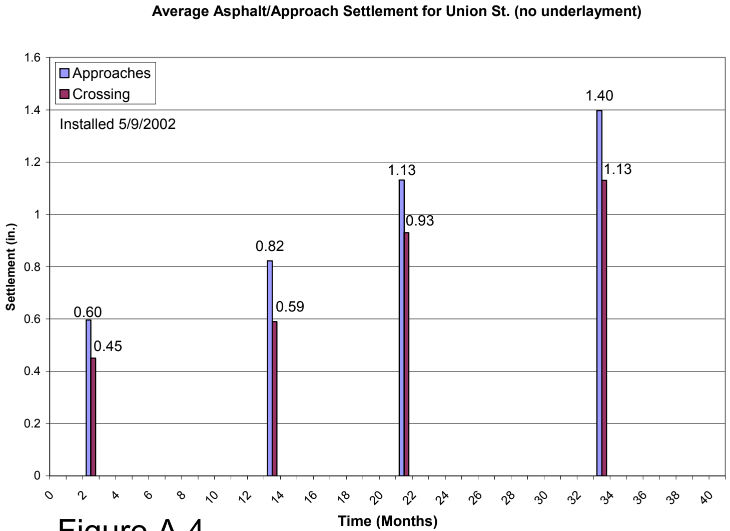
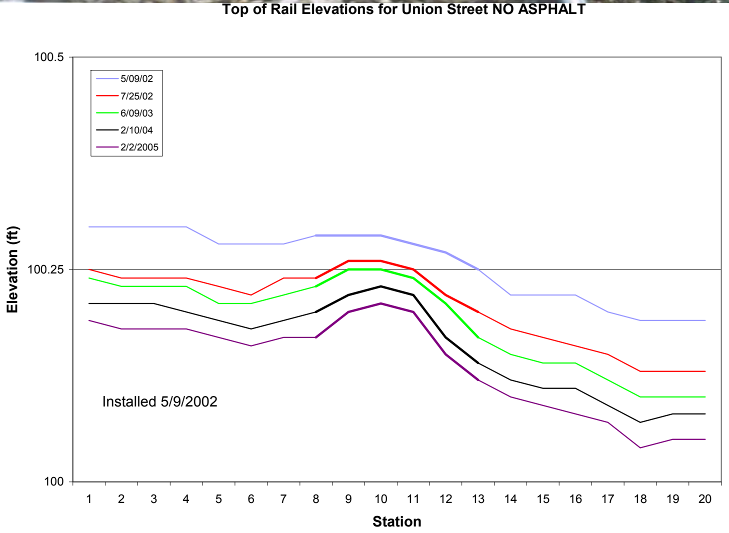


Figure A.4



Results for Cincinnati Subdivision Crossings with Underlayment

Similar to the previously mentioned crossings on the Cincinnati Subdivision, these four crossings were installed during the 2002 timbering and surfacing operation. Unlike the other crossings in the Cincinnati Subdivision, these contained an asphalt underlayment. Each of these four crossings received a different surface for comparative and experimental purposes. These crossings on the CSXT line carry 38 MGT of traffic each year and after five years of service show no signs of fatigue, cracks or failure. Figures A.5 through A.8 contain the settlement data and plots.

The crossing on Rt. 8 near Concord utilized an Endurance Composite crossing, a recently developed material comprised of waste material and adhesive. There is no rubber flangeway material. Kentucky Department of Transportation (KYDOT) District 9 assisted by providing traffic control and the asphalt for the underlayment and highway approaches. This crossing carries 200 ADT. After 40 months the approaches settled 1.28 in. and the crossing settled 0.31 in.

The access road to South Portsmouth also received an Endurance Composite crossing, but containing rubber flangeways. The Greenup County Road Department assisted by providing traffic control and the asphalt for the underlayment and highway approaches. While studied over a 42 month period the approaches settled 1.65 in. and the crossing settled 0.56 in.

The Main Street Crossing in South Shore utilized a solid wood timber crossing surface on the #2 track. KYDOT District 9 assisted with the traffic control and asphalt for the underlayment and highway approaches. Over 42 months the approaches settled 1.23 in. and the crossing settled 0.20 in.

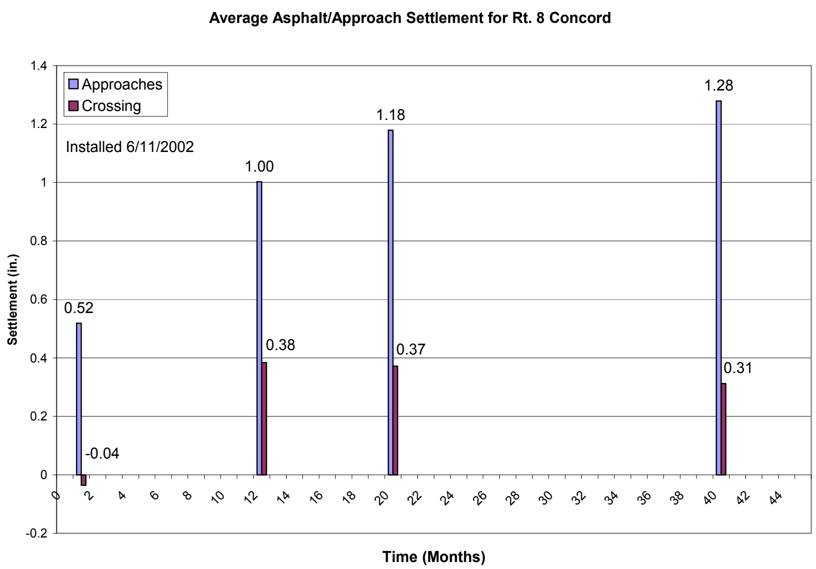
Main Street Crossing in Vanceburg utilized a full-width concrete crossing. KYDOT assisted in a similar manner as with other crossings on this subdivision. This crossing receives 2200 ADT. After 43 months the approaches settled 1.96 in. and the crossing 1.04 in.

After 42 months, the average settlement was 1.53 in. for the approaches and 0.53 in. for the crossings. As stated earlier, the approach settlement for these four crossings is comparable to the crossing with an all-granular trackbed, however, the crossing settlement is significantly less. These differences between the crossings performance should be noted because they are similar in many ways. The crossings carry the same amount of train traffic and the highway traffic is minimal. In places such as the approaches where the track was only supported by ballast, the settlement is similar to the crossings with no underlayment. However, through the crossing surface where an underlayment was utilized for additional support, the settlement was significantly less indicating that the added stability prevented the track from such large settlements.

The approach and crossing surface settlement for the four crossings on the same subdivision with similar traffic volume utilizing an underlayment averaged 1.53 in. and 0.53 in respectively. When comparing the average approach settlements of these two groups the results are comparable. However, when the differences between the average crossing settlement is analyzed, the crossings with no underlayment, which as stated previously settled 1.29 in., is considerably larger than 0.53 in. This is significant because it demonstrates that these four crossings lack the additional support the underlayment provides. Also note that when the approach settlements are compared, the average settlements are similar – 1.50 in. and 1.53 in. In the images of these four crossings, seen in Figures A.1-A.4 it is evident that moisture has penetrated the trackbed resulting in track pumping and settlement. Despite the low ADT, these crossings display signs of a typical deteriorating crossing surface.

Top-of-Rail Settlements

Rt. 8 Concord



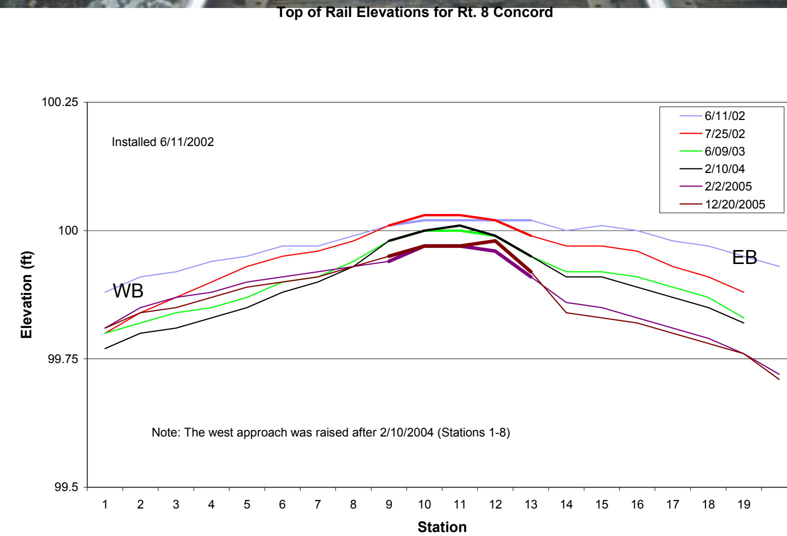
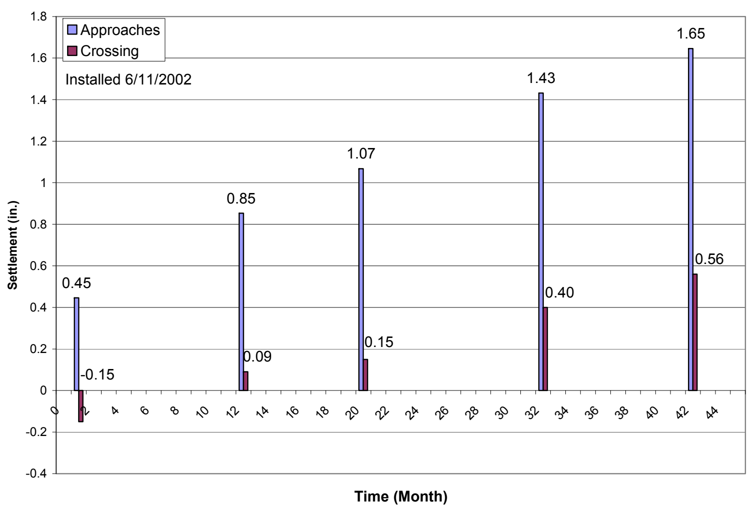


Figure A.5

Top-of-Rail Settlements
South Portsmouth

Average Asphalt/Approach Settlement for South Portsmouth



Top of Rail Elevations for South Portsmouth

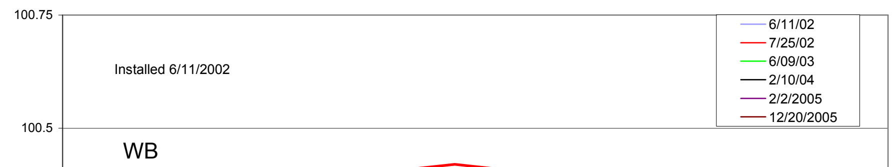
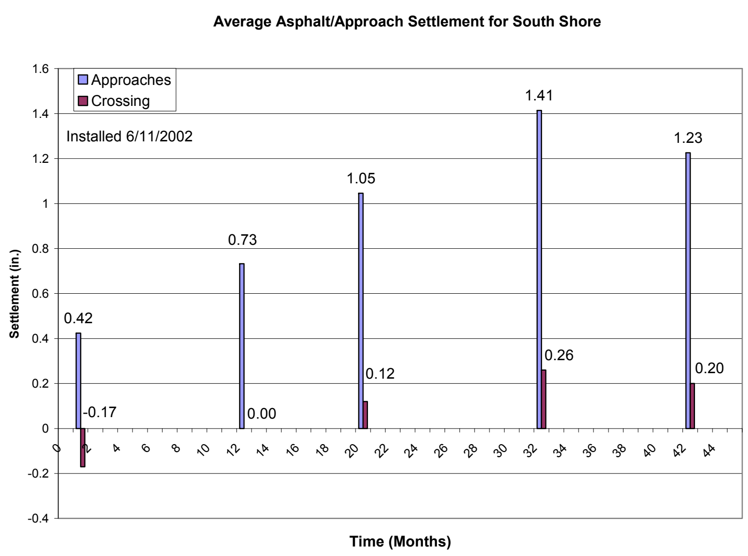


Figure A.6

Top-of-Rail Settlements

South Shore



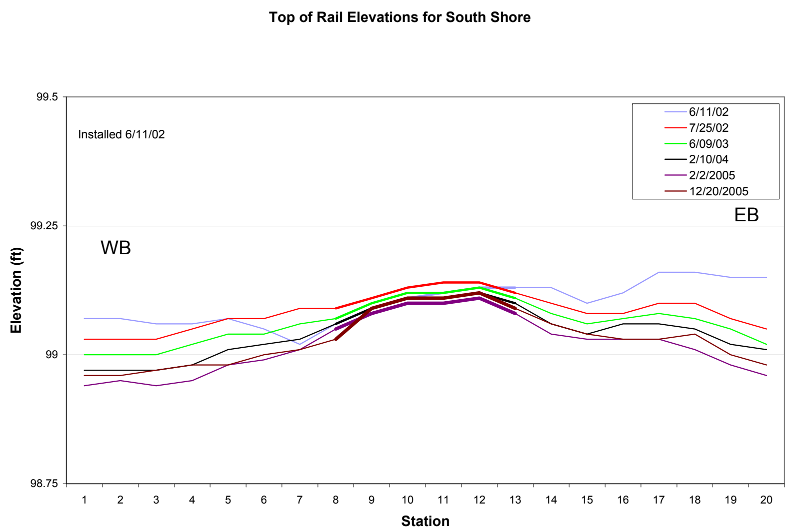
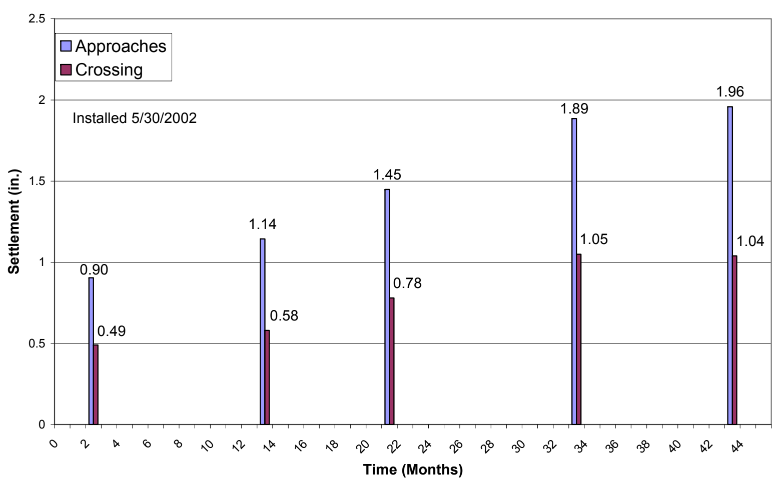


Figure A.7

Top-of-Rail Settlements

Vanceburg- Main Street

Average Asphalt/Approach Settlement for Vanceburg - Main Street



Top of Rail Elevations for Vanceburg - Main Street

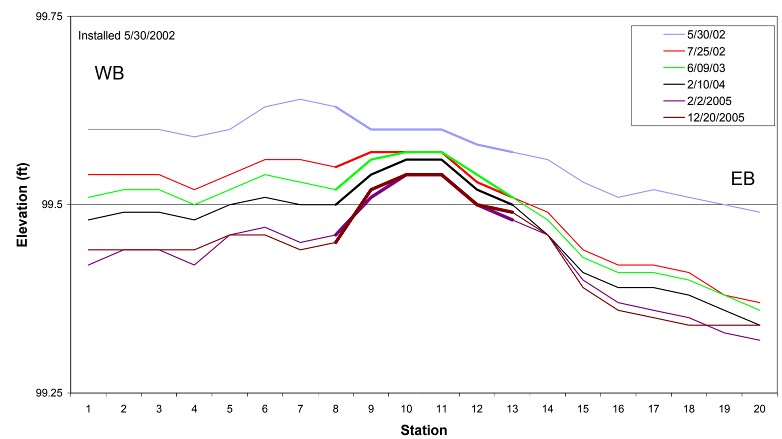


Figure A.8

Results for Rockhouse Subdivision Crossings

Six crossings on the Rockhouse Subdivision were rehabilitated during a 2005 CSXT timbering and surfacing program on KY 7 in Letcher County. This highway carries significant highway and rail traffic volumes, including a large percentage of highway trucks and 21 MGT of rail traffic. In addition to receiving an asphalt underlayment the crossing geometrics were also renewed in order to improve highway traffic operations. The approaches were widened and smoothed thereby minimizing speed reductions and improving traffic flow. KYDOT District 12 personnel provided traffic impact announcements, traffic control, and the asphalt for the underlayments, highway approaches and rubber seal/asphalt surfaces. KYDOT also assisted with spreading and compacting the asphalt. CSXT provided trackbed materials, including new track panels, new ballast and rubber seals as well as providing equipment and personnel for removing and replacing the track, roadbed, and crossing surface. Initial Top-of-Rail measurement readings were taken just prior to the crossings being reopened to traffic.

In order to minimize the inconvenience to highway traffic all crossing renewals were completed in one day, generally the crossing would close at 8:00 a.m. and reopen at 6:00 to 8:00 p.m. The entire crossing was renewed, including removing the old crossing surface, track panel, roadbed and replacing with an asphalt underlayment, new ballast, new wood tie track panel, and new rubber seal/asphalt surface. These crossings are evaluated in order to evaluate the performance of the rubber seal/asphalt surfaces on a heavy rail tonnage line and heavy tonnage highway. Figures A.9 through A.14 contain the settlement data and plots.

The first crossing installed on KY 7 was on July 21, 2005 at Colson OVG 281.16. The crossing is very stable. Due to the excess asphalt the approaches were higher than the crossing surface. In order to smooth out the crossing the approaches were subsequently milled level with the crossing. Over a 22 month period the approaches settled 1.30 in. and the crossing settled 0.81 in. The crossing carries 2800 ADT with 24% trucks.

The crossing at Indian Bottom Church, OVG 269.13, was installed October 17, 2005. This crossing was widened in order to improve the ease and safety of vehicles meeting on the crossing which was difficult to negotiate due to a sharp approach angle. The crossing was further improved when the approaches were paved as part of the KY 7 resurfacing program in September 2006. During the 19 month study of this crossing, the approaches settled 1.52 in. and the crossing settled 0.96 in. This crossing carries 2580 ADT with 13% trucks.

On October 14, 2005 the crossing at No Name, OVG 269.84, was installed. The crossing underwent much of the same improvements as Indian Bottom Church, due to a sharp approach angle, as well as repaving of the crossing approaches. Over 19 months the approaches settled 1.17 in. and the crossing settled 0.37 in. This crossing carries 2580 ADT with 13% trucks.

The Old Letcher School crossing, OVG 269.39, was installed November 1, 2005. During the rehabilitation of this crossing a detour was necessary for school and local traffic. In addition to installing an asphalt underlayment, the crossing was widened to increase traffic safety and mobility. Similar to previously mentioned crossings, the approaches were improved during a subsequent KY 7 resurfacing program. During an 18 month study, the approaches settled 1.16 in. and the crossing surface settled 0.20 in. This crossing carries 2580 ADT and 13% trucks.

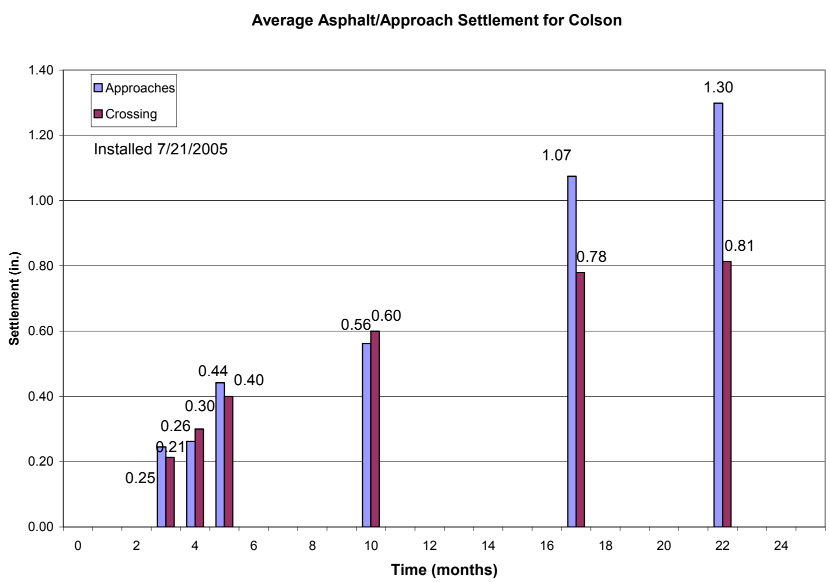
The crossing at Letcher Elementary School, OVG 272.12, was installed August 2, 2005. Due to this crossings proximity to a railroad bridge, it was not possible to raise the crossing. As a result of these circumstances, the existing highway approaches were higher than the crossing, causing a low, rough point in the roadway. During the 2006 KY 7 resurfacing program the approaches were milled and replaced and are now smooth. This crossing receives 2580 ADT with 13% trucks and during 21 months of service the approaches and crossing settled 0.76 in. and 0.25 in. respectively.

The Thornton Gap crossing, OVG 279.93, was installed July 28, 2005. During the installation of this underlayment, the asphalt plant had a malfunction resulting in only one load of hot mix asphalt available for use. In place of the hot mix asphalt two loads of asphalt millings were used for the underlayment. With time available to place the asphalt on the approaches in two lifts, the crossing was reasonably smooth. However, the smoothness was further improved during the 2006 KY 7 resurfacing program. However, there was a derailment close to this crossing in April 2006. The rail approaches to the crossing were raised and resurfaced. Therefore, the long-term approach settlement data is inaccurate due to a change in the original elevation data.

On average the five evaluated crossings have been in service for 20 months. The average approach settlement is 1.18 in. and the average crossing settlement is 0.52 in. As stated previously, the difference between the approach and crossing settlement is significant. The crossings, which carries not only rail, but highway traffic as well, settled consistently less than the approaches, which only receive loadings from train traffic.

Top-of-Rail Settlements

Colson



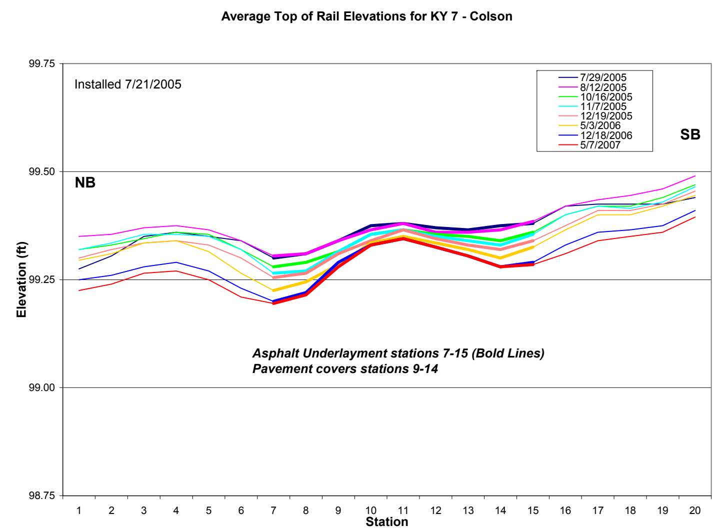
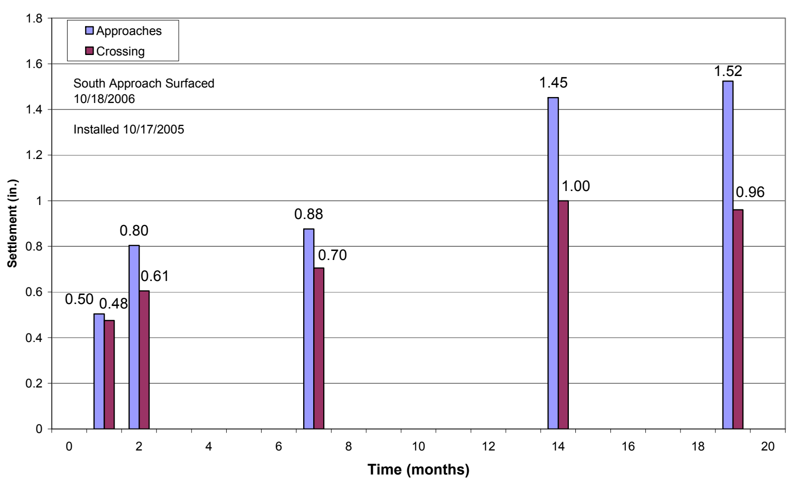


Figure A.9

Top-of-Rail Settlements

Indian Bottom Church

Average Asphalt/Approach Settlement for Indian Bottom Church



Average Top of Rail Elevations for KY 7 - Indian Bottom Church

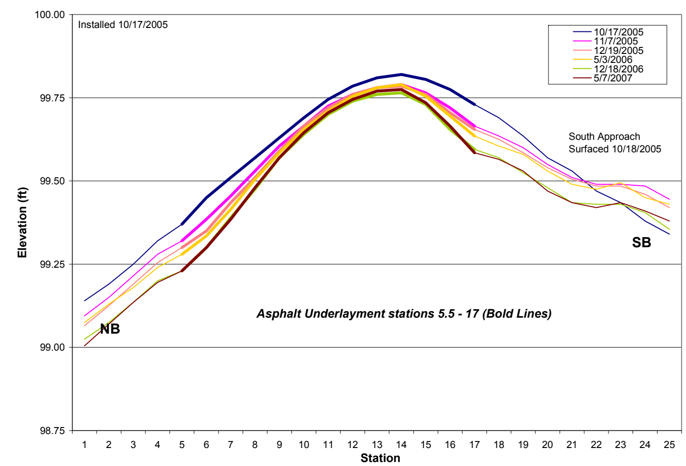
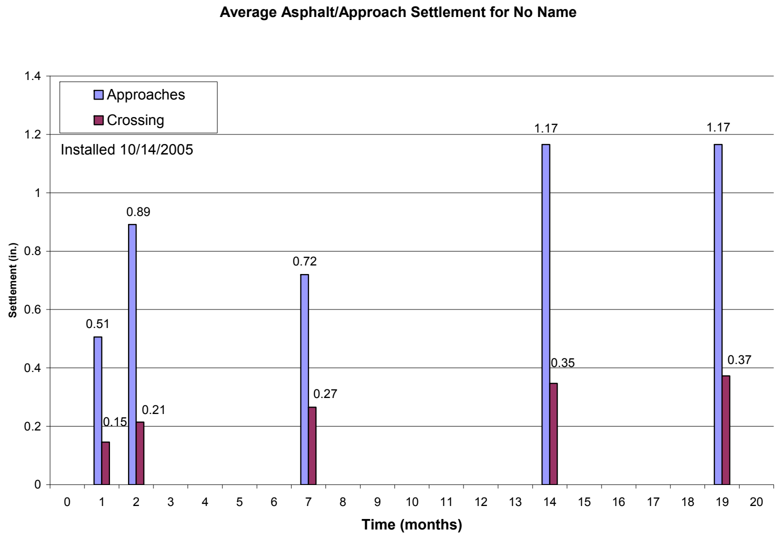


Figure A.10

Top-of-Rail Settlements

No Name



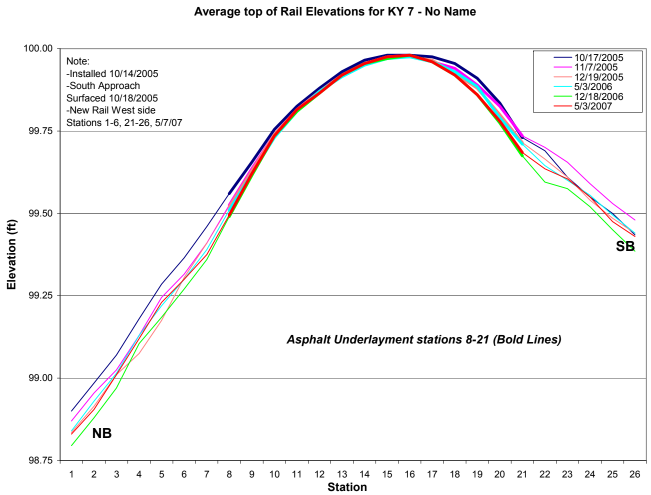
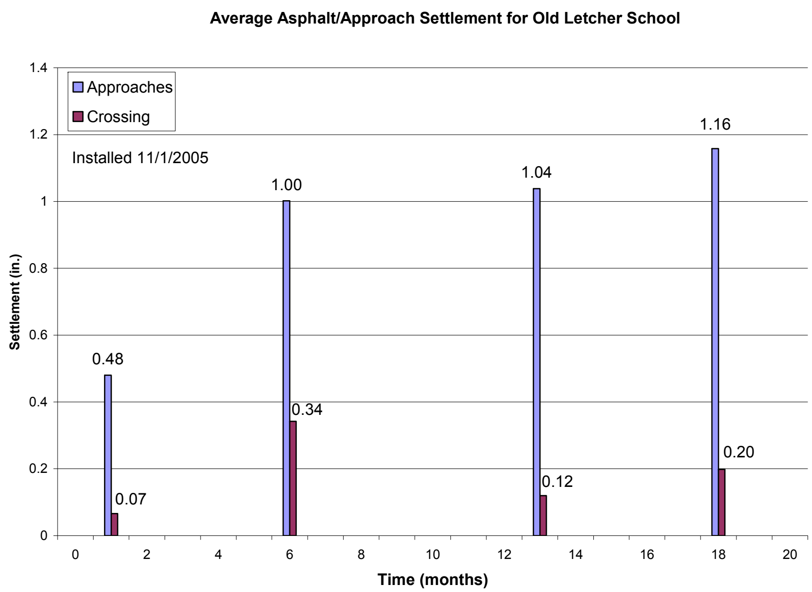


Figure A.11

Top-of-Rail Settlements

Old Letcher School



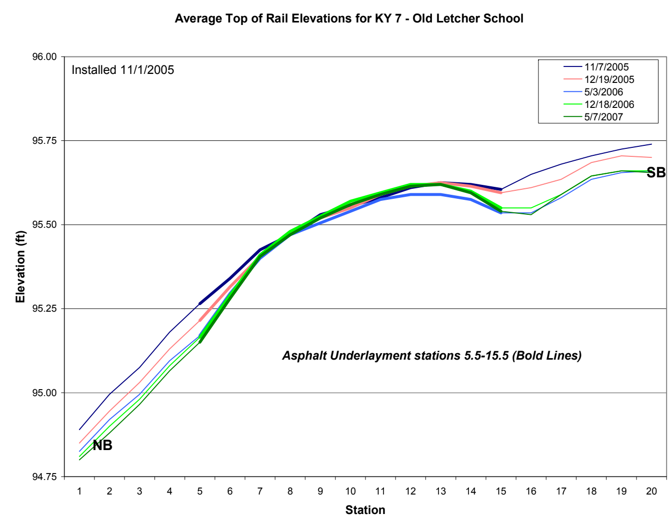
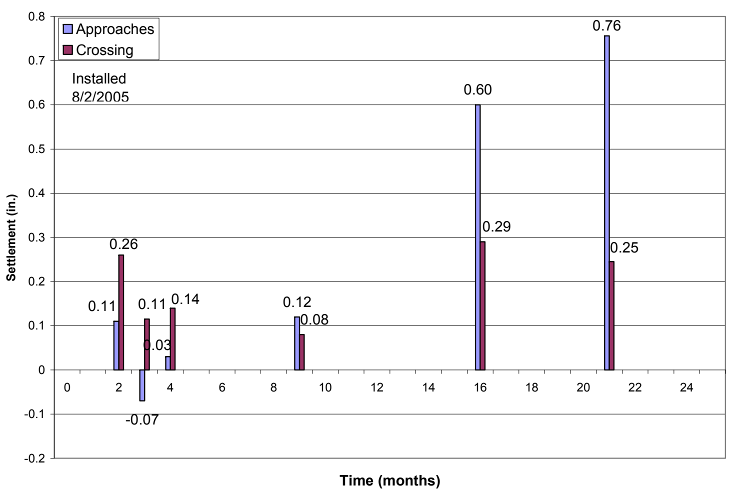


Figure A.12

Top-of-Rail Settlements

Letcher School

Average Asphalt/Approach Settlement for Letcher Elem. School (OVG 272.12)



Average Top of Rail Elevations for KY 7 - Letcher Elem. School

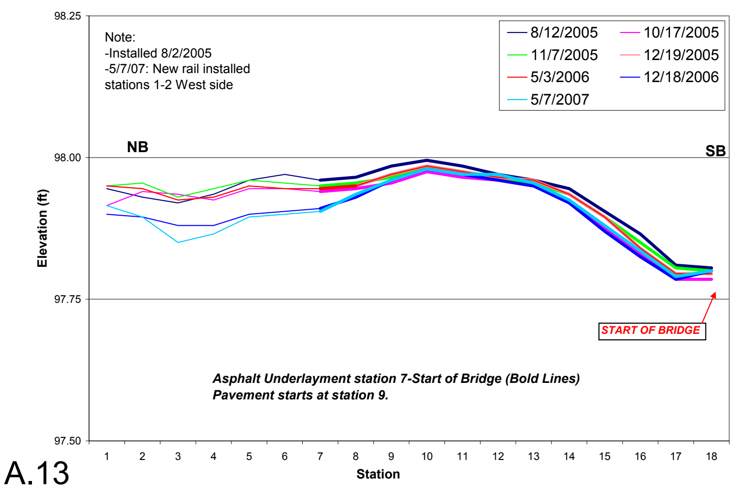
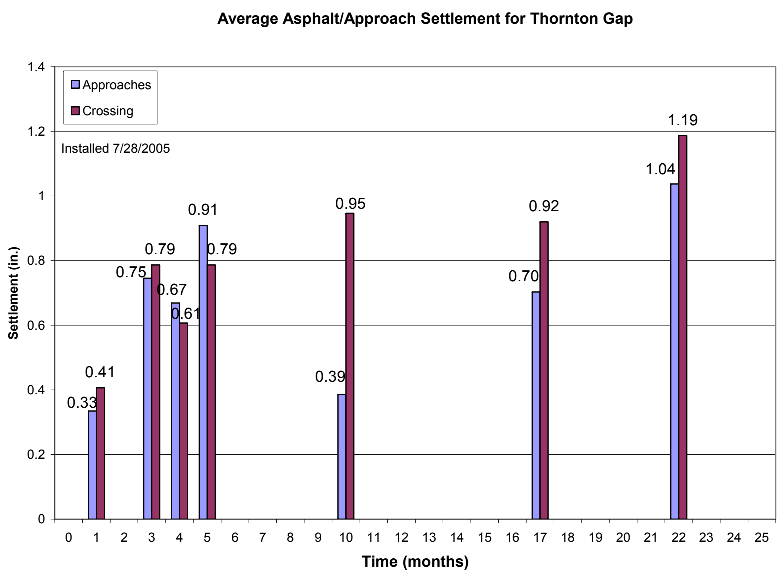


Figure A.13

Top-of-Rail Settlements

Thornton Gap

(Data inconclusive due to derailment near the crossing 9 months after installation, subsequent surfacing affected elevation datum, data omitted from analysis)



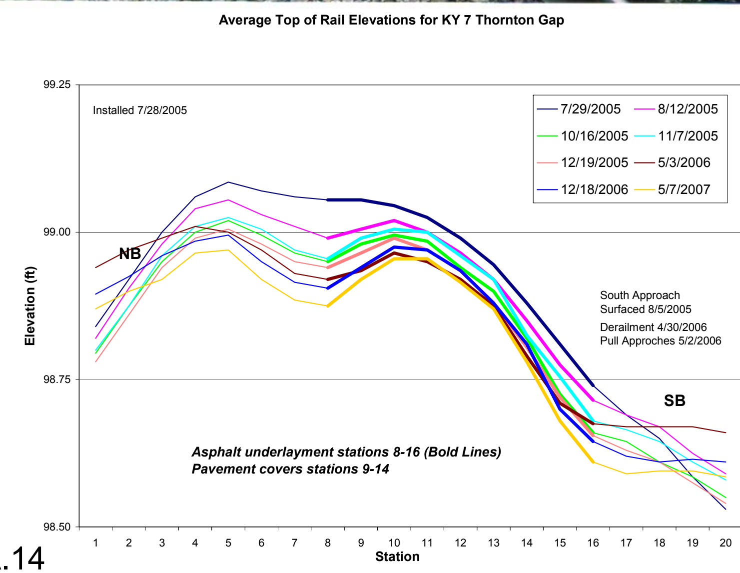


Figure A.14

Results for LH&StL Subdivision Crossing

One crossing was studied on the LH&StL Subdivision of the CSXT line in Western Kentucky which carries a heavy amount of highway traffic and a moderate 8 MGT of rail traffic each year. This crossing was rehabilitated in May of 2002, prior to a timbering and surfacing operation. The old crossing was removed and replaced with a rubber seal/asphalt surface. The initial rail traffic included the tie change-out equipment as it passed by immediately after bolting the new track panel to the existing track. This crossing remains very smooth for the heavily trafficked 60 mile-per-hour traffic it is exposed to. Typically, rubber seal/asphalt surfaces are not predicted to perform well under such circumstances, however, this crossing shows no signs of fatigue and remains smooth. Figure A.15 contains the settlement data and plot.

KYDOT District 2 personnel provided traffic control as well as the asphalt paving. This crossing has been monitored by Top-of-Rail studies for 54 months, in this time the approaches have settled 0.93 in. and the crossing has settled 0.45 in. This result is consistent with other crossings, which illustrates the additional support from the underlayment is preventing premature wear to the crossing surface.

Top-of-Rail Settlements

US 60 Stanley

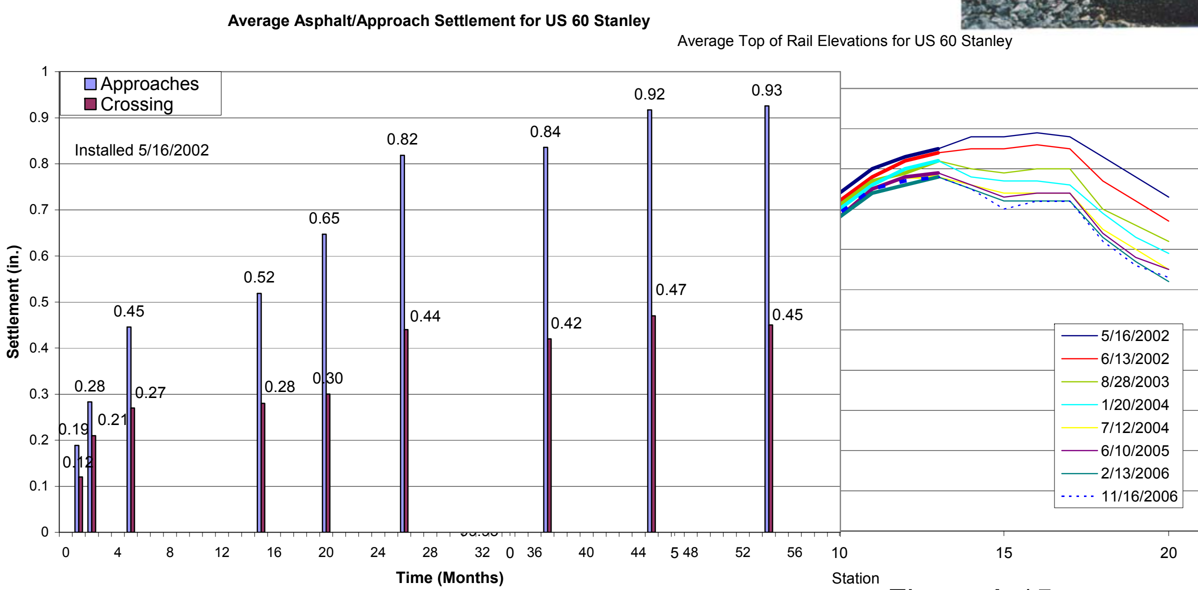


Figure A.15

Results for Big Sandy/Rockhouse Subdivision Crossings

Four crossing were analyzed on the Big Sandy/ Rockhouse Subdivision. These are some of the heaviest trafficked CSXT crossings in Eastern Kentucky. The crossings were installed in November of 2002 after positive evaluations of crossings in the area which received underlayments in 2001. Top-of-Rail measurements were performed in order to establish the performance of the asphalt underlayment under such heavy loadings. Figures A.16 through A.19 contain the settlement data and plots.

The KY Coal Terminals crossing is a section of double track in the Big Sandy Subdivision at CMG 6.6. These tracks carry 45 MGT and serve as a private access to a coal unloading facility. Due to the extreme loadings, these crossing have a history of rapidly deteriorating. On a typical weekday, in addition to service traffic, approximately 500 coal trucks at or above the legal extended weight of 126,000 lbs. cross these tracks. With these large loadings it can stated that this is one of the heaviest loaded rail/highway crossings in the state. Previous attempts to establish a long-life smooth crossing have not been successful, however, since the implementation of the asphalt underlayment and concrete crossing panels the crossing has required no maintenance and shows no signs of deterioration.

KY Coal Terminal #1 and #2 track have been in service for 37 months and the approaches have settled 1.16 in. and 1.71 in. respectively, whereas on average the crossings settled: 0.68 in. and 0.90 in.

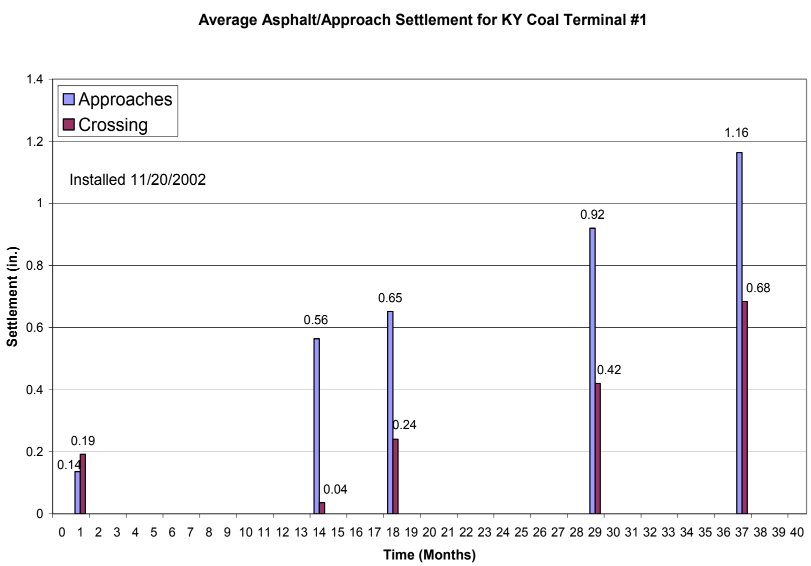
KY 15 crossing at Isom, OVG 276.4, is a 60 MPH highway located on the Rockhouse Subdivision and is the primary highway route serving southeastern Kentucky. This crossing was rehabilitated November 6, 2002. This rail line carries 21 MGT and the highway carries 9440 ADT. The Isom crossing carries 13% loaded coal trucks in addition to local traffic. Much like previously mentioned crossings, Isom routinely required maintenance in order to service the deteriorating crossing surface which posed as a safety risk to the traveling public. During the installation procedure KYDOT District 12 provided traffic control and the asphalt for the approaches and underlayment. After four years, the metal encasement for one of the field side concrete panels loosened and the impact cracked and deteriorated the concrete panel. Despite recent cracks found in the concrete panels after the installation of an underlayment the crossing remains smooth. After 37 months of service, the approaches settled 2.10 in. and the crossing settled 1.17 in.

KY Power Louisa is a private crossing in the Rockhouse Subdivision on single track 45 MGT line several miles south of KY Coal Terminal crossing. It was rehabilitated in 2002 with a concrete surface, new track panel and asphalt underlayment. The crossing had been cribbed out, surfaced and renewed with a rubber seal and asphalt surface in 2000. The rapid deterioration was attributed to mud and fouling, which is prevalent in this area. In addition to these conditions, when the concrete panel was installed the tie spacing did not match the holes for the lag screws, resulting in panels which were always loose. The rail approaches beyond the underlayment have displayed signs of significant pumping and require surfacing. Despite heavily loaded coal trucks as the primary traffic the crossing is performing well. During the 37 months of service, the approaches have settled 1.35 in. and the crossing has settled 0.59 in.

On average, after 37 months the four crossings approaches in this subdivision have settled 1.58 in. while the crossings have settled 0.84 in. Of all the crossings studied, these four carry the largest amounts of rail and highway traffic. The significant difference between the total settlement between the crossing and approaches clearly illustrates the effectiveness of using an asphalt underlayment.

Top-of-Rail Settlements

KY Coal Terminal Track #1



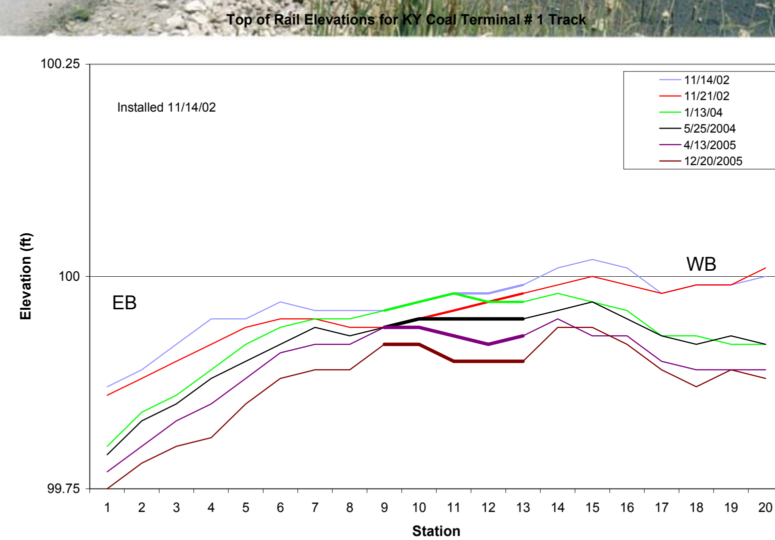
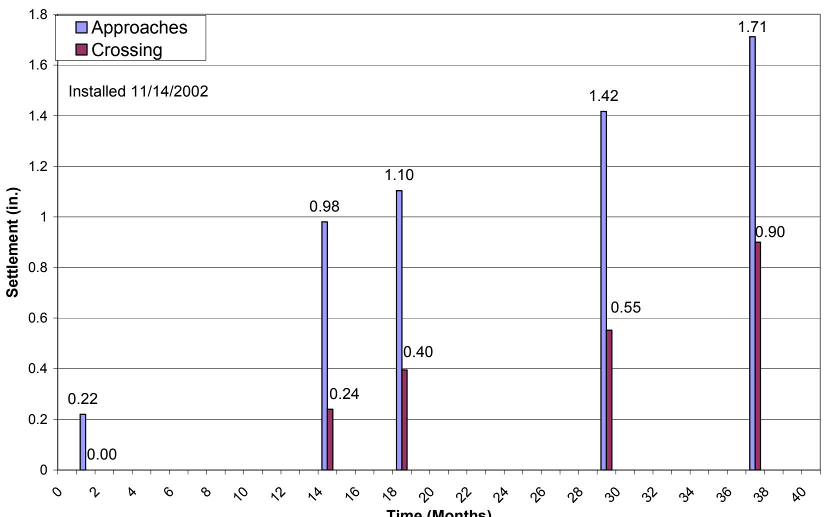


Figure A.16

Top–of-Rail Settlements

KY Coal Terminal Track #2

Average Asphalt/Approach Settlement for KY Coal Terminal #2



Top of Rail Elevations for KY Coal Terminal # 2 Track

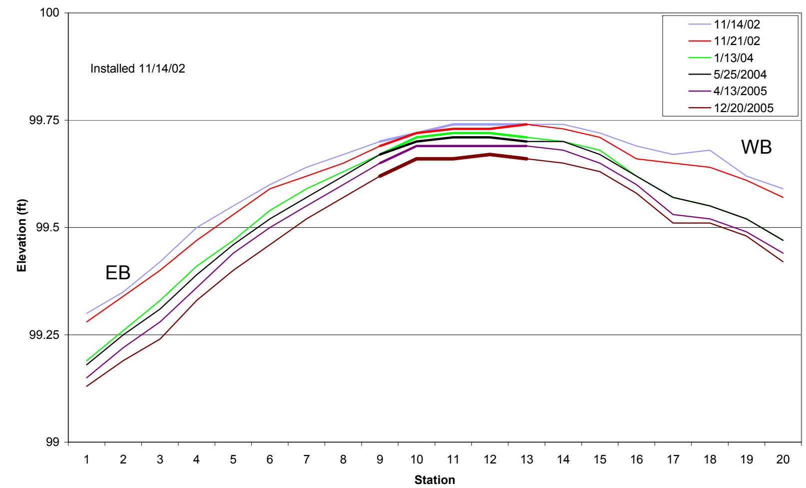
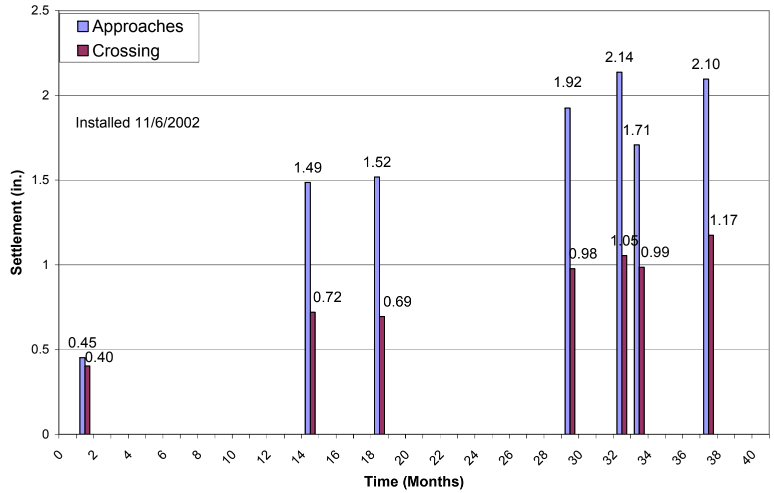


Figure A.17

Top-of-Rail Settlements

KY 15-Isom

Average Asphalt/Approach Settlement for KY 15 Isom



Top of Rail Elevations for KY 15 - Isom, KY

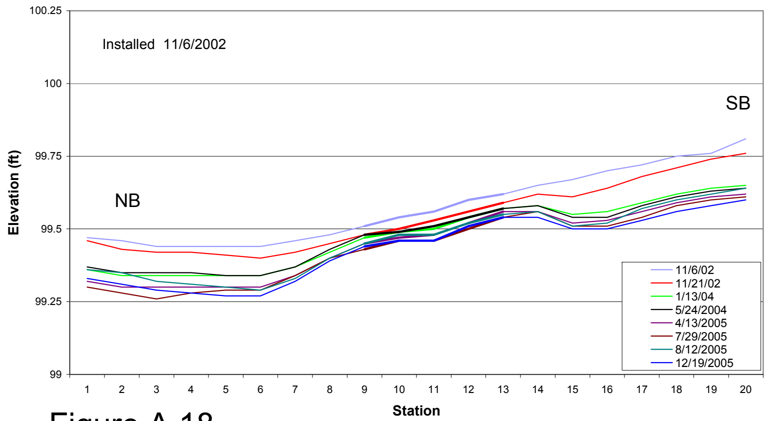
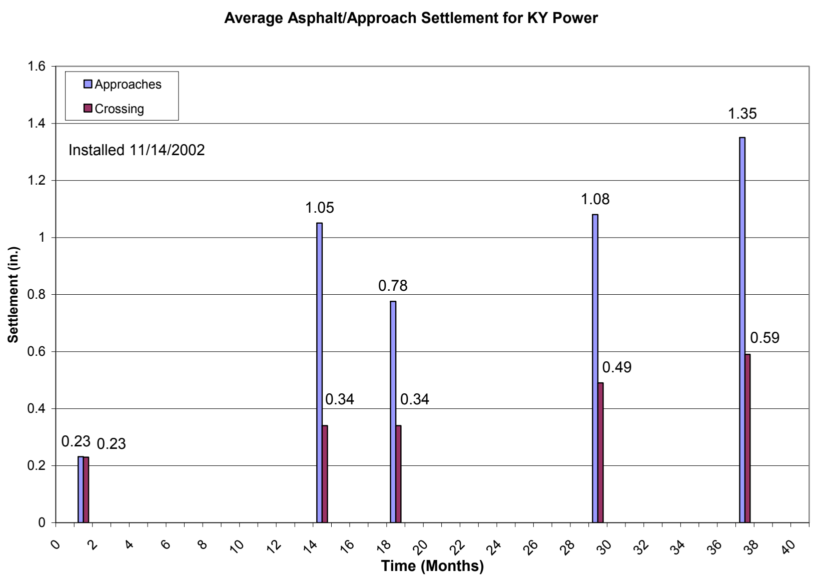


Figure A.18

Top-of-Rail Settlements

Kentucky Power- Louisa



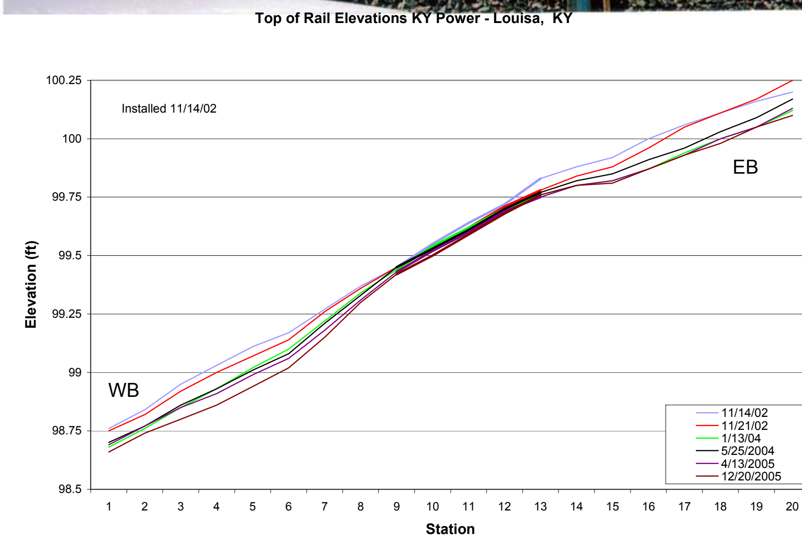


Figure A.19

Results for Ann Arbor, Michigan Crossings

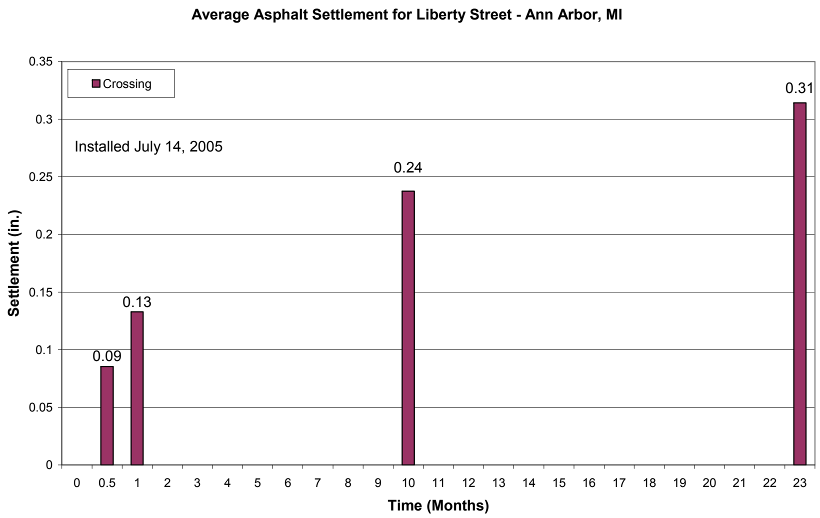
Two crossings on the Ann Arbor Railroad in Ann Arbor, MI were renewed during 2005 with the Michigan Department of Transportation (MDOT) Local Grade Crossing Demonstration Program. In the past three years MDOT has provided financial support for ten projects which incorporated asphalt underlayments. MDOT has monitored two crossings in Ann Arbor -- Liberty Street and State Street -- by Top-of-Rail measurements. Figures A.20 and A.21 contain the settlement data and plots. These surveys differ from previously discussed crossings in the fact that no elevations were taken of the approaches, as a result, there can be no comparison of the approaches to the crossing surface settlement. Liberty Street and State Street are on the same rail line and carry 1 MGT or 2 trains a day, average daily highway traffic is 11,200, and 25,560 respectively.

Liberty Street was installed with an experimental endurance composite crossing surface consisting of 100% recycled materials. After 23 months, the crossing surface has settled 0.31 in.

State Street connects the University of Michigan with downtown Ann Arbor. The crossing contains four lanes of highway traffic on a skew. During rehabilitation, the old crossing surface was removed and replaced with a full depth rubber crossing in addition to the asphalt underlayment. This crossing has also settled 0.31 in. after 24 months.

Top-of-Rail Settlements

Liberty Street – Ann Arbor, MI



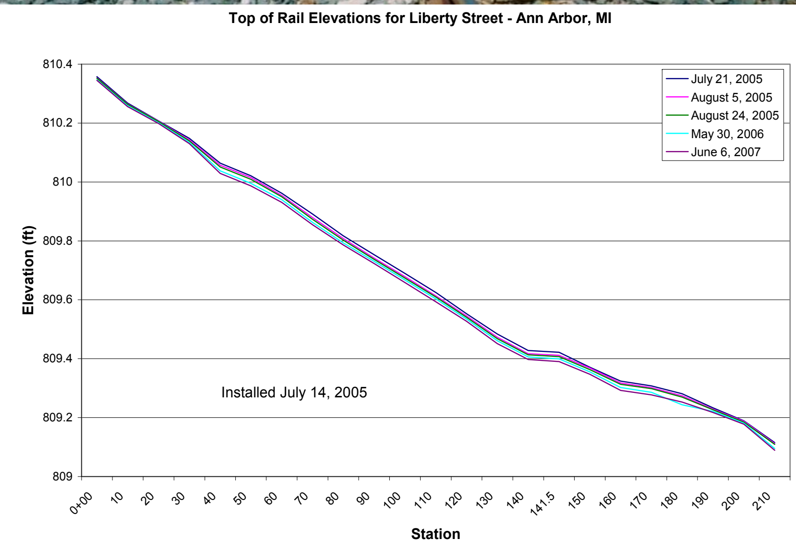
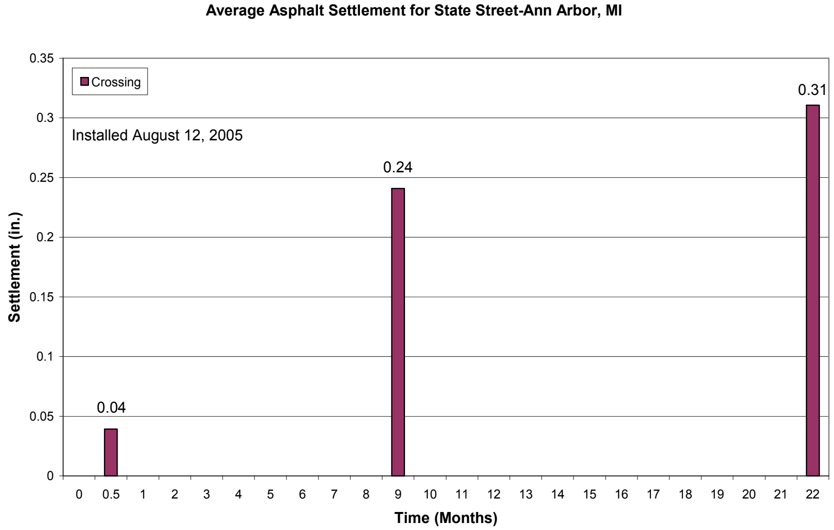


Figure A.20

Top-of-Rail Settlements

State Street – Ann Arbor, MI



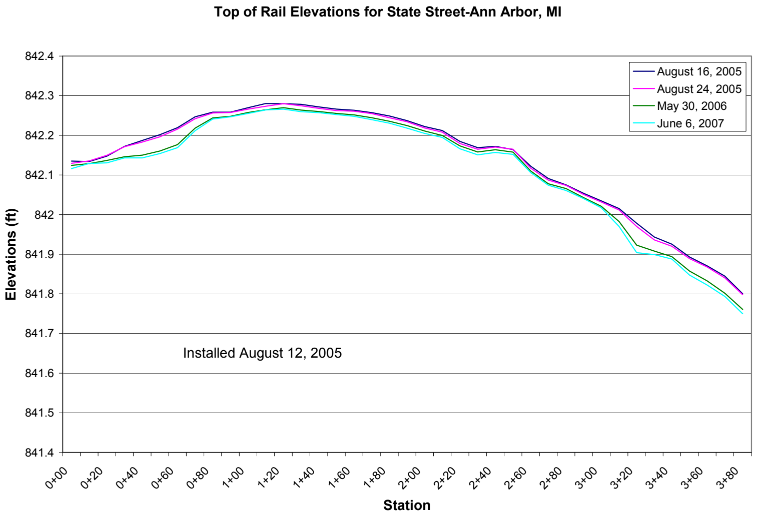


Figure A.21

Appendix B

Longitudinal Profile Measurements

Longitudinal Highway Profile Measurements

The Total Station procedure was utilized to gather the data necessary to plot the longitudinal wheelpath profiles of the highway approaches and the crossing. Settlements occurs primarily in the vehicle wheelpaths, and this is the location on the crossing where the rail experiences both train and highway traffic. The wheelpaths of the vehicle were identified for both sets of wheels on each side of the centerline as indicated in Figure B.1a. Specific attention was given to calculating the Top-of-Rail Settlements from the Total Station data. Two Top-of-Rail elevations on each rail were taken during each wheelpath profile measurement. This data is presented along with the profiles.

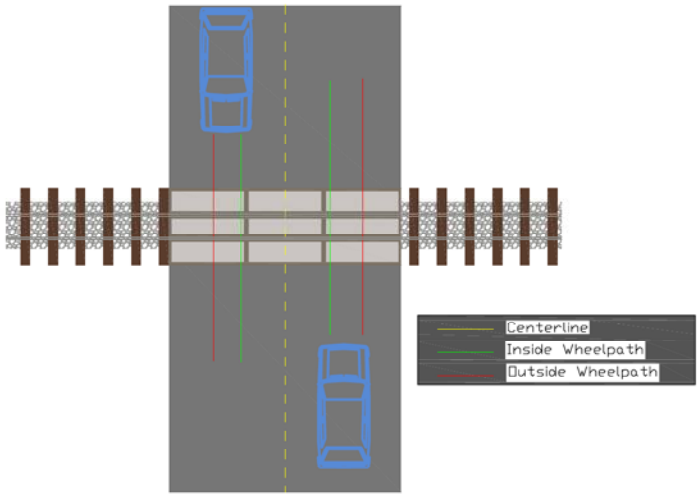


Figure B.1a: Plan View of Wheelpaths for Pavement Profiles

The process for obtaining measurements is shown in Figure B.1b. Elevations are taken from a line in all four wheel paths using a total station instrument and prism. For this study a Topcon Total Station GTS-300 and a HP 48 GX data collector were used. The prism is placed at each desired measurement point and the total station records the coordinates of the point relative to the benchmark (Adwell, 2004). The distance from the total station to the prism along with the horizontal and vertical angles are then transferred electronically to the data collector.

In order to develop a plot of changes over time due to settlement, vertical deviations in the roads surface were found. It is assumed that the crossing approaches were smooth when installed, and the only deformations would be due to settlement. To determine these points, a rod was used and laid flat against the ground surface measuring from the beginning to the end of the wheel path. A point where the rod does not lay flat indicates a change in slope, this position is marked and recorded by the total station. In some cases, where the crossing was recently paved and still smooth, readings were taken at intervals equivalent to the length of the rod to ensure a representative profile was established.

Although this method is considered accurate, this is a time consuming and meticulous procedure and one traffic lane must be closed for several hours while measurements are taken.

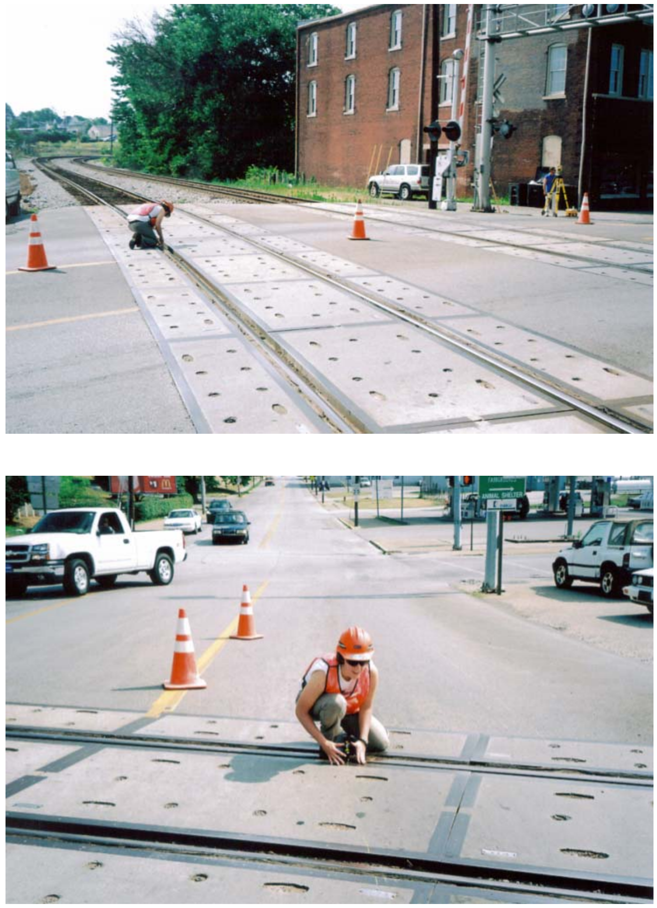


Figure B.1b: View of Total Stationing Procedure

Descriptions of Crossings

Four heavily travelled crossings were included in this study. Measurements were taken at Rosemont Garden and Waller Avenue -- Lexington, Main Street – Winchester, and Main Street – Richmond. Rosemont Garden and Waller Avenue are on a Norfolk Southern line and Main Street Winchester and Richmond are on a CSX line. Table B.1 includes information regarding the trains per day and average daily traffic at each crossing.

Table B.1: Traffic Information Regarding Crossings

Crossing	MGT	Trains/Day	ADT	% Trucks
Waller*	**76**	**40-45**	**15,600**	**1**
Rosemont Garden*	**76**	**40-45**	**8,780**	**1**
Winchester*	**34**	**15-20**	**11,650**	**3**
Richmond	**51**	**20-25**	**15,530**	**11**
* Indicates Double Track				

Pictures of each of these crossing can be seen in Figures B.2a – B.2d.

Figure B.2a: View of Waller Avenue Crossing

Figure B.2b: View of Rosemont Garden Crossing

Figure B.2c: View of Main Street – Winchester Crossing

Figure B.2d: View of Main Street - Richmond Crossing

Data Plots

Once the data was collected, the program SurvCADD which runs within AutoCAD was used to plot the pavement profiles. On these profiles the x-axis represents the horizontal distance of the profile and the y-axis represents the elevation. A representative profile can be seen in Figure B.3. Profiles for all four crossings are included in this Appendix.

When viewing the profiles such as the one in Figure B.3, each line on the graph represents a different period of time when settlement was measured. For the crossing in Figure B.3 measurements were taken in July 2002 just before construction, in August 2002 immediately after construction, and subsequently in March 2004 and June 2007. Note that the sharp drop in elevations are due to the flanges, the flanges are necessary to guide the wheel of the train along the track and are included for profile purposes.

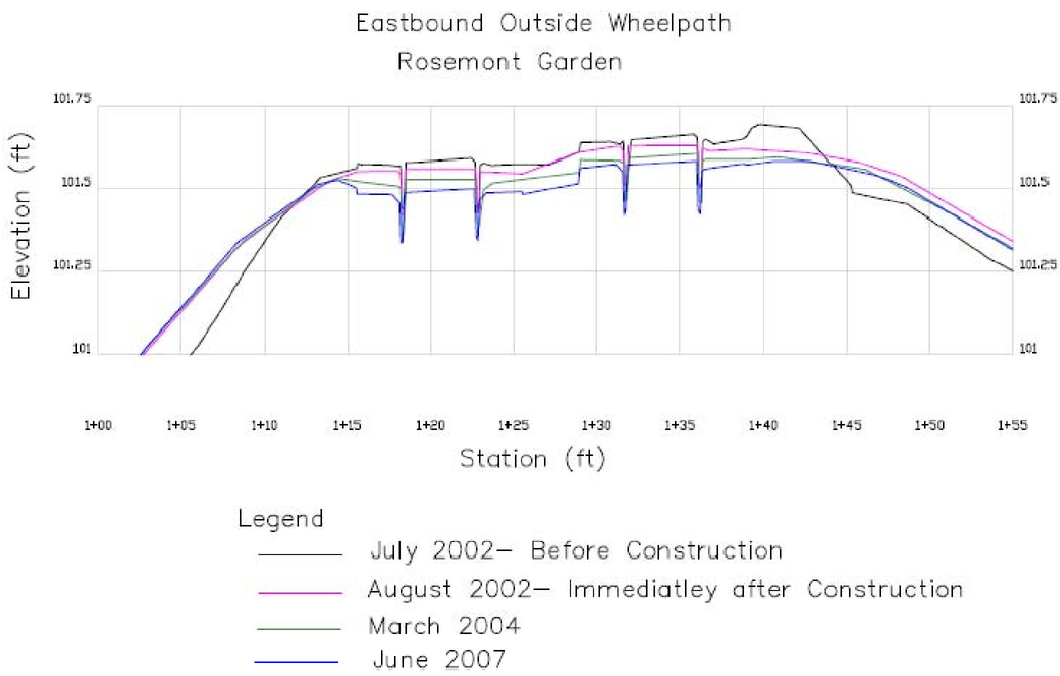


Figure B.3: Characteristic Chart of Pavement Profile

Results for Top-of-Soil Settlements

The average rail settlement for each wheelpath at the four studied crossings can be seen in Tables B.2a-B.2d. The values in these tables represent the average rail settlement for the directional wheelpaths, the inside and outside wheelpaths were averaged to present a general rail settlement. The tables containing the average rail settlement from the longitudinal survey are divided into different study dates. The study dates include the initial study date (generally 2001 or 2002) to 2004, 2004 through 2007, and finally a column from the initial study date through 2007 which shows cumulative settlement. In Figures B.4a -B.4d, the settlement of all the individual wheelpaths for each crossing is illustrated, in several cases four measurements were taken, however, typically only two wheelpaths were evaluated.

At the beginning of these surveys, only settlements in the outer wheelpaths was studied, as the study progressed, measurements were taken in both the inner and outer wheelpaths when possible. Often heavy highway traffic prevented the collection of data in all four wheelpaths. Generally two readings were taken at the head of the rail at each time a rail was encountered. Therefore, for a crossing with double track there would be eight readings from the rail in one wheelpath, and assuming four wheelpaths, there is a potential of 32 rail readings. The two readings from one rail were averaged and compared to previous data to calculate settlement. For readability purposes, the results are reported in both feet and inches.

Table B.2a: Average Rail Settlement for Waller Avenue Crossing, Lexington KY.

Waller Avenue - Lexington (Installed August 2002)						
	Wheel Path		Wheel Path		Wheel Path	
	8/2002 -3/2004		3/2004 - 7/2007		3/2002 - 7/2007	
East Bound	0.035 ft	0.42 in.	0.024 ft	0.28 in.	0.059 ft	0.71 in.
West Bound	0.031 ft	0.37 in.	0.033 ft	0.40 in.	0.064 ft	0.77 in.

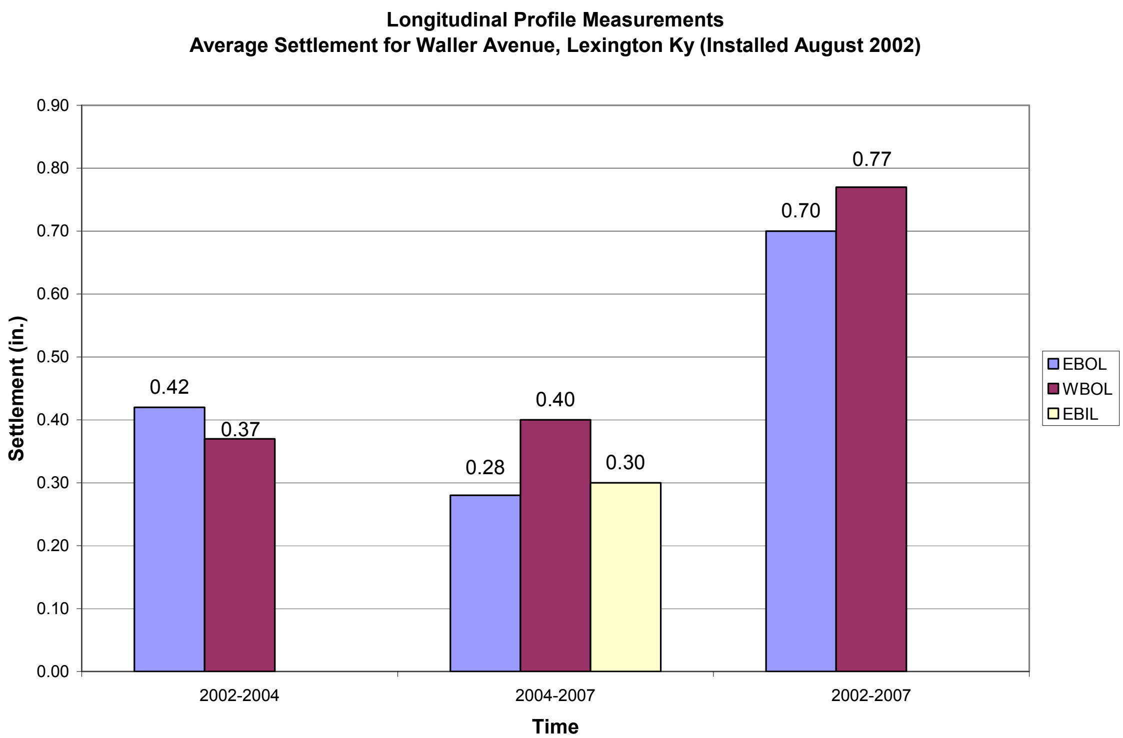


Figure B.4a: Average Rail Settlement for Waller Avenue Crossing, Lexington KY.

Table B.2b: Average Rail Settlement for Rosemont Garden Crossing, Lexington KY.

Rosemont Garden - Lexington (Installed July 2002)						
	Wheel Path		**Wheel Path**		**Wheel Path**	
	7/2002 -7/2004		**3/2004 - 7/2007**		**3/2002 - 7/2007**	
East Bound	0.062 ft	0.74 in.	0.031 ft	0.37 in.	0.093 ft	1.11 in.
West Bound	0.062 ft	0.74 in.	0.043 ft	0.51 in.	0.104 ft	1.25 in.

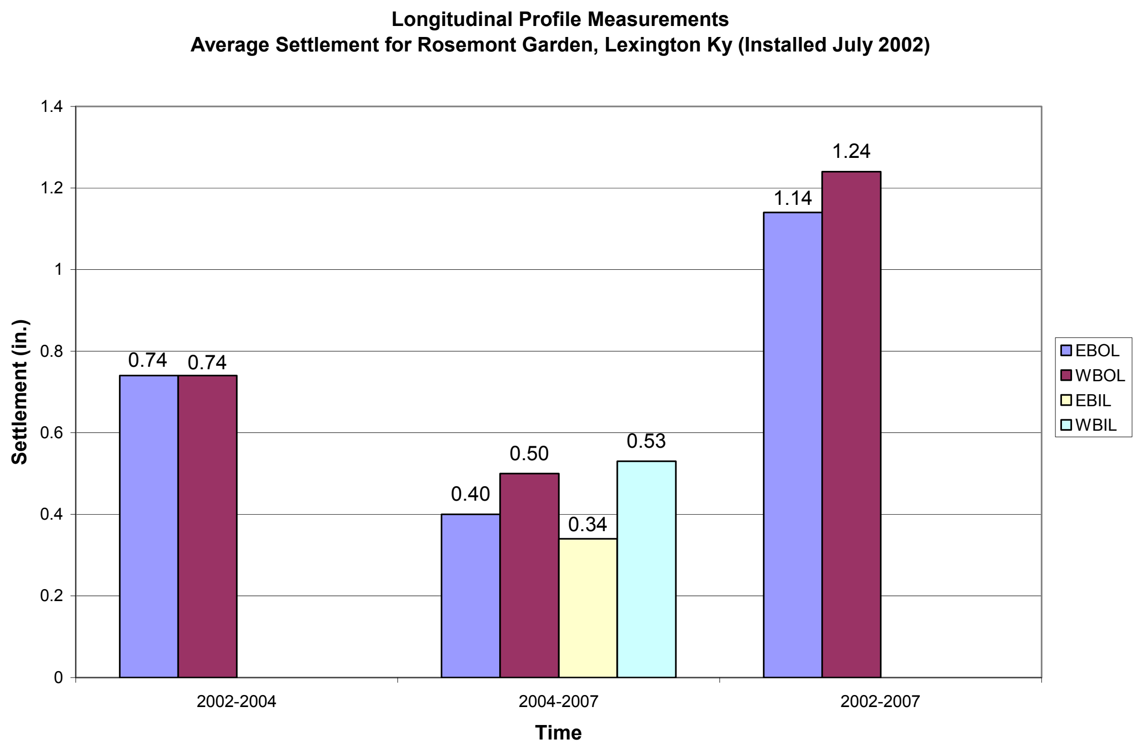


Figure B.4b: Average Rail Settlement for Rosemont Garden Crossing, Lexington KY.

Table B.2c: Average Rail Settlement for Main Street Crossing, Winchester KY.

Main Street - Winchester (Installed November 2003)		
	Wheel Path	
	3/2004 -7/2007	
East Bound	0.024 ft	0.29 in.
West Bound	0.012 ft	0.14 in.

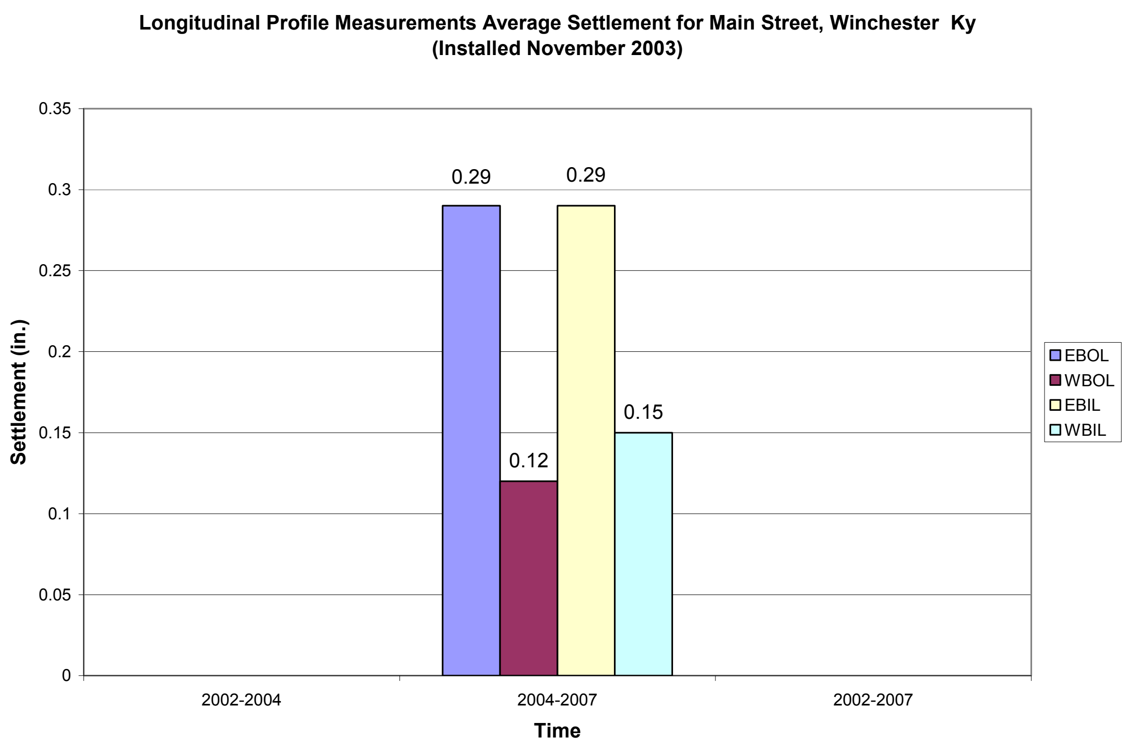


Figure B.4c: Average Rail Settlement for Main Street Crossing, Winchester KY

Table B.2d: Average Rail Settlement for Main Street Crossing, Richmond KY.

Main Street - Richmond (Installed September 2000)						
	Wheel Path		**Wheel Path**		**Wheel Path**	
	12/2001 -3/2004		**3/2004 - 7/2007**		**3/2001 - 7/2007**	
North Bound	0.031 ft	0.37 in.	0.053 ft	0.63 in.	0.083 ft	1.00 in.
South Bound	0.025 ft	0.30 in.	0.039 ft	0.47 in.	0.064 ft	0.77 in.

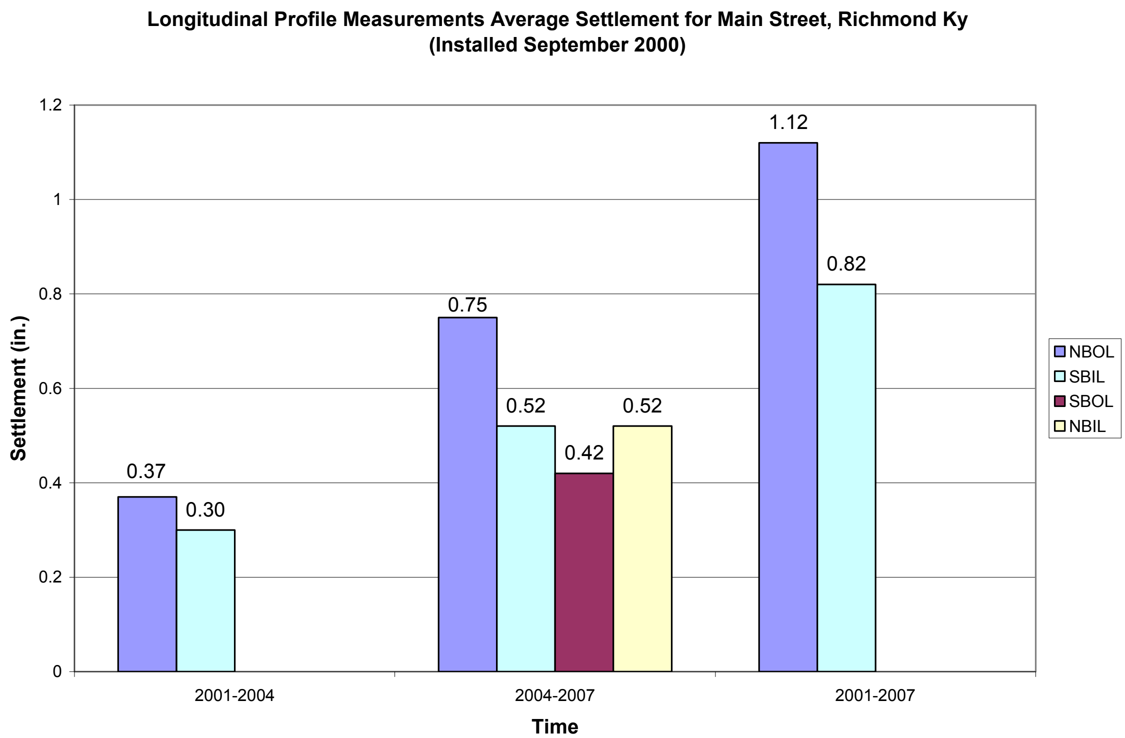


Figure B.4d: Average Rail Settlement for Main Street Crossing, Richmond KY.

Results for Waller Avenue Lexington Longitudinal Profiles

The underlayment was installed on August 6th and 7th, 2002 at Waller Avenue, (DOT 724 527 H), a rail highway crossing along the Norfolk Southern Railway. This is a section of double track along a very heavily trafficked highway and rail crossings. This crossing was renewed in conjunction with Rosemont Garden, a crossing approximately one mile away. The road was closed at 8:30 a.m. and reopened around 6:00 p.m. for two consecutive days. During the intervening evening a temporary devil strip was installed in order to keep the crossing functional during the night. During the rehabilitation of this crossing the "fast track" method was used in order to minimize interference with daily highway traffic. This system is a highly efficient way of completely renewing a crossing. KYDOT and the Lexington Fayette Urban County Government assisted by providing public announcements, traffic control, asphalt and crossing surfaces.

A longitudinal survey was taken immediately before construction in July of 2002, a profile of which can be seen in Figures B.5a-B.5c. Immediately after construction in August, the second longitudinal survey was taken. As can be seen there is a significant difference before and after the crossing was rehabilitated. The track was raised and the approaches were smoothed out. Before construction the crossing was in a low point along the highway, requiring drivers to slow down to safely and comfortably cross. Since installations in 2002, the crossings have performed well, the surface remains smooth and it is not necessary for drivers to slow down in order to travel across the crossing. It should be noted in Table B.4a that the greater part of the total rail settlement occurred immediately after construction. This is expected and is predominately caused by train vibrations as it travels through the crossing, which consolidates the newly placed ballast.

It was found that the total average rail settlements in the outer wheelpaths in the East and West bound lanes from August 2002 and July 2007 were 0.70 in. and 0.77 in. respectively. Due to a high traffic volume there was only one study in the inner wheelpath. The eastbound inner wheelpath was studied from March 2004 to July 2007 and an average rail settlement of 0.30 in. was found. For the same period of time the outer East and West rail settlements were 0.28 in. and 0.40 in., respectively.

In addition to increased ride quality, one other indication that the underlayment is performing well is the lack of maintenance required to maintain the smooth surface. Generally Norfolk Southern has a Tie and Surfacing program (T & S) maintain the track every four years. The T&S program removes and replaces ties as well as surfaces the track. Additionally, crossings are renewed as needed. Prior to rehabilitation in 2002, which included installing an asphalt underlayment, the crossing was very rough and difficult to maintain. However, during a 2003 surfacing program the No. 1 track was skipped. In 2006, four years after the installation the No. 1 track was skipped during a T&S program. In 2007, the No. 2 track received a T&S program, and due to the current condition of the crossing, it was skipped over and omitted from the program. The implementation of the underlayment has resulted in financial savings to the railroad and the smooth surface and lack of traffic disruptions for maintenance have inherent benefits to the traveling public.

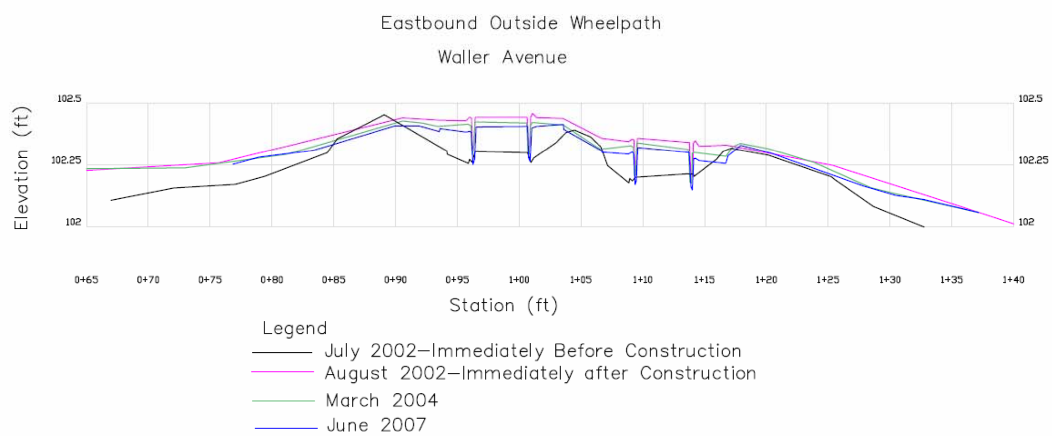


Figure B.5a

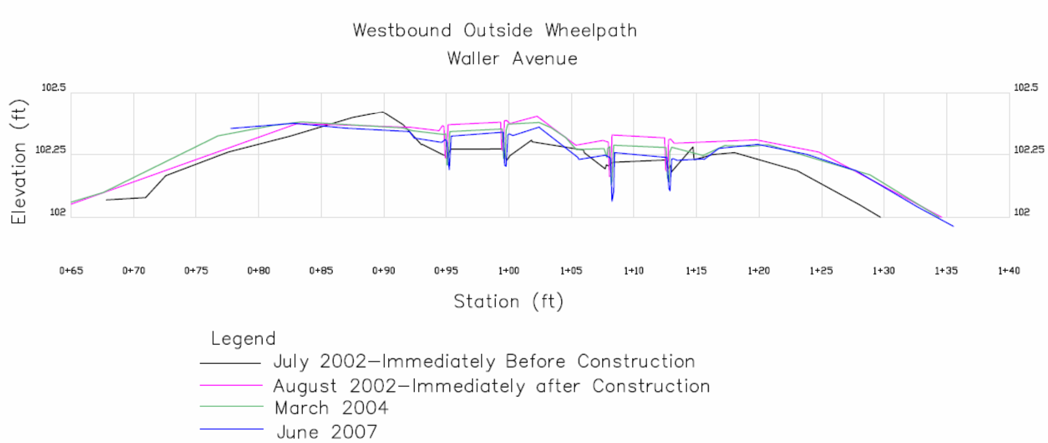
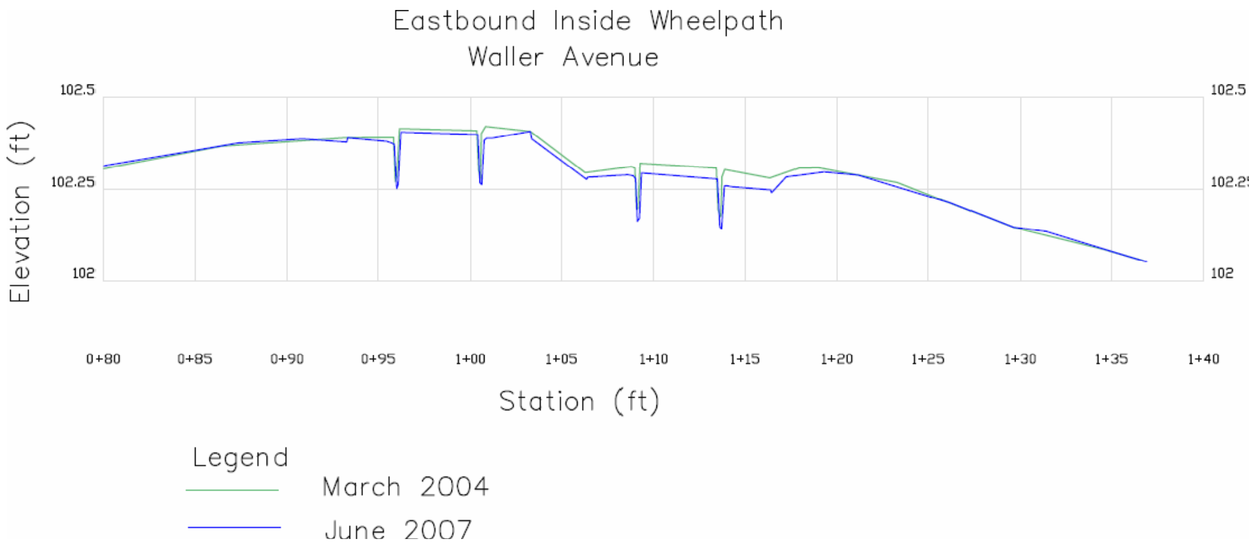


Figure B.5b



Eastbound Inside Wheelpath
Waller Avenue
Elevation (ft)
102.5
102.25
102
0+80
0+85
0+90
0+95
1+00
1+05
1+10
1+15
1+20
1+25
1+30
1+35
1+40
Station (ft)
Legend
March 2004
June 2007

Figure B.5c

Results for Rosemont Garden Lexington Longitudinal Profiles

Rosemont Garden, a heavily traveled highway rail crossing along the Norfolk Southern Railway (DOT 724 528 P), received an asphalt underlayment on July 23rd and 24th, 2002. As mentioned earlier, this was renewed during the same time period as Waller Avenue, a crossing in close proximity. Much like Waller Avenue this crossing was closed at 8:30 a.m. and reopened around 6:00 p.m. and the "fast track" methodology was implemented in order to impact rush hour traffic as little as possible. A devil strip provided a temporary surface for the traffic during the intervening night. KYDOT and the Lexington Fayette Urban County Government assisted in the same manner by providing public announcements, traffic control, asphalt and the crossing surface.

Similar to the profile of Waller Avenue, this crossing was surveyed prior to the crossing rehabilitation, which allows analysis regarding the changes of the track and approaches. The track and approach raise removed the crossing from a low point in the highway. Figures B.6a-B.6d in Appendix B illustrates the profiles. It should be noted that the first crossing survey was taken in 2001, one year prior to construction, therefore it can be predicted that prior to resurfacing the crossing surface experienced further settlement. One other observation from the July 2002 profile is that the approaches contain a large hump and seem rough and low relative to later readings. The survey of July 2002 was taken prior to smoothing out the approaches and the changes can be seen in the August 2002 profile taken after the new crossing was installed

When the crossing was first studied in 2002 only the outer wheelpaths were studied, however, later readings included all four wheelpaths. The data from 2002 through 2007 indicated that the rails in the east and west bound outer wheelpaths, settled 1.14 in., and 1.24 in. respectively. From 2004 through 2007, the rails settled as follows: eastbound outer and inner wheelpaths, 0.40 in. and 0.34 in., and westbound outer and inner wheelpaths, 0.50 in. and 0.53 in. From the data, it can be seen that the rail settlement in the eastbound and westbound lanes is comparable to one another, which is expected. Although both Waller Avenue and Rosemont Garden are in close proximity to one another, the latter is settling more than the former. The reason for this is unknown, although higher traffic volume or increased soil settlement has been suggested.

As mentioned with Waller Avenue, this section of double track receives surfacing approximately every four years. The lack of maintenance from the T&S program which was mentioned previously applies to this crossing as well. The current condition of the crossing is considered very smooth and there are no indications of surface deterioration. This result, particularly on such a highly traveled crossing, demonstrates that the underlayment is effective which is beneficial to both the railroad company and traveling public.

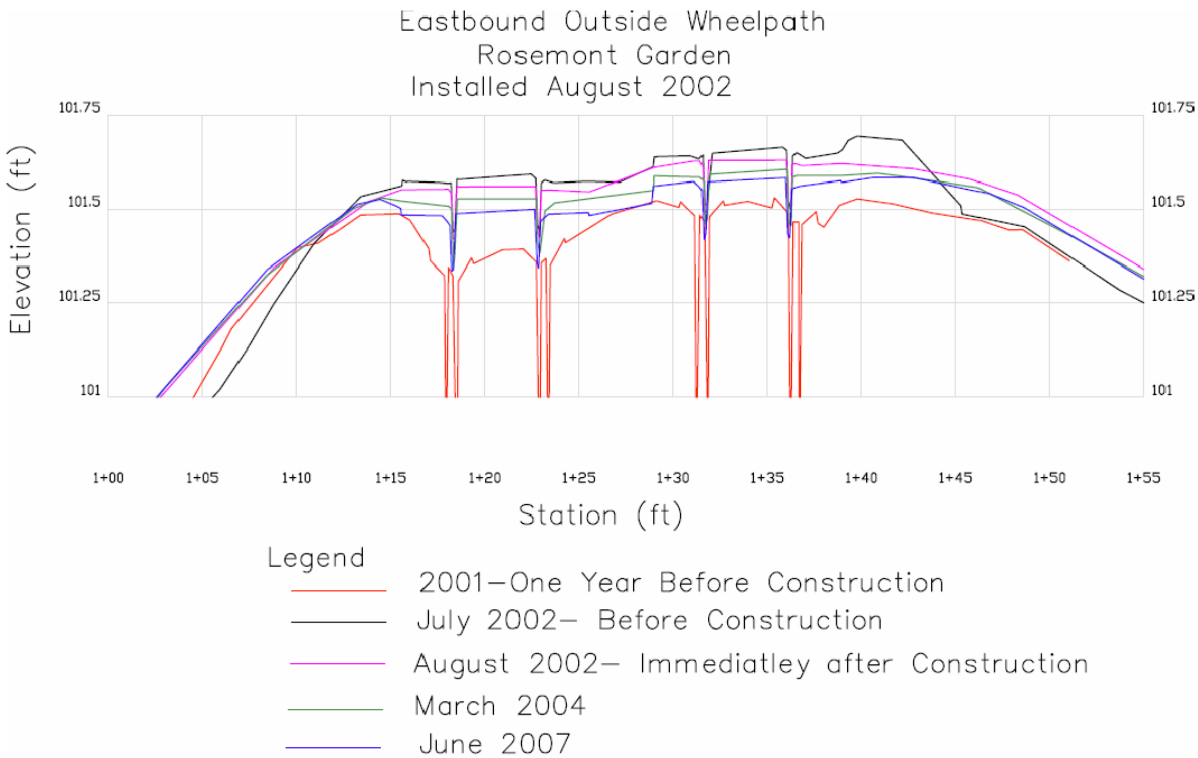


Figure B.6a

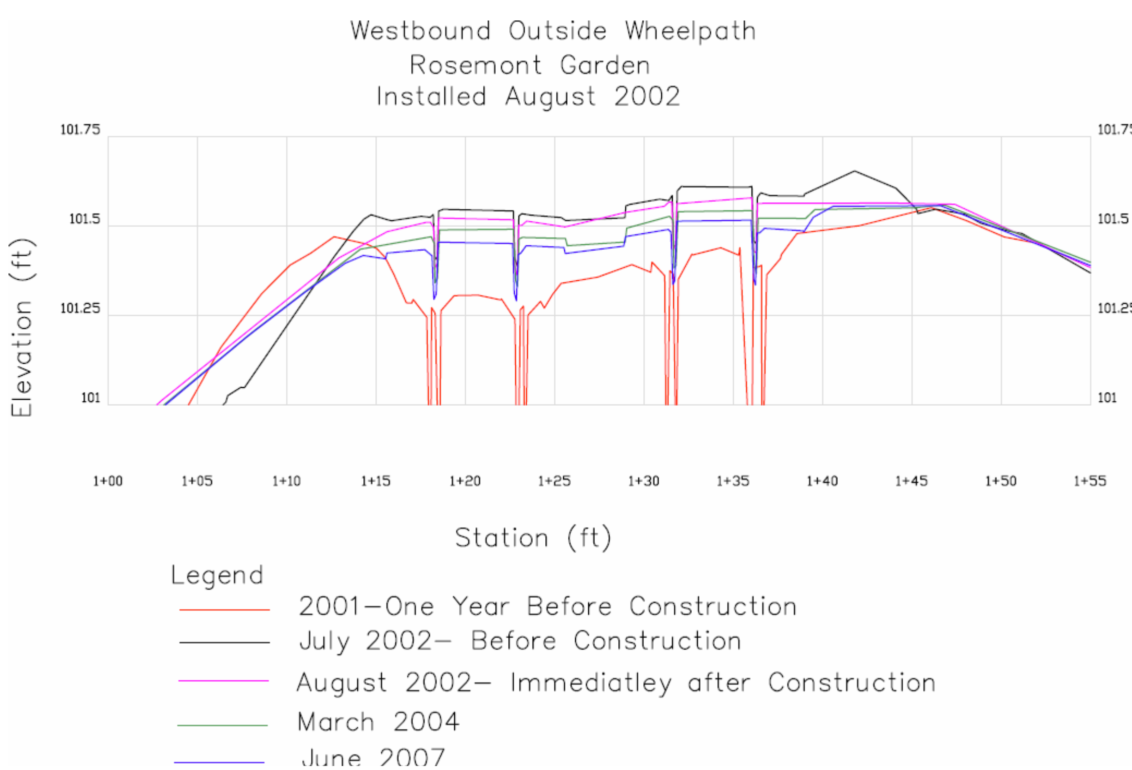


Figure B.6b

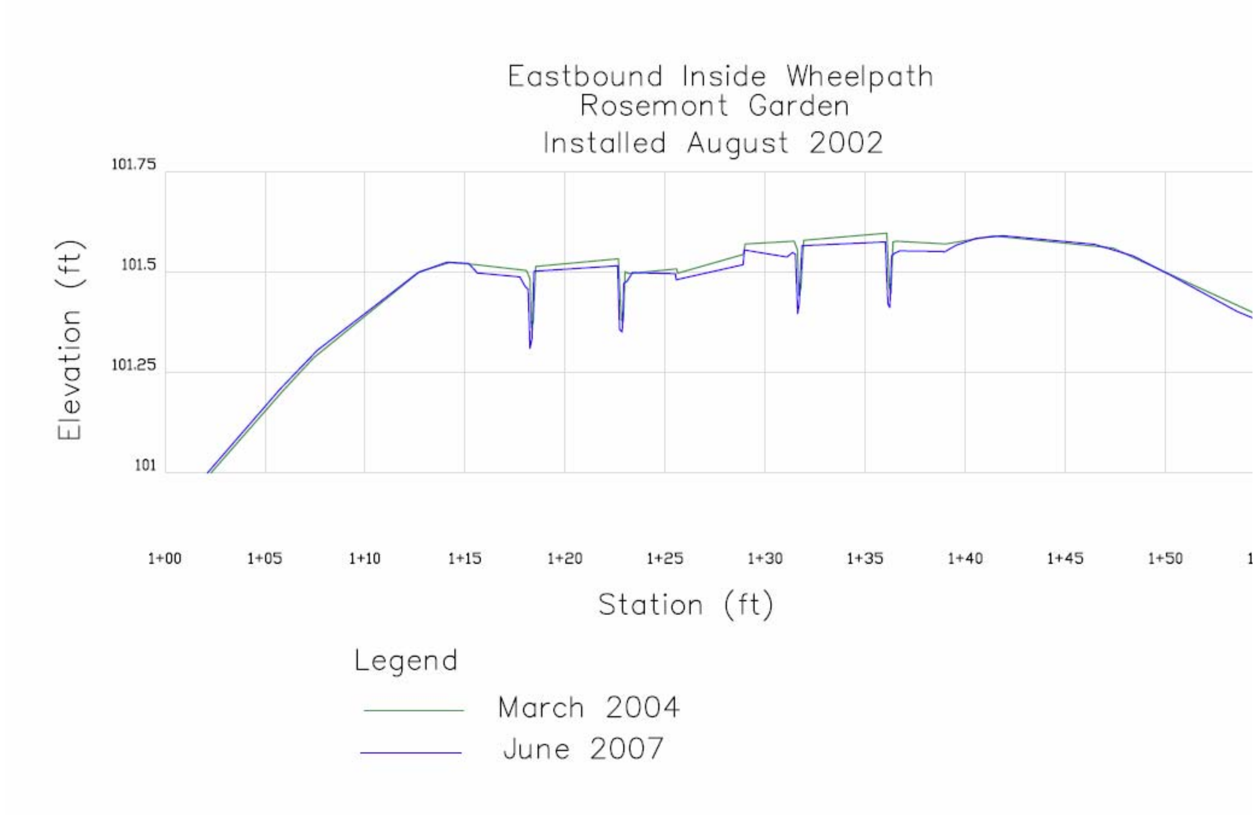


Figure B.6c

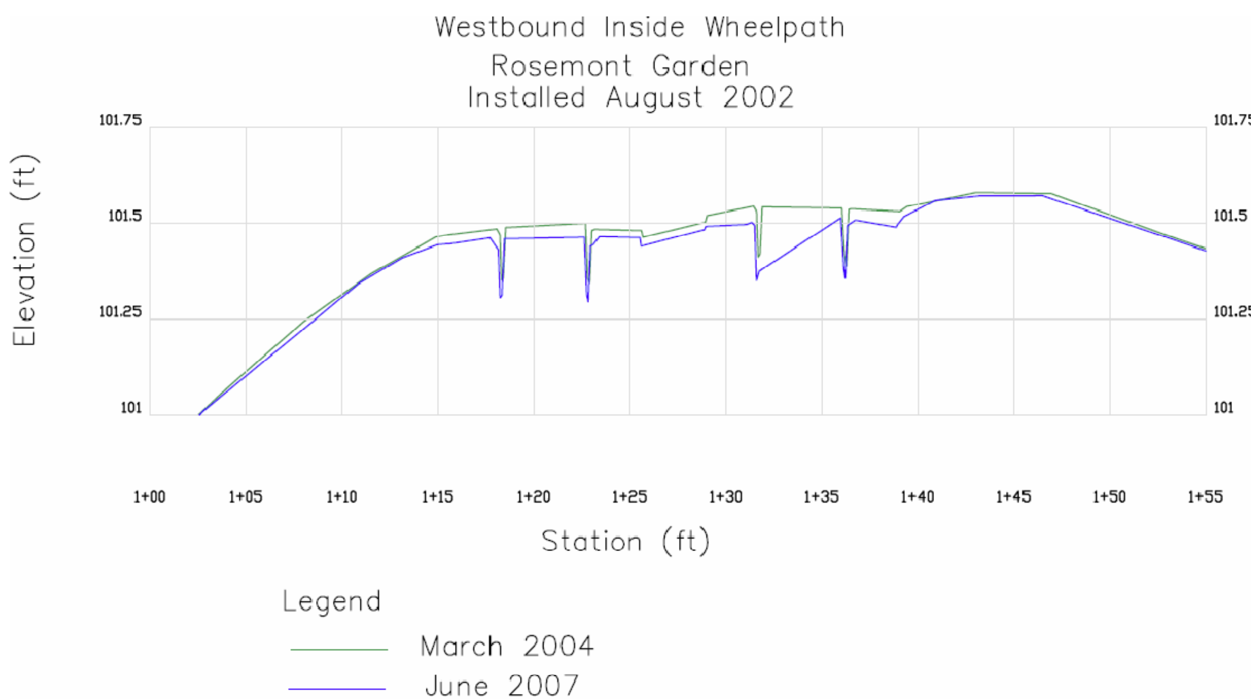


Figure B.6d

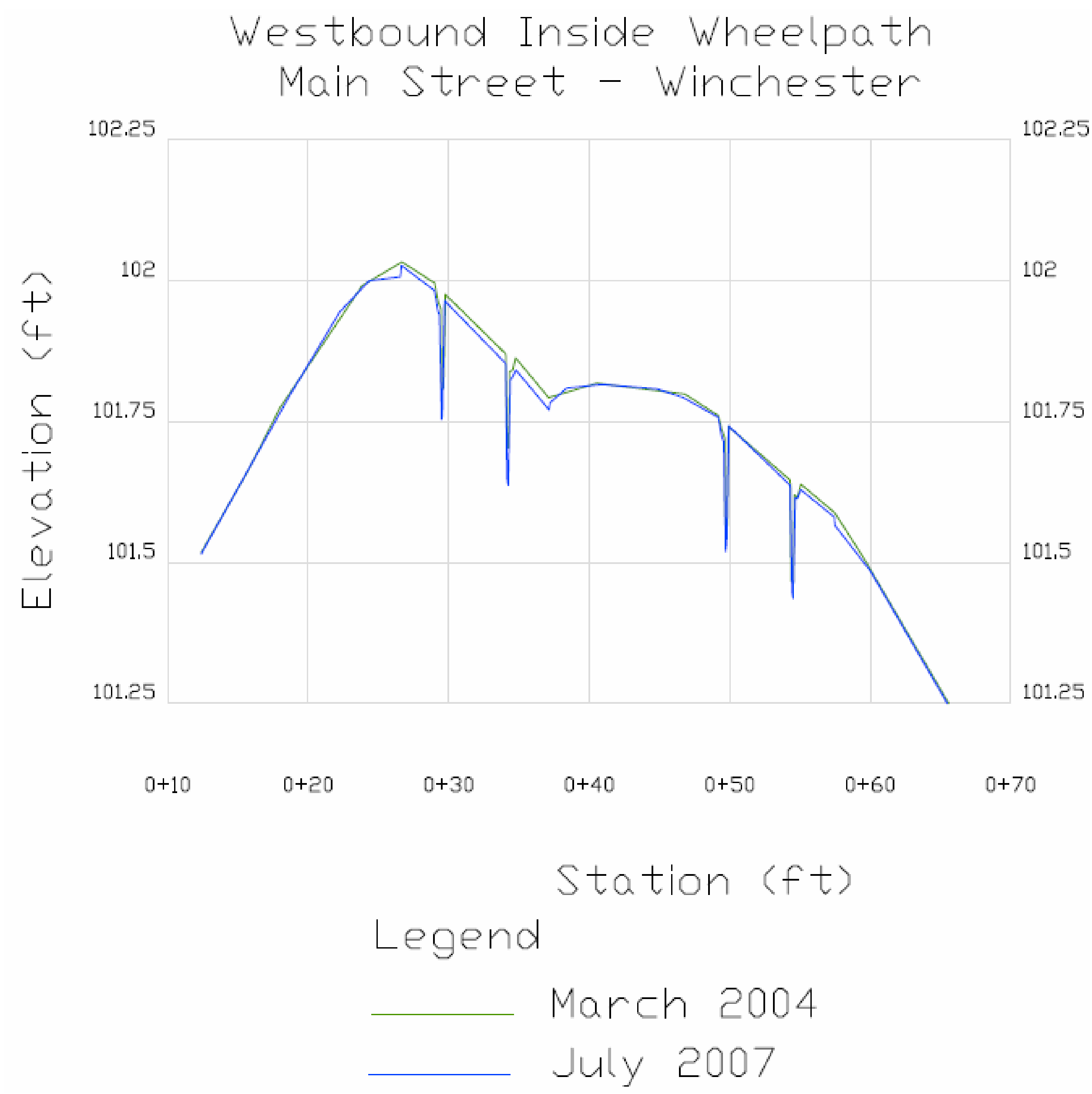
Results for Main Street Winchester Longitudinal Profiles

The underlayment for Main Street, Winchester (OKC 96.52), a double track crossing on CSXT was installed between November 17th and 20th, 2003. The fast track method was not used due to availability of convenient detours for highway traffic and an additional track, which allowed trains to operate on a parallel track during construction. During rehabilitation two 95 feet long track panels were removed and replaced, 80 feet KSA concrete crossings were installed and wood instead of rubber headers were used along the field side of the rail. KYDOT District 7 personnel provided traffic control, asphalt, paving and the concrete crossing surface.

Unlike the previously mentioned crossings, Winchester was not surveyed prior to rehabilitation so comparison to previous surface condition is not possible. Profiles of the crossings can be seen in Figures B.7a-B.7d. Also, it should be noted that the first longitudinal survey was not performed until four months after the underlayment was installed. This is significant because much of the consolidation that occurs in the track occurs soon after construction. The train consolidates the newly placed ballast and trackbed as it passes over the track. Therefore, it can be inferred that the results of the survey are not complete since a considerable amount of the settlement occurred prior to the study.

As can be seen from the track profiles, the rail and crossing material are settling with time. In Figure B.4c it can be seen that the rails in both the eastbound outside and inside wheelpaths settled 0.29 in. These similar results might be the result of having accurately located the vehicles wheelpath, which is a subjective assessment. The rails in the westbound outside and inside wheelpath settled 0.12 in. and 0.15 in. respectfully. The reason for the difference in the rail settlement between the two lanes is unknown.

During the T&S program of 2004, ties were changed on both tracks, but the crossing was skipped. Since the crossing renewal, the surface has remained smooth and its performance is perfect.



Westbound Inside Wheelpath
Main Street - Winchester
102.25
102
101.75
101.5
101.25
102.25
102
101.75
101.5
101.25
Elevation (ft)
0+10
0+20
0+30
0+40
0+50
0+60
0+70
Station (ft)
Legend
March 2004
July 2007

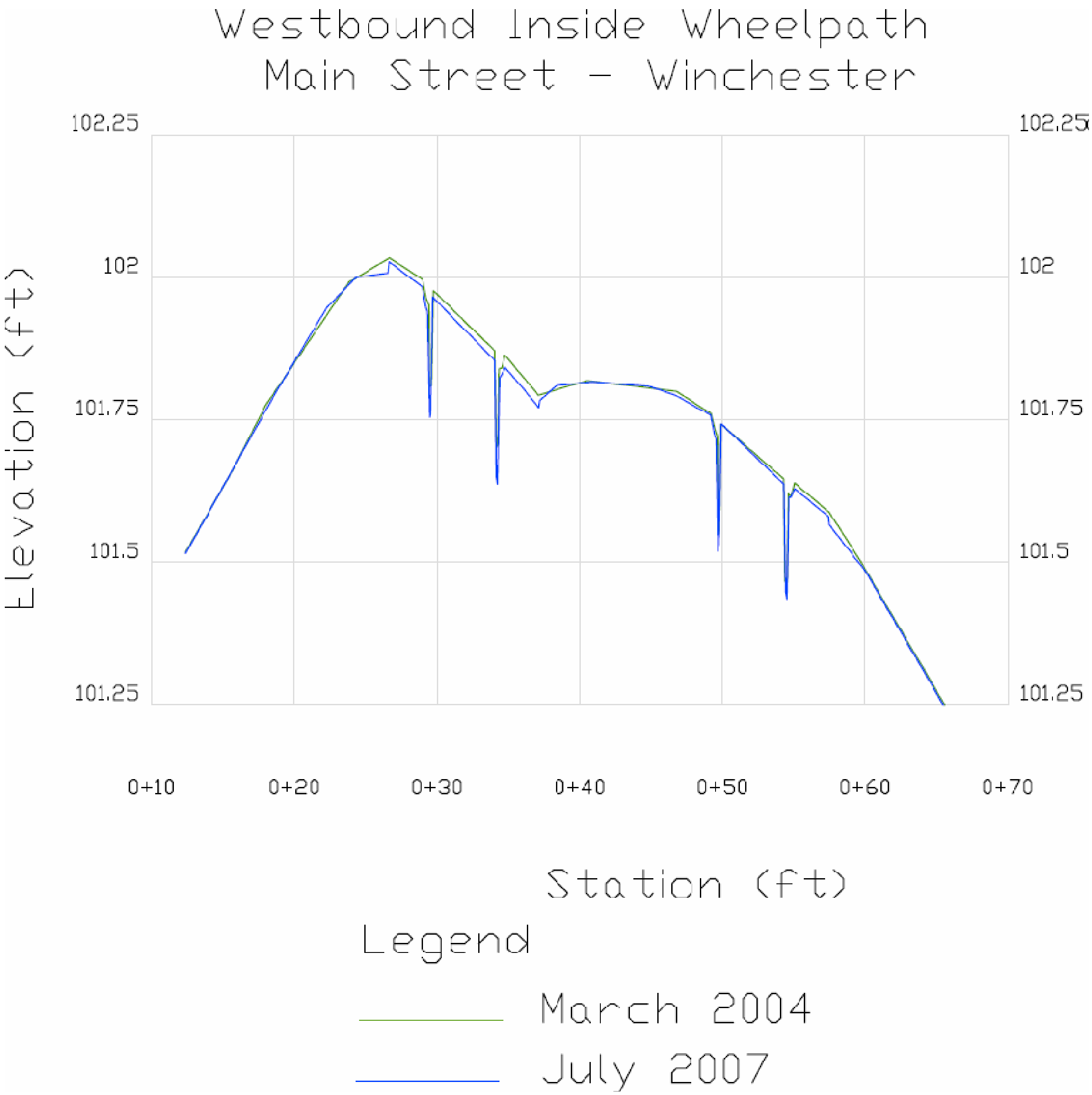
Figure B.7a


Eastbound Outside Wheelpath
Main Street - Winchester
Installed November 2003
102.25
102
101.75
101.5
101.25
102.25
102
101.75
101.5
101.25
Elevation (ft)
0+00
0+10
0+20
0+30
0+40
0+50
0+60
Station (ft)
Legend
March 2004
July 2007

Figure B.7b


Eastbound Inside Wheelpath
Main Street - Winchester
Installed November 2003
102.25
102
101.75
101.5
101.25
101
100.75
Elevation (ft)
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
Station (ft)
Legend
March 2004
July 2007

Figure B.7c



Westbound Inside Wheelpath
Main Street - Winchester
102.25
102
101.75
101.5
101.25
102.25
102
101.75
101.5
101.25
Elevation (ft)
0+10
0+20
0+30
0+40
0+50
0+60
0+70
Station (ft)
Legend
March 2004
July 2007

Figure B.7d

Results for Main Street, Richmond Longitudinal Profiles

This asphalt underlayment for the crossing on the CSXT line (OKC 118.77) was installed September 13, 2000. This heavily traveled crossing had an existing concrete tie panel which was removed due to a geometry defect. In place of the concrete panel a new wood tie panel, asphalt underlayment and KSA concrete surface was implemented. KYDOT District 7 personnel provided traffic control, paving, the concrete crossing surface and asphalt during the project. This project was the first "fast track" change out project and was available to train traffic in four hours and highway traffic in eleven hours. This crossing has been performing very well and has required no maintenance since installation.

Similar to the crossing at Main Street, Winchester, this crossing was not surveyed prior to installation so visual comparison of the changes cannot be identified. Additionally, there was a fifteen month lapse in between the installation of the underlayment and the first longitudinal profile measurement. As with Winchester, this is significant due to the amount of settlement which is predicted immediately after construction. Longitudinal profiles of the crossings can be seen in Figures B.8a-B.8d. Generally, when the longitudinal surveys began it was customary to only measure rail settlement in the outer wheelpaths. However, it soon became routine to gather data from all lanes if traffic volume allowed it. This crossing differs from the others in the sense that an inner wheelpath was among the first to be measured, the rationale behind this is unknown, however, that fact can be seen when noting the average rail settlement in Table B.2d.

The data in Table B.2d indicates that from 2001 through 2007, the rail in the northbound outside wheelpath has settled 1.12 in. and the southbound inside wheelpath settled 0.82 in. In a three year period between 2004 and 2007, the rails in the northbound outer and inner wheelpath settled 0.75 in. and 0.52 in. respectfully. In the same period of time, the rails in the southbound inner and outer wheelpath settled 0.42 in. and 0.52 in. respectfully. It is expected that the northbound outside wheelpath and the southbound inside wheelpath having been studied longer would have settled more.

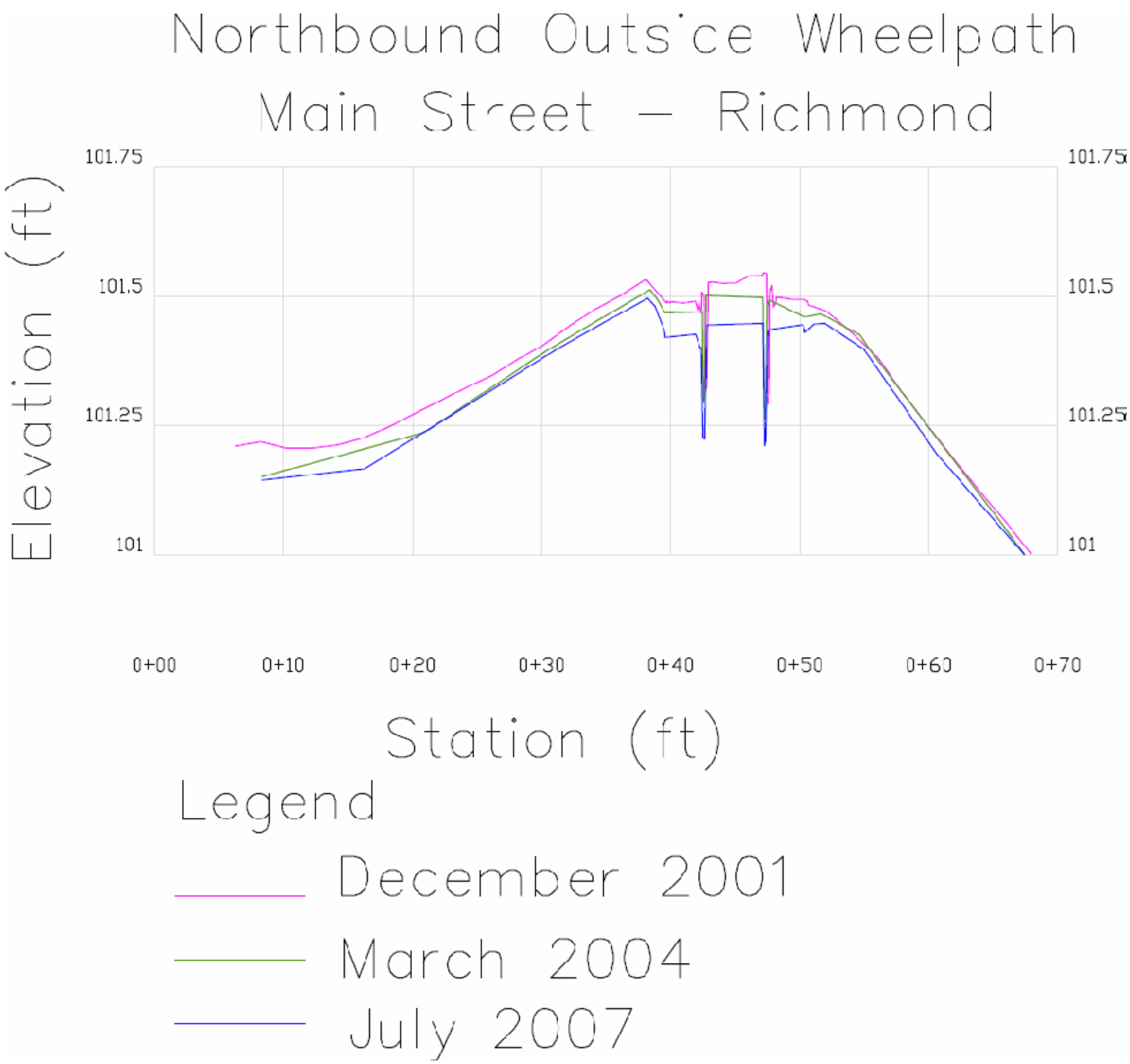
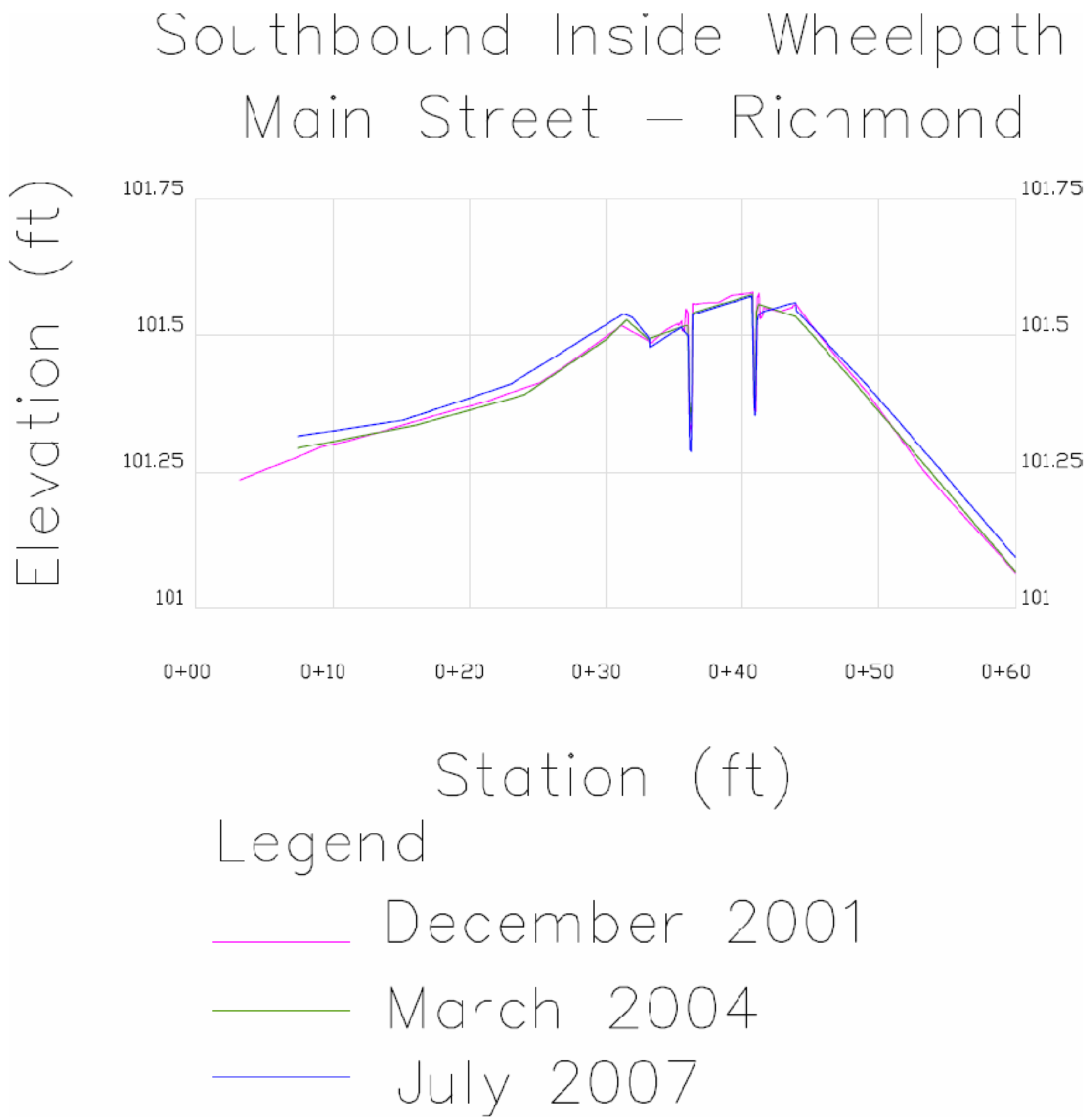

Northbound Outs'ce Wheelpath
Main Str'eet – Richmond
Elevation (ft)
101.75
101.5
101.25
101
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
Station (ft)
Legend
December 2001
March 2004
July 2007

Figure B.8a



Southbound Inside Wheelpath
Main Street — Richmond
Elevation (ft)
101.75
101.5
101.25
101
0+00
0+10
0+20
0+30
0+40
0+50
0+60
Station (ft)
Legend
December 2001
March 2004
July 2007

Figure B.8b

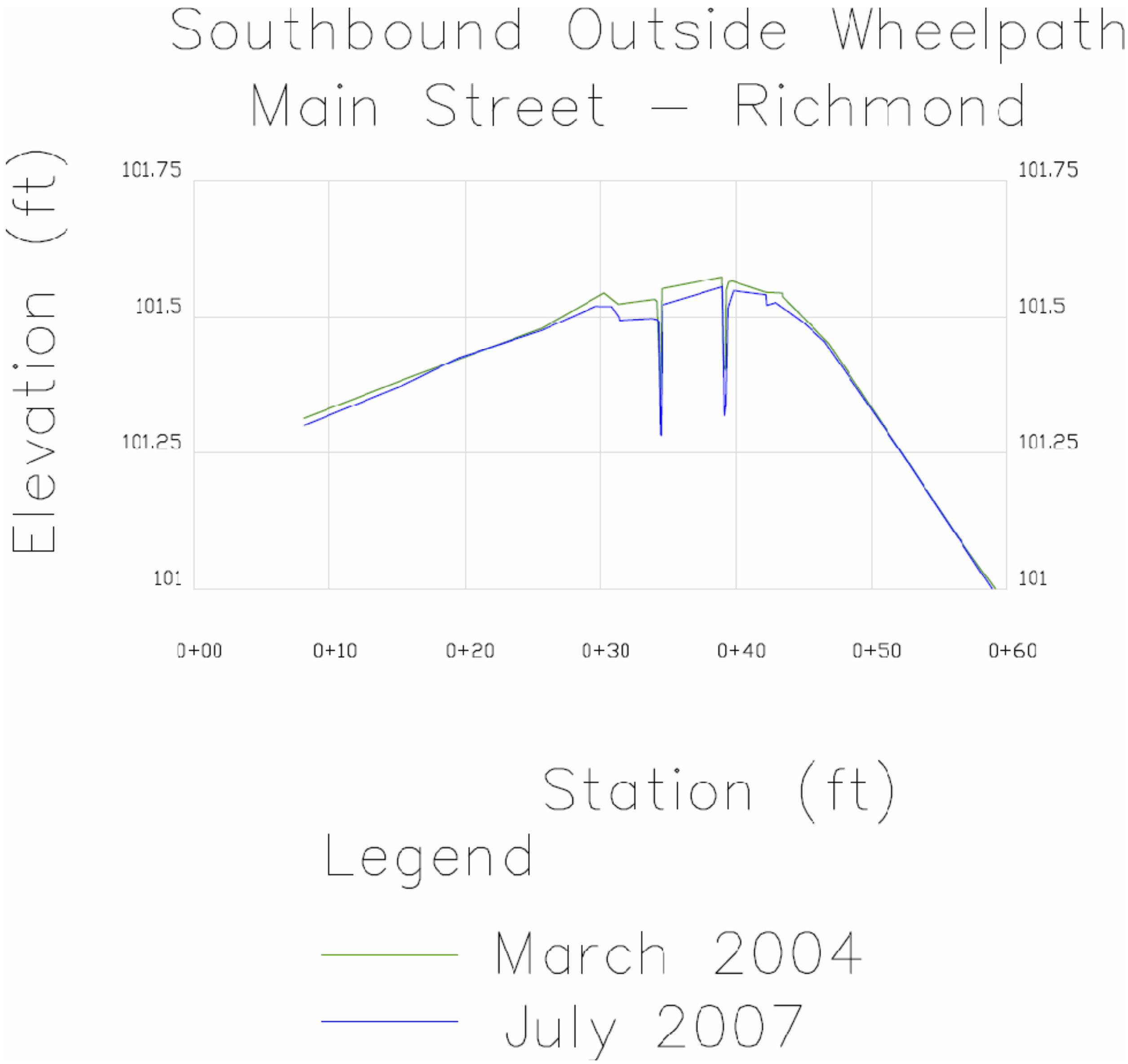

Southbound Outside Wheelpath
Main Street – Richmond
Elevation (ft)
101.75
101.5
101.25
101
0+00
0+10
0+20
0+30
0+40
0+50
0+60
Station (ft)
Legend
March 2004
July 2007

Figure B.8c

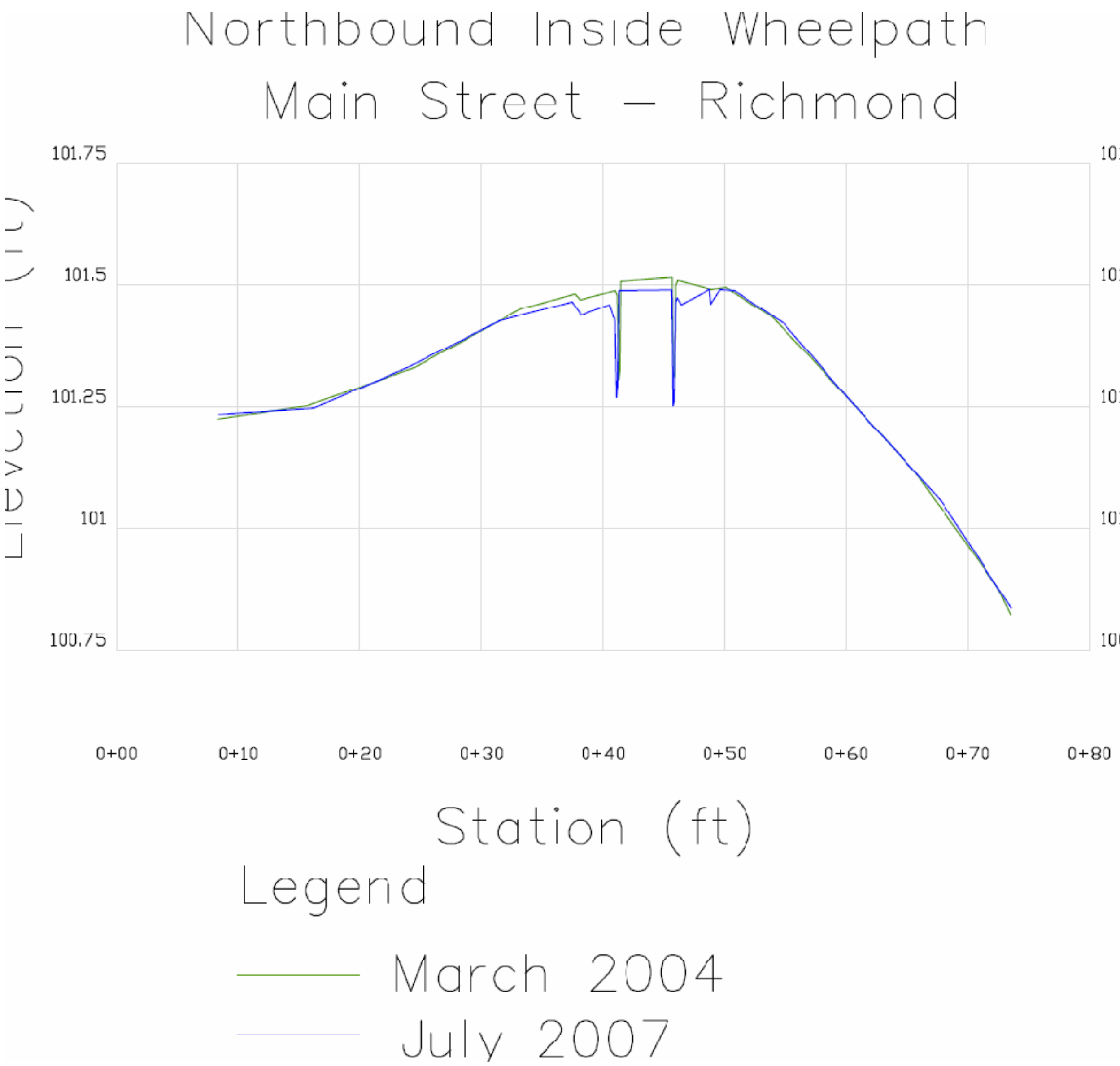

Northbound Inside Wheelpath
Main Street – Richmond
101.75
101.5
101.25
101
100.75
Elevation (ft)
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
0+80
Station (ft)
Legend
March 2004
July 2007

Figure B.8d

Appendix C

Detailed Results of t-test for Top-of-Rail Settlement Measurements

(All measurements reported in inches – 1.0 in. = 25.4 mm)

Average Settlement of crossing area for crossings without an underlayment vs. average settlement of crossing area for crossings with an underlayment

Crossing Area Without Underlayment	Crossing Area With Underlayment
1.25	0.31
1.49	0.56
1.28	0.20
1.13	1.04
	0.81
	0.96
	0.37
	0.20
	0.25
	0.45
	0.68
	0.90
	1.17
	0.59
	0.31
	0.31

avg.(approach) = 1.29 — avg. (crossing) = 0.57

n_1= 4 — n_2= 16

s_1^2= 0.02 — s_2^2= 0.10

Null Hypothesis: $H_0: \mu_1 = \mu_2$

Alternate Hypothesis: $H_A: \mu_1 \neq \mu_2$

Test Statistic: avg. (approach) - avg. (crossing) = 1.29 - 0.57 = 0.72

p -value: Sampling distribution of avg. (approach) - avg. (crossing) if $\mu_1 = \mu_2 = 0$

$$\sigma^2 = \frac{0.02\,(4\text{-}1) + 0.10\,(16\text{-}1)}{(14\text{-}1) + (16\text{-}1)} = 0.090$$

est. s.d = $(\sigma^2/n_1 + \sigma^2/n_2)^{1/2}$ = 0.167

t- statistic = $\frac{0.72}{0.167}$ = 4.29

In t-table with (4-1)+(16-1) = 18 degrees of freedom (dof) $p < 0.001$

Conclusion: Reject H_o and conclude that $u_1 > u_2$

Notes:

1. μ_1 & μ_2 represent the population mean, and avg. (approach and crossing) represent the sample mean
2. σ^2 represents pooled variance estimate
3. est. s.d represents estimated standard deviation

95% Confidence Interval for average settlement of crossing area for crossings without an underlayment vs. average settlement of crossing area for crossings with an underlayment

Point Estimate: avg. (approach) - avg. (crossing) = 1.29-0.57 = 0.72

L= $(t_{18})(\sigma/n^{1/2})$ Refer to t-table with 18 dof
L= (2.101)(0.167)
L= 0.346
L= 0.72 ± 0.346

95% Confidence Interval: (0.374, 1.066)

We are 95% confident that the difference between the two population means is between (0.374, 1.066) where μ_1= mean crossing settlement for crossings which did not receive an underlayment and μ_2 = mean crossings settlement for crossings which received an underlayment.

Cincinnati Subdivision: Average Settlement of crossing area for crossings without an underlayment vs. average settlement of crossing area for crossings with an underlayment

Crossing Area Without Underlayment	Crossing Area With Underlayment
1.25	0.31
1.49	0.56
1.28	0.20
1.13	1.04

avg.(approach) = 1.29 avg. (crossing) = 0.53

$n_1 = 4$ $n_2 = 4$

$s_1^2 = 0.02$ $s_2^2 = 0.14$

Null Hypothesis: $H_0: \mu_1 = \mu_2$

Alternate Hypothesis: $H_A: \mu_1 \neq \mu_2$

Test Statistic: avg. (approach) - avg. (crossing) = 1.29 - 0.53 = 0.76

p -value: Sampling distribution of avg. (approach) - avg. (crossing) if $\mu_1 = \mu_2 = 0$

$$\sigma^2 = \frac{0.02\,(4-1) + 0.14(4-1)}{(4-1) + (4-1)} = 0.081$$

$$\text{est. s.d} = (\sigma^2/n_1 + \sigma^2/n_2)^{1/2} = 0.201$$

$$\text{t- statistic} = \frac{0.76}{0.201} = 3.78$$

In t-table with (4-1)+(4-1) = 6 degrees of freedom (dof) $p < 0.05$

Conclusion: Reject H_o and conclude that $u_1 > u_2$

Notes:

1. μ_1 & μ_2 represent the population mean, and avg. (approach and crossing) represent the sample mean
2. σ^2 represents pooled variance estimate
3. est. s.d represents estimated standard deviation

Cincinnati Subdivsion: 95% Confidence Interval for average settlement of crossing area of crossings with an underlayment vs. average crossing settlement of crossings without an underlayment.

Point Estimate: avg. (approach) - avg. (crossing) = 1.29-0.53 = 0.76

$L = (t_6)(\sigma/n^{1/2})$ Refer to t-table with 6 dof

$L = (2.447)(0.201)$

$L = 0.492$

$L = 0.76 \pm 0.492$

95% Confidence Interval: (0.268, 1.252)

We are 95% confident that the difference between the two population means is between (0.268, 1.252) where μ_1= mean crossing settlement for crossings in the Cincinnati Subdivision which did not receive an underlayment and μ_2 = mean crossing settlement for crossings in the Cincinnati Subdivision which received an underlayment.

Average Settlement of approaches for crossings with an underlayment vs. average settlement of crossing area for crossings with an underlayment

Approaches With Underlayment	Crossing Area With Underlayment
1.28	0.31
1.65	0.56
1.23	0.20
1.96	1.04
1.30	0.81
1.52	0.96
1.17	0.37
1.16	0.20
0.76	0.25
0.93	0.45
1.16	0.68
1.71	0.90
2.10	1.17
1.35	0.59
	0.31
	0.31

avg.(approach) = 1.38 avg. (crossing) = 0.57

n_1= 14 n_2= 16

s_1^2= 0.14 s_2^2= 0.10

Null Hypothesis: H_0: $\mu_1 = \mu_2$

Alternate Hypothesis: H_A: $\mu_1 \neq \mu_2$

Test Statistic: avg. (approach) - avg. (crossing) = 1.38 - 0.57 = 0.81

p -value: Sampling distribution of avg. (approach) - avg. (crossing) if $\mu_1 = \mu_2 = 0$

$$\sigma^2 = \frac{0.14\,(14-1) + 0.10\,(16-1)}{(14-1) + (16-1)} = 0.119$$

est. s.d = $(\sigma^2/n_1 + \sigma^2/n_2)^{1/2}$ = 0.126

t- statistic = $\frac{0.81}{0.126}$ = 6.427

In t-table with (14-1)+(16-1) = 28 degrees of freedom (dof) $p < 0.001$

Conclusion: Reject H_o and conclude that $u_1 > u_2$

Notes:

1. μ_1 & μ_2 represent the population mean, and avg. (approach and crossing) represent the sample mean
2. σ^2 represents pooled variance estimate
3. est. s.d represents estimated standard deviation

C.2a

95% Confidence Interval for average settlement of approaches for crossings with an underlayment vs. average settlement of crossing area for crossings with an underlayment

Point Estimate: avg. (approach) - avg. (crossing) = 1.38 - 0.57 = 0.81

$L = (t_{28})(\sigma/n^{1/2})$ Refer to t-table with 28 dof

$L = (2.048)(0.119)$

$L = 0.243$

$L = 0.81 \pm 0.243$

95% Confidence Interval: (0.567, 1.053)

We are 95% confident that the difference between the two population means is between (0.567, 1.053) where μ_1 = mean approach settlement for crossings which received an underlayment and μ_2 = mean crossing settlement for crossings which received an underlayment.

Cincinnati Subdivision: Average Settlement of approaches for crossings with an underlayment vs. average settlement of crossing area for crossings with an underlayment

Approaches With Underlayment	Crossing Area With Underlayment
1.28	0.31
1.65	0.56
1.23	0.20
1.96	1.04

avg.(approach) = 1.53 avg. (crossing) = 0.53

$n_1 = 4$ $n_2 = 4$

$s_1^2 = 0.12$ $s_2^2 = 0.14$

Null Hypothesis: $H_0: \mu_1 = \mu_2$

Alternate Hypothesis: $H_A: \mu_1 \neq \mu_2$

Test Statistic: avg. (approach) - avg. (crossing) = 1.53 - 0.53 = 1.00

p -value: Sampling distribution of avg. (approach) - avg. (crossing) if $\mu_1 = \mu_2 = 0$

$$\sigma^2 = \frac{0.12\,(4-1) + 0.14(4-1)}{(4-1) + (4-1)} = 0.128$$

est. s.d = $(\sigma^2/n_1 + \sigma^2/n_2)^{1/2} =$ 0.253

t- statistic = $\frac{1.00}{0.253} = 3.96$

In t-table with (4-1)+(4-1) = 6 degrees of freedom (dof) $p < 0.05$

Conclusion: Reject H_o and conclude that $u_1 > u_2$

Notes:

1. μ_1 & μ_2 represent the population mean, and avg. (approach and crossing) represent the sample mean
2. σ^2 represents pooled variance estimate
3. est. s.d represents estimated standard deviation

C.2b

Cincinnati Subdivsion: 95% Confidence Interval for average settlement of crossing area of crossings with an underlayment vs. average settlement of approaches for crossings with an underlayment

Point Estimate: avg. (approach) - avg. (crossing) = 1.53-0.53 = 1.00

$L= (t_6)(\sigma/n^{1/2})$ Refer to t-table with 6 dof

$L= (2.447)(0.253)$

$L= 0.619$

$L= 1.00\pm 0.619$

95% Confidence Interval: (0.381, 1.619)

We are 95% confident that the difference between the two population means is between (0.381, 1.619) where μ_1= mean approach settlement for crossings in the Cincinnati Subdivision which did receive an underlayment and μ_2 = mean crossings settlement for crossings in the Cincinnati Subdivision which received an underlayment.

C.2b

Average Settlement of approaches for crossings without an underlayment vs. average settlement of approaches for crossings with underlayment

Approaches Without Underlayment	Approaches With Underlayment
1.65	1.28
1.46	1.65
1.50	1.23
1.40	1.96
	1.30
	1.52
	1.17
	1.16
	0.76
	0.93
	1.16
	1.71
	2.10
	1.35

avg.(approach) = 1.50 — avg. (crossing) = 1.38

$n_1 = 4$ — $n_2 = 14$

$s_1^2 = 0.01$ — $s_2^2 = 0.14$

Null Hypothesis: H_0: $\mu_1 = \mu_2$

Alternate Hypothesis: H_A: $\mu_1 \neq \mu_2$

Test Statistic: avg. (approach) - avg. (crossing) = 1.50 - 1.38 = 0.12

p -value: Sampling distribution of avg. (approach) - avg. (crossing) if $\mu_1 = \mu_2 = 0$

$$\sigma^2 = \frac{0.01\,(4\text{-}1) + 0.14\,(14\text{-}1)}{(4\text{-}1) + (14\text{-}1)} = 0.116$$

$$\text{est. s.d} = (\sigma^2/n_1 + \sigma^2/n_2)^{1/2} = 0.193$$

$$\text{t- statistic} = \frac{0.116}{0.193} = 0.62$$

In t-table with (4-1)+(14-1) = 16 degrees of freedom (dof) $p > 0.05$

Conclusion: Fail to Reject H_o

Notes:

1. μ_1 & μ_2 represent the population mean, and avg. (approach and crossing) represent the sample mean
2. σ^2 represents pooled variance estimate
3. est. s.d represents estimated standard deviation

C.3a

Cincinnati Subdivision: Average Settlement of approaches for crossings without an underlayment vs. average settlement of approaches for crossings with underlayment

Approaches Without Underlayment	Approaches With Underlayment
1.65	1.28
1.46	1.65
1.50	1.23
1.40	1.96

avg.(approach) = 1.50   avg. (crossing) = 1.53

$n_1 = 4$ $n_2 = 4$

$s_1^2 = 0.01$ $s_2^2 = 0.12$

Null Hypothesis: $H_0: \mu_1 = \mu_2$

Alternate Hypothesis: $H_A: \mu_1 \neq \mu_2$

Test Statistic: avg. (approach) - avg. (crossing) = 1.50 - 1.53 = -0.03

p -value: Sampling distribution of avg. (approach) - avg. (crossing) if $\mu_1 = \mu_2 = 0$

$$\sigma^2 = \frac{0.01\,(4-1) + 0.12\,(4-1)}{(4-1) + (4-1)} = 0.064$$

est. s.d = $(\sigma^2/n_1 + \sigma^2/n_2)^{1/2} =$ 0.179

t- statistic = $\frac{0.03}{0.179} =$ 0.15

In t-table with (4-1)+(4-1) = 6 degrees of freedom (dof) $p > 0.05$

Conclusion: Fail to Reject H_o

Notes:

1. μ_1 & μ_2 represent the population mean, and avg. (approach and crossing) represent the sample mean
2. σ^2 represents pooled variance estimate
3. est. s.d represents estimated standard deviation

C.3b

Cincinnati Subdivision: Average Settlement of approaches for crossings without an underlayment vs. average settlement of crossing area for crossings without underlayment

Approaches Without Underlayment	Crossing Area Without Underlayment
1.65	1.25
1.46	1.49
1.50	1.28
1.40	1.13

avg.(approach) = 1.50 avg. (crossing) = 1.29

$n_1 = 4$ $n_2 = 4$

$s_1^2 = 0.01$ $s_2^2 = 0.02$

Null Hypothesis: H_0: $\mu_1 = \mu_2$

Alternate Hypothesis: H_A: $\mu_1 \neq \mu_2$

Test Statistic: avg. (approach) - avg. (crossing) = 1.50 - 1.29 = 0.21

p -value: Sampling distribution of avg. (approach) - avg. (crossing) if $\mu_1 = \mu_2 = 0$

$$\sigma^2 = \frac{0.01\,(4-1) + 0.02\,(4-1)}{(4-1) + (4-1)} = 0.017$$

$$\text{est. s.d} = (\sigma^2/n_1 + \sigma^2/n_2)^{1/2} = 0.092$$

$$\text{t- statistic} = \frac{0.21}{0.092} = 2.29$$

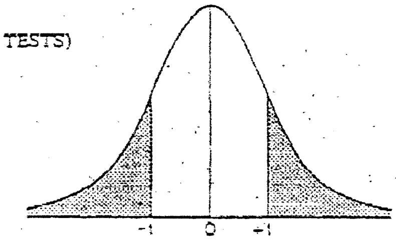
In t-table with (4-1)+(4-1) = 6 degrees of freedom (dof) $p > 0.05$

Conclusion: Fail to Reject H_o

Notes:

1. μ_1 & μ_2 represent the population mean, and avg. (approach and crossing) represent the sample mean
2. σ^2 represents pooled variance estimate
3. est. s.d represents estimated standard deviation

TABLE A 4
DISTRIBUTION OF t (TWO-TAILED TESTS)



Degrees of Freedom	Probability of a Larger Value, Sign Ignored								
	0.500	0.400	0.200	0.100	0.050	0.025	0.010	0.005	0.001
1	1.000	1.376	3.078	6.314	12.706	25.452	63.657		
2	0.816	1.061	1.886	2.920	4.303	6.205	9.925	14.089	31.598
3	.765	0.978	1.638	2.353	3.182	4.176	5.841	7.453	12.941
4	.741	.941	1.533	2.132	2.776	3.495	4.604	5.598	8.610
5	.727	.920	1.476	2.015	2.571	3.163	4.032	4.773	6.859
6	.718	.906	1.440	1.943	2.447	2.969	3.707	4.317	5.959
7	.711	.896	1.415	1.895	2.365	2.841	3.499	4.029	5.405
8	.706	.889	1.397	1.860	2.306	2.752	3.355	3.832	5.041
9	.703	.883	1.383	1.833	2.262	2.685	3.250	3.690	4.781
10	.700	.879	1.372	1.812	2.228	2.634	3.169	3.581	4.587
11	.697	.876	1.363	1.796	2.201	2.593	3.106	3.497	4.437
12	.695	.873	1.356	1.782	2.179	2.560	3.055	3.428	4.318
13	.694	.870	1.350	1.771	2.160	2.533	3.012	3.372	4.221
14	.692	.868	1.345	1.761	2.145	2.510	2.977	3.326	4.140
15	.691	.866	1.341	1.753	2.131	2.490	2.947	3.286	4.073
16	.690	.865	1.337	1.746	2.120	2.473	2.921	3.252	4.015
17	.689	.863	1.333	1.740	2.110	2.458	2.898	3.222	3.965
18	.688	.862	1.330	1.734	2.101	2.445	2.878	3.197	3.922
19	.688	.861	1.328	1.729	2.093	2.433	2.861	3.174	3.883
20	.687	.860	1.325	1.725	2.086	2.423	2.845	3.153	3.850
21	.686	.859	1.323	1.721	2.080	2.414	2.831	3.135	3.819
22	.686	.858	1.321	1.717	2.074	2.406	2.819	3.119	3.792
23	.685	.858	1.319	1.714	2.069	2.398	2.807	3.104	3.767
24	.685	.857	1.318	1.711	2.064	2.391	2.797	3.090	3.745
25	.684	.856	1.316	1.708	2.060	2.385	2.787	3.078	3.725
26	.684	.856	1.315	1.706	2.056	2.379	2.779	3.067	3.707
27	.684	.855	1.314	1.703	2.052	2.373	2.771	3.056	3.690
28	.683	.855	1.313	1.701	2.048	2.368	2.763	3.047	3.674
29	.683	.854	1.311	1.699	2.045	2.364	2.756	3.038	3.659
30	.683	.854	1.310	1.697	2.042	2.360	2.750	3.030	3.646
35	.682	.852	1.306	1.690	2.030	2.342	2.724	2.996	3.591
40	.681	.851	1.303	1.684	2.021	2.329	2.704	2.971	3.551
45	.680	.850	1.301	1.680	2.014	2.319	2.690	2.952	3.520
50	.680	.849	1.299	1.676	2.008	2.310	2.678	2.937	3.496
55	.679	.849	1.297	1.673	2.004	2.304	2.669	2.925	3.476
60	.679	.848	1.296	1.671	2.000	2.299	2.660	2.915	3.460
70	.678	.847	1.294	1.667	1.994	2.290	2.648	2.899	3.435
80	.678	.847	1.293	1.665	1.989	2.284	2.638	2.887	3.416
90	.678	.846	1.291	1.662	1.986	2.279	2.631	2.878	3.402
100	.677	.846	1.290	1.661	1.982	2.276	2.625	2.871	3.390
120	.677	.845	1.289	1.658	1.980	2.270	2.617	2.860	3.373
∞	.6745	.8416	1.2816	1.6448	1.9600	2.2414	2.5758	2.8070	3.2905

C.5

Appendix D

Detailed Findings and Conclusions

DETAILED FINDINGS AND CONCLUSIONS

Rapid deterioration of rough highway/railway at-grade crossings results in routine maintenance ultimately becoming a financial burden to highway agency/railroad company and a nuisance to the traveling public. A possible solution to this ongoing problem is the implementation of an asphalt underlayment as the subballast layer. The enhanced structural support and waterproofing layer reduce long term crossing settlement. From Top-of-Rail Settlement and Longitudinal Profile Measurements it has been shown that the installation of the asphalt underlayment reduces total amount of the settlement that would otherwise reduce ride quality.

Several findings are apparent based on Top-of-Rail Settlement Measurements. These relate to comparing average settlements 1). Within the crossing areas to those on the track approaches, 2). Within the crossing areas, and 3). On the approaches. The following four comparisons relate to the 16 asphalt underlayment crossings and the 4 all-granular crossings.

- For the 16 crossings underlain with asphalt, the average settlements in crossing areas was 0.57 in., or 44% of the average 1.29 in. settlements for the 4 all-granular crossings. Thus the all-granular crossings settled 126% more than the asphalt underlayment crossings.

- For the approaches to the 16 crossings underlain with asphalt, the average approach settlements were 1.38 in., or 92% of the average 1.50 in. approach settlements for the all-granular crossing approaches. Thus the all-granular approaches settled 9% more than the asphalt underlayment approaches.

- For the 16 crossings containing asphalt underlayments, the average settlements in the crossing areas was 0.57 in., or 41% of the average 1.38 in. settlements on the abutting all-granular track approaches. Thus, the approaches settled 142% more than the crossings.

- For the 4 all-granular (without asphalt underlayments) crossings, the crossing areas settled 1.29 in., or 86% of the average 1.50 in. settlements on the abutting all-granular track approaches. Thus the approaches settled 16% more than the crossings.

Isolating the 4 asphalt underlayment and 4 all-granular crossings on the Cincinnati Subdivision reveals the following relationships for rail traffic on the same division. Note that the 4 asphalt underlayment crossings have more highway traffic and have been in service longer than the all-granular crossings.

- The average settlements for crossing areas underlain with asphalt was 41% of the average settlements for the crossing area consisting of all-granular materials. This value compares to 44% when all 16 asphalt underlayment crossings are used for comparison, as discussed previously.

- The track approaches to the two types of crossing supports varied by only 2%. This was expected since there is no difference in the composition of the approaches. This compares to variations of 8% when all 16 asphalt underlayment crossings are used for comparisons, as discussed previously.

- The average settlements for the crossing areas underlain with asphalt was 35% of the average settlements for the abutting track approaches. This compares to variations of 41% when all 16 asphalt underlayment crossings are used for comparisons, as discussed previously.

This illustrates the effectiveness of implementing an underlayment as additional support beneath the crossings surface. The approaches which are subjected to the loadings of train traffic have settled many times more than the crossing, which is subjected to both train and highway traffic. Furthermore, most of the crossings that did receive an underlayment are subject to heavy highway and a high percentage of truck traffic, the four crossings which did not install an underlayment receive little traffic. Despite this fact, the four Cincinnati Subdivision crossings which did not receive an underlayment and receive low amounts of traffic are showing substantial signs of deterioration. Conversely, the four crossings which did receive an underlayment are performing well and maintain a smooth crossing surface.

In addition to comparing the settlement of crossing utilizing an underlayment and those with an all-granular trackbed, one other distinction can be made between the crossings which were studied with the Top-of-Rail Settlement Measurements. Several different crossing materials were analyzed for experimental comparisons. The four crossings on the Cincinnati Subdivision, that did not receive an underlayment, and the crossings on the Rockhouse and LH&StL Subdivisions were composed of asphalt/rubber seal surfaces. Typically an asphalt/rubber seal crossing is thought to be an inferior crossing surface, inadequate under any traffic condition. The remaining crossings received premium crossing surfaces due to the higher volume of traffic. In regard to total settlement relative to surface type there seems to be no correlation. These findings show that an asphalt/rubber seal crossing with adequate support can perform as well, if not better, than a premium crossing such as precast concrete.

The Longitudinal Profile Measurements illustrated how the pavement profiles and railway/highway intersections change with time. Prior to the installation of the underlayment all four crossings were very rough and required regular maintenance in order to maintain a smooth crossing surface. The four crossings, Waller Avenue, Rosemont Garden, Main Street -- Winchester, and Main Street -- Richmond are currently performing well and as of the rehabilitation, no maintenance has been required, a very unusual occurrence for railway/highway crossings.

A summary of the Top-of-Rail Settlements obtained from the Longitudinal Profile Measurements follows:

Crossings	Waller Avenue		Rosemont Garden		Winchester*	Richmond**	
Settlement Intervals	2 years	5 years	2 years	5 years	3 years	3 years	6 years
Average Top of Rail Settlements	0.40 in.	0.73 in.	0.74 in.	1.19 in.	0.21 in.	0.34 in.	0.92 in.
* Initial Measurement 4 months after crossing installed							
** Initial Measurement 18 months after crossing installed							

The initial measurements were taken on the Waller Avenue and Rosemont Garden crossings within a day or so after the new crossings were installed. Initial measurements were taken on the Winchester and Richmond crossings several months after the new crossings were installed.

Note that the Top-of-Rail Settlements increase with time. Also, the average values are typical of the values for the larger sample of crossing measurements obtained from top-of-rail profiles taken along the rails, described previously.

After reviewing the collected data which has been assembled over approximately a six year period, the advantages of installing an asphalt underlayment seem clear. Statistical evaluations of the long-term settlement data confirm this fact. The crossings studied, many of which were very rough prior to rehabilitation and needed regular maintenance, are performing well and provide a smooth crossing surface for the traveling public. Also, the railroads have not had to replace or surface these crossings due to good performance. This results in a cost savings to the railroads and associated governmental agencies.

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