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BEST PRACTICES FOR BICYCLE TRAIL PAVEMENT CONSTRUCTION AND MAINTENANCE IN ILLINOIS

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Pavement Construction and Maintenance in Illinois

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16. Abstract

The main objectives of this report were to provide the Illinois Department of Transportation (IDOT) with guidelines for the structural design of bicycle trail pavement and recommendations for bicycle trail pavement maintenance. A design procedure based on three construction traffic factors and three pavement load levels was developed for Portland cement concrete, hot-mix asphalt, and granular/surface treatment surfaces. The bicycle trail design is determined by the level of construction traffic and the weight characteristics of maintenance vehicles or any other vehicle that regularly operate on the trail. Comparisons were made between the proposed design procedures and the performance of trails surveyed in northern, central, and southern Illinois. The results of the survey indicated that the proposed design procedure should produce a structural trail section that performs well over time. Detailed life cycle cost analyses were conducted for different trail designs and different pavement materials for a design period of 20 years. The analyses showed that relative costs were influenced by surface type and maintenance strategies that were required based on the particular surface type used.

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EXECUTIVE SUMMARY

The main objectives of this report were to provide the Illinois Department of Transportation (IDOT) with guidelines for the structural design of bicycle trail pavement and recommendations for maintenance of bicycle trail pavement.

A design procedure based on three construction traffic factors and three pavement load levels was developed for Portland cement concrete (PCC), hot-mix asphalt (HMA), and granular/surface treatment surfaces. The bicycle trail design was determined by the level of construction traffic and the weight of maintenance vehicles or any other vehicles that regularly operate on the trail.

Comparisons were made between the proposed design procedures and the performance of trails surveyed in northern, central, and southern Illinois. The results of the comparisons indicated that the proposed design procedure should produce a structural trail section that performs well over time.

Detailed life cycle cost analyses were conducted for different trail designs and different pavement materials for a design period of 20 years. The analyses showed that relative costs were influenced by surface type and maintenance strategies that were required based on the particular surface type used.

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CHAPTER 1 INTRODUCTION

During bicycle trail design, little guidance is provided about pavement structural design and maintenance processes. For example, Chapter 17 of the Illinois Department of Transportation (IDOT) *Bureau of Design and Environment Manual* (2010) which addresses bicycle and pedestrian accommodations, provides only typical cross sections for trail pavement design. These cross sections do not take into account many variables, including subgrade soils and projected traffic types. Additionally, minimal information is provided about pavement material selection and installation practices.

As with pavement design, little information is presented in the manual about bicycle trail maintenance activities and end-of-life rehabilitations. While funding may not always be available to perform maintenance activities, the maintenance required with various trail surface types should be considered along with initial construction costs when determining a trail surface type. End-of-life rehabilitation options should also be considered because techniques associated with a particular surface type may be more desirable to an agency.

The following pavement design guidelines take a straightforward approach to assist agencies in designing bicycle trail pavements. The goal of the developed pavement design process is to give agencies sufficient flexibility to apply the process over the wide range of construction site conditions, in situ materials, and anticipated types of vehicular traffic. Additionally, general recommendations for the incorporation of recycled materials into the pavement structure are provided.

Pavement maintenance guidelines not only provide long-term maintenance activities, but they also discuss numerous considerations that should be addressed during trail design and construction, all of which directly affect future maintenance requirements of the pavement structure. Regular maintenance activities are discussed along with proposed frequencies, and end-of-life rehabilitation approaches are proposed. A discussion that spans from pre-construction design characteristics to end-of-life rehabilitation options provides a comprehensive depiction of a particular trail surface throughout its life span. This information will allow agencies to base their trail surface and design decisions on more than initial construction costs alone.

To better quantify costs associated with initial construction and regular maintenance, a life cycle cost analysis was completed for a 20-year period. The design process presented within this report was used to determine the initial pavement design and to calculate initial construction costs. The maintenance schedules presented in this report were then applied over the 20-year analysis period. In addition to the life cycle cost analysis, additional initial construction cost analyses were completed to highlight the flexibility of the design process.

To provide an evaluation of the proposed design and maintenance procedures, existing trails throughout the state were observed and assessed. These trails spanned the northern, central, and southern climate regions of Illinois and included four surface types: Portland cement concrete (PCC), hot-mix asphalt (HMA), aggregate, and bituminous surface treatments.

To address these topics, research was conducted to

1. Develop pavement design guidelines.
2. Define and develop standards for trail maintenance.
3. Analyze the life cycle cost for potential trail designs.
4. Evaluate proposed pavement design and maintenance recommendations against existing trails with similar characteristics.
5. Prepare a final report.

CHAPTER 2 TRAIL PAVEMENT DESIGN GUIDELINES

2.1 TRAIL DESIGN INPUTS

For all bicycle trail design procedures, three input factors were applied:

1. Pavement use: Pavement stresses and strains related to vehicle loading were used because bicycle loadings are considered negligible in comparison.
2. Construction traffic: Determines the amount of protection the subgrade requires in order to limit subgrade rutting from equipment and to ensure a stable base for pavement construction.
3. The IDOT district number: Used as a climatic indicator for a given bicycle trail location. District number is primarily used for asphalt binder grade selection in this guide.

Depending on bicycle trail surface type, the influence of these input factors will vary in the design process. The various design factors allow an agency to develop and build a trail that fits their projected long-term vehicular traffic conditions, specific site conditions, and construction method.

2.1.1 Pavement Use Factors

Three pavement use factors are proposed: light duty, regular duty, and heavy duty. The trail's location and surroundings and the maintenance agency's vehicles are some of the factors that will determine the use factor.

For example, a trail slated to traverse a large park or a golf course may not need to be designed to sustain an 18,000-pound axle. On the other hand, a trail that parallels high-voltage power lines on a utility easement might be regularly traversed by the power company's commercial-grade vehicles when performing electrical system maintenance and repair.

Maintenance agency vehicles also need to be considered. Low-speed, light-duty vehicles have different pavement requirements than highway equipment (pickup trucks and dump trucks) for maintenance.

2.1.1.1 Light-Duty Pavement Use Factor

The light-duty pavement use factor accounts for loading by low-speed vehicles. This category includes golf carts and vehicles in the "utility side-by-side" category, such as the Polaris Ranger and Kawasaki Mule. For this class of vehicle, it is assumed that the load is distributed evenly over both axles and all four wheels (axle breakdown information is not readily available from manufacturers). Additionally, this class of vehicle generally does not have significant cargo bed weight and has relatively small engines compared to pickup trucks; thus, a more evenly distributed weight is expected.

For this analysis, one utility golf cart model was chosen for comparison purposes. The other three vehicles examined were commercially available four-person, side-by-side models. The four-person models were chosen because they have the highest potential gross vehicle weight rating (GVWR). Table 1 lists the vehicles that were considered.

Table 1. Weight Information for Light Duty Pavement Design Vehicles

Vehicle Make	Vehicle Model	Maximum GVWR (lbs)	Tire Pressure (psi)
Club Car	Utility	800	12
Polaris	Ranger Crew 800 EPS Gas	3,265	12
Kawasaki	Mule 4010 Trans4×4 Gas	2,895	12
Kawasaki	Mule 4010 Trans4×4 Diesel	3,369	12

The Kawasaki Mule 4010 Trans4x4 diesel, with a GVWR of 3,369 pounds, was chosen as the design vehicle for the light-duty pavement use type. The gross axle weight rating (GAWR) of 1,685 pounds was determined by dividing the GVWR by two.

2.1.1.2 Regular-Duty Pavement Use Factor

The use factor for regular-duty pavement accounts for loading by one-ton (nominal rating) pickup trucks. The one-ton pickup truck was selected because it is arguably the workhorse of highway maintenance agencies and contractors. The axle loadings were determined based on the highest GAWR for 2011 (model year) one-ton domestic diesel-fuel pickup trucks with crew cab, long bed, long wheel base, and a single rear axle. (Note: Vehicle manufacturers regularly change suppliers and component designs during the production of a particular model-year vehicle, which can affect vehicle capacity. The information in this report was obtained from manufacturer websites and is current as of September 2011.)

The GAWR rather than the GVWR was selected for pavement loadings to account for “worst-case” axle loading on the pavement. Using one half of the GVWR as the GAWR is not accurate, however, because a vehicle’s weight is seldom distributed evenly over both axles. For example, a pickup truck with a heavy bed load will have a greater axle weight on the rear axle than on the front axle. The converse would be true for a pickup truck with a front-mounted snow plow and empty bed. Table 2 shows the information for vehicles that were considered. The Ford F350, with a rating of 7,280 pounds, was chosen as the design vehicle for testing regular-duty pavement.

Table 2. Weight Information for Regular Duty Pavement Design Vehicles

Vehicle Make	Vehicle Model	Maximum GAWR (lb)	GVWR (lb)	Tire Pressure (psi)
Ford	F350	7,280	13,000	35–41
Dodge	Ram 3500	6,500	12,300	35–41
Chevrolet	Silverado 3500	7,050	13,000	35–41

2.1.1.3 Heavy-Duty Pavement Use Factor

This vehicle group includes single-axle dump trucks, full-size garbage trucks, and commercial boom/bucket trucks. Vehicles considered within the heavy-duty use factor have a dual-wheel, single-axle GAWR of 18,000 pounds.

2.1.2 Construction Traffic Factor

As discussed in the IDOT *Subgrade Stability Manual* (2005), limiting subgrade rutting and providing a solid base for pavement construction are just as applicable to bicycle trail construction as to road construction. In terms of constructability and long-term pavement performance, a subgrade and an aggregate base that can limit rutting by construction equipment and limit deflections of the final pavement system are required.

Regardless of the construction traffic factor, there will be a constant minimum level of traffic on the subgrade and base material. This constant traffic includes compaction equipment for the subgrade and the aggregate base, equipment for uniform spreading of base material prior to compaction, equipment to ensure a uniform surface of the compacted aggregate base, and paving equipment (a concrete slipform machine, an asphalt paver, or a spreader or paver for the top layer on aggregate-surfaced trails). Therefore, the different construction traffic factors account primarily for the amount of traffic on the subgrade and aggregate base from material haul vehicles. It is assumed that these haul vehicles will produce the heaviest loading on the subgrade and base materials.

The different levels of subgrade traffic, along with the different strengths of subgrade material, are most commonly accounted for through use of an aggregate base layer. Because of the unique conditions of bicycle trail construction, which include relatively low construction traffic on the subgrade in relation to typical road construction, following the design curves presented in the *Subgrade Stability Manual* will create an “overdesigned” construction platform.

To provide more realistic aggregate base thicknesses for bicycle trails, the Dutch approach was selected (van Gurp and van Leest 2002). In that method, total base thickness is calculated by using the characteristics of the construction traffic, number of axle passes that traverse the subgrade, and maximum allowable rut depth. This approach was developed as part of a low-volume, thin asphalt–pavement design process. Along with the similar loading characteristics between low-volume roads and bicycle trails, poor-quality subgrades are common in the Netherlands and Illinois.

Equation 1 is used to determine base material thickness, based on subgrade properties and maximum allowable rutting:

$$h_d = \frac{125.7[\log(N_{constr})] + 496.52[\log(P)] - 294.14[RD_{constr}] - 2412.42}{f_{undr}^{0.63}} \tag{1}$$

where

N_{constr} is the number of axle loads on the subgrade and aggregate base during construction

P is the average load (in newtons)

RD_{constr} is the allowable rut depth at the surface of the aggregate base in meters

f_{undr} is the undrained shear strength of the subgrade (in pascals)

In general, the undrained shear strength of the subgrade (in pascals) is determined by Equation 2:

$$f_{undr} = 1000 \quad (cohesion) \tag{2}$$

where cohesion is reported with a unit of kilo pascals. However, there are two different equations that can be used to determine cohesion from California bearing ratio (CBR) measurement. Cohesion in kilo pascals can be calculated from CBR values with a high and low groundwater table, as indicated in Equations 3 and 4, respectively.

$$cohesion = 20\,(CBR) \tag{3}$$

$$cohesion = 30\,(CBR) \tag{4}$$

When Equation 1 is discussed, there is no indication which base material properties were used to develop the relationship. According to recent studies of the Dutch method, the base material should have a minimum CBR of 15 and should not be moisture susceptible (Tutumluer et al. 2005). Therefore, a quality aggregate that meets the gradations specified in the design methodologies for each trail type is acceptable.

Equation 1 was used to calculate thicknesses of aggregate base needed for bicycle trail construction, based on subgrade CBR and water table depth. A water table is considered high when it is within 20 inches of the bottom of the aggregate base material.

To determine aggregate base thicknesses with this method, the average value for *P* was assumed to be 15,000 pounds, which represents the average axle load of a tandem dump truck and concrete mixer (one 9,000-pound single front axle with two 18,000-pound dual rear axles). The acceptable level of rutting, as denoted by RD_{constr}, is 0.5 inch.

If construction equipment or techniques will vary from these assumptions, the agency can use Equation 1 directly to address special construction situations and determine acceptable base material thicknesses.

2.1.2.1 Low Construction Traffic Factor

In the low construction traffic category, the subgrade is trafficked only by base-course haul vehicles as they actively discharge material. There is adequate room for the base-course haul vehicles to approach the discharge area off the prepared subgrade. The paving-material haul vehicles can discharge into the paver while being driven to the side of the prepared subgrade and aggregate base. Therefore, the low subgrade traffic factor is used almost exclusively for PCC trails where concrete mixers can discharge into the paver or formwork from beside the trail. While a similar arrangement could be achieved with HMA pavement through the use of a material transfer device, the additional equipment cost with this method will likely be cost prohibitive. Also, the thin aggregate base over a low CBR subgrade may not provide enough stiffness to ensure proper compaction of the HMA layer.

For the low subgrade traffic factor, the design number of axle passes is six. While most of the subgrade will have only three axle loadings as the aggregate base is off-loaded, transition areas where one truck empties and a second truck begins off-loading have six axle loadings. Compacted aggregate base thicknesses are shown in Table 3. If subgrade strengths are above those shown in Table 3, the minimum subgrade thickness indicated in the design method should be used.

Table 3. Aggregate Base Thickness for Low Construction Traffic

	Aggregate Base Thickness (in)*	
Subgrade CBR	**Low Water Table**	**High Water Table**
2	3.0	4.0
3 or greater	3.0	3.0

*When the water table is within 20 inches of the bottom of the aggregate base, the high water table thickness should be used.

2.1.2.2 Medium Construction Traffic Factor

In the medium construction traffic category, base-course and pavement-material haul vehicles both traverse the subgrade and aggregate base to discharge materials. However, there is adequate room for both vehicles to approach the discharge area off the prepared subgrade and base material. As previously mentioned, this subgrade traffic factor is the lowest used for HMA trails. Therefore, the design number of axle passes is 12 for the medium subgrade traffic factor. Compacted aggregate base thicknesses are shown in Table 4. If subgrade strengths are above those shown in Table 4, the minimum subgrade thickness indicated in the design method should be used.

Table 4. Aggregate Base Thickness for Medium Construction Traffic

	Aggregate Base Thickness (in)*	
Subgrade CBR	**Low Water Table**	**High Water Table**
2	4.5	6.0
3	3.5	4.5
4	3.0	4.0
5	3.0	3.5
6 or greater	3.0	3.0

*When the water table is within 20 inches of the bottom of the aggregate base, the high water table thickness should be used.

2.1.2.3 High Construction Traffic Factor

In the high construction traffic category, the proposed trail is the only means for site access. All haul vehicles must use the prepared subgrade and base course to reach the job site and while off-loading.

Obviously, the number of axle passes varies significantly, depending on the particular construction characteristics and limitations of each job site. Therefore, a total of 42 axle passes is assigned to the high subgrade traffic factor, which represents 14 passes of a three-axle haul vehicle. Once again, for special situations, the agency can employ Equation 1 to determine the aggregate base thickness needed. Compacted aggregate base thicknesses are shown in Table 5. If subgrade strengths are above those shown in Table 5, the minimum base thickness indicated in the design method should be used.

Table 5. Aggregate Base Thickness for High Construction Traffic

Subgrade CBR	Aggregate Base Thickness (in)*	
	Low Water Table	**High Water Table**
2	7.0	9.0
3	5.5	7.0
4	5.0	6.0
5	4.0	5.5
6	4.0	5.0
7	3.5	4.5
8	3.0	4.0
9	3.0	4.0
10	3.0	3.5
11	3.0	3.5
12 or greater	3.0	3.0

*When the water table is within 20 inches of the bottom of the aggregate base, the high water table thickness should be used.

2.1.2.4 Other Methods to Achieve Required Construction Base Strength

In some situations, it might be advantageous for an agency to perform subgrade soil stabilization (such as lime modification) in order to reduce the thickness required for the aggregate base. In this case, the CBR of the modified soil can be used with Tables 3 through 5 to determine the amount of aggregate base needed.

2.1.2.5 Note on CBR/IBR Designation

Up to this point, CBR has been used to identify subgrade strength, as it is the parameter found in referenced literature. However, in all subsequent sections, the Illinois Bearing Ratio (IBR) nomenclature will be used to define subgrade strength, in order to align with IDOT policy and procedures. IBR is determined in nearly the same fashion as CBR, except for slight modifications in the test procedure. Additional information on the IBR test procedures can be found in the IDOT *Geotechnical Manual* (1999).

2.1.3 IDOT District Number

The district number provides the temperature inputs for the design method.

2.2 HOT-MIX ASPHALT TRAIL DESIGN METHODOLOGY

2.2.1 Subgrade Preparation

Compacted subgrade should have a minimum dry density of 95% of the standard laboratory dry density. Densities should be determined in accordance with IDOT's *Standard Specifications for Road and Bridge Construction* (SSRBC) Section 205.06 (2012). Areas with unstable subgrade should be remediated. Typically, these areas are undercut and backfilled using a geotextile and aggregate base material. A stabilized layer can also be considered.

2.2.2 Material Specifications and Installation Requirements

2.2.2.1 Aggregate Base

Aggregate base material should be in compliance with SSRBC Section 1004.04, Aggregate Materials. The aggregate should be Class C quality or better and meet a CA-6 or CA-10 gradation. Aggregate base should be constructed in accordance with SSRBC Section 351.

2.2.2.2 Bituminous Emulsions

Prime coat should be applied to the prepared aggregate base. Prime coat material should be MC-30, which meets SSRBC Section 1032 requirements. Application of the prime coat should be in accordance with Section 406.05.

In some instances, the trail can be paved with a single lift of asphalt. If multiple lifts are used, tack coat should be applied between asphalt lifts. Tack coat material and application should be in accordance with the SSRBC Sections 406.05 and 1032.

2.2.2.3 Hot-Mix Asphalt Binder

The asphalt binder selection chart depicted in Table 6 was developed based on IDOT's *Bureau of Local Roads and Streets Manual* (Chapter 37) binder grade specifications and binder grades obtained using LTPPBind (Long-Term Pavement Performance Binder selection software developed by the Federal Highway Administration), using the 98% reliability level. Differences between loading and environmental factors and differences in functional requirements for bike paths and highway pavements were taken into consideration when developing the recommendations shown in Table 6.

The designer is cautioned against substituting PG XX-22 binders when a PG XX-28 binder is specified. While doing so may be justifiable from the standpoint of highway pavements (rutting considerations often take precedence over cracking concerns), this is not the case for bike trails. For bike trails, precedence should be given to cracking and durability considerations over rutting considerations, since the magnitude and number of heavy loads on bike paths is relatively low and the functional problems associated with thermal cracks on bike paths (safety concerns for users and maintenance of cracks) are of concern.

Table 6. Asphalt Binder Grade Recommendations

IDOT District	Pavement Use Factor		
	Light Duty	**Regular Duty**	**Heavy Duty**
1–4	PG 58-28	PG 58-28	PG 64-28
5–7	PG 58-28	PG 58-28	PG 64-28*
8–9	PG 64-22	PG 64-22	PG 64-22

*PG 64-28 binder is not always available and/or economical in this region. In this case, a PG 64-22 or PG 58-28 binder may be substituted, based on local binder cost and engineer experience with bike path pavement performance in this region. If PG 64-22 binder is selected, the use of recycled asphalt pavement (RAP) should be avoided to minimize durability issues.

2.2.2.4 Hot-Mix Asphalt Aggregate

Coarse and fine aggregate should meet the requirements identified in SSBRC Sections 1004.03 and 1003.03, respectively.

2.2.2.5 Hot-Mix Asphalt Concrete Mix Design and Installation

The guidance, process, and quality control as outlined in SSBRC Section 1030 should be followed for bicycle trail pavements.

For light- and regular-duty pavements, an IL-19.0L binder mixture and an IL-9.5L surface mixture are recommended. If it is expected that the trail will commonly be used by roller bladers and skate boarders, or if a smoother surface is desired, an IL-4.75 mix should be considered. The IL-19.0L and IL-9.5L mixes have 30 design gyrations. The IL-4.75 mix has 50 design gyrations, as defined in Section 1030.

For heavy-duty pavements, an IL-19.0 or IL-25.0 leveling binder mixture and an IL-9.5 surface mixture are recommended. Mixes intended for use with the heavy-duty pavement use factor should use 50 design gyrations.

The asphalt paving process should be in accordance with SSBRC Section 406.05. For reference, the recommended minimum and maximum lift thicknesses outlined in the SSBRC are listed in Table 7.

Table 7. Minimum and Maximum Compacted Asphalt Lift Thicknesses

Mix	Minimum (in)	Maximum (in)
IL-4.75	0.75	1.25
IL-9.5L/IL-9.5	1.25	*
IL-19.0L/IL-19.0	2.25	*
IL-25.0	3.00	*

*No maximums are provided. Maximum thicknesses are determined by attainment of mat compaction requirements.

Special provisions for placement of the IL-4.75 mix are identified in SSBRC Section 406.05 and should be followed.

2.2.2.6 Recycled Products

2.2.2.6.1 Use of recycled products in bases

A number of different recycled materials can be used in bicycle trail aggregate bases. From a sustainability standpoint, bicycle trail bases are a prime location for the use of recycled materials. Fractionated recycled asphalt pavement (RAP) can be used, assuming the final product meets the identified gradation requirements. It is suggested that RAP replacement of virgin aggregate not exceed 30% replacement (FHWA User Guidelines, n.d.). While increased replacement percentages using RAP generally strengthens the aggregate base with time, the main goal of the aggregate base in bicycle trail construction is to allow for construction traffic. Therefore, immediate strength of the aggregate base is of primary concern.

In addition, fractionated, recycled PCC pavement can be used in 100% replacement of virgin aggregate for aggregate bases. The recycled PCC must meet the identified aggregate base gradations and quality requirements.

2.2.2.6.2 Use of recycled products in asphalt surfaces

The most common recycled product in HMA is RAP. Unlike bases and sub-bases, where use of RAP materials should be strongly considered as a strategy to enhance pavement sustainability, care must be exercised in using recycled asphalt materials in bike trail asphalt surfaces. This derives from the fact that the main performance issues with bike paths are cracking and durability, and the tendency for RAP to contain hard, brittle binder (especially since most RAP originates from highway projects) suggests that it must be used with caution. RAP material should meet the specifications identified in SSBRC Section 1031. Fractionated RAP affords better control over gradation and recycled binder content and is therefore recommended for use with bike trail asphalt surfaces.

As a conservative approach, it is recommended that the amount of RAP used in bike trail surfaces be limited to 15%. Beyond 15% RAP, a “grade bump” to a softer binder grade would normally be required; however, PG XX-34 binders are generally not available in districts 1–7, nor are PG XX-28 binders readily available in districts 8–9. Additionally, it is recommended that a contractor experienced in the application of recycled products in hot mix asphalt be used.

Other recycled products include recycled granulated glass and recycled asphalt shingles (RAS). Due to the potential durability concerns associated with the use of these materials (stripping in the case of granulated glass, and cracking in the case of shingles), their use for bike trail surface mixtures is not recommended.

2.2.3 Conventional Hot-Mix Asphalt Thickness Design

Low vehicular traffic levels on bicycle trail pavements mean that the primary cause of pavement failure will be durability-related distresses, as opposed to load-related distresses (fatigue cracking and rutting). Therefore, the primary focus for the HMA pavement design is to provide a surface that has good durability and can perform well under the applied loading.

Temperature aspects of the design are accounted for with the proper binder grade selection, as outlined in Section 2.2.2.3. Rutting performance of the design is accounted for through the number of gyrations specified during the mix design. Therefore, the thickness design was evaluated to ensure that it provides proper protection from fatigue-related distresses under the varying pavement use factors.

The design process for HMA-surfaced trails is summarized in Figure 1 and is subsequently explained in further detail.

2.2.3.1 Aggregate Base Thickness

The aggregate base should be determined based on subgrade strength and construction traffic factor, as discussed in Section 2.1.2. Due to the construction traffic required for HMA pavement, the medium construction traffic factor should be used. Minimum aggregate base thickness should be 4 inches in order to provide an adequate base for HMA compaction.

Numerous combinations of subgrade strength and aggregate base are possible. A conservative assumption is made that the asphalt pavement is placed on a surface with an elastic modulus (E) of 30,000 pounds per square inch. The Poisson's ratio of this layer is assumed to be 0.35.

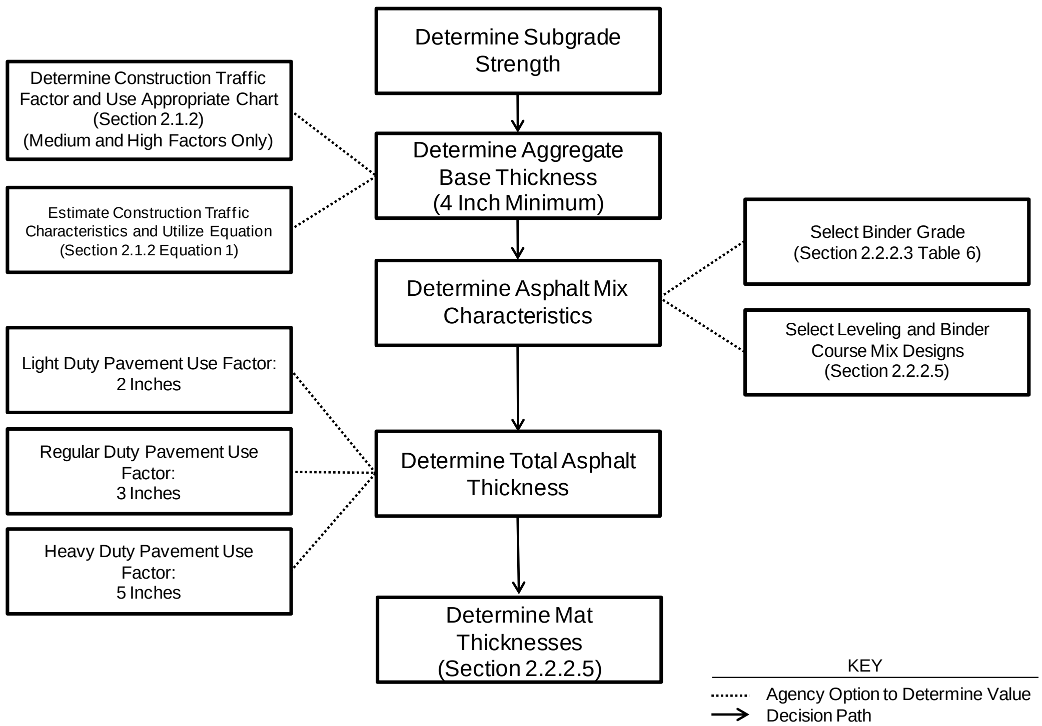

Figure 1. Conventional HMA trail design methodology.

2.2.3.2 Allowable Strain in the Asphalt Layer

As previously mentioned, fatigue distresses dictate the HMA pavement design. To assess fatigue in asphalt pavements, the number of passes to failure must be calculated. Several different equations relate tensile strain in the bottom of an asphalt layer to number of passes to failure. For this analysis, Equation 5 is used to determine the number of passes to failure, based on work by Thompson (Huang 2004).

$$N_f = 5x10^{-6}(\varepsilon_t)^{-3.0} \tag{5}$$

where ε_t is the tensile strain at the bottom of the HMA layer.

BISAR 3.0 (Shell Bitumen 1998) is used to obtain the tensile stain at the bottom of the asphalt layer. BISAR 3.0 can calculate stresses, strains, and deflections at various user-defined points in a pavement structure. This is accomplished through user input of load information, pavement material information (including modulus and Poisson's ratio), and pavement layer thicknesses.

BISAR was used to calculate the strains under a single circular load. The vertical load is equal to one half the axle load for each vehicle type. In addition, the radius of the load is needed as an input; therefore, the radius in inches was determined using Equation 6.

$$a = \sqrt{\frac{P}{\pi(TP)}} \tag{6}$$

where *P* is the load in pounds and *TP* is the tire pressure in pounds per square inch.

2.2.3.3 Conventional Hot-Mix Asphalt Pavement Thickness

To determine tensile strain at the bottom of the HMA layer, the properties outlined in Table 8 were assumed.

Table 8. Assumed HMA Properties

Property	**Value**
Modulus of Elasticity (ksi)	200
Poisson's Ratio	0.35

In addition to the asphalt properties, the load characteristics used in the analysis were selected from the control vehicles described by the pavement use factor discussed in Section 2.1.1.

Based on field verifications discussed in Chapter 5, it was determined that a 2-inch minimum HMA thickness for the light-duty pavement use factor is adequate. The 2-inch-thick HMA trails observed showed reasonably good performance from a durability standpoint and should have good performance under the relatively low loading observed in the light-duty pavement use factor. Careful inspection and use of an experienced contractor are recommended when constructing the 2-inch HMA lift to ensure a consistent thickness throughout the project.

A minimum HMA thickness for the regular-duty and heavy-duty pavement use factor designs is 3 inches. This 3-inch minimum thickness will allow for adequate thickness over the entire project, after accounting for construction variability, and perform well under these loading conditions while also having adequate strength to account for potential occasional overloads.

Using the process described in Section 2.2.3.2, the tensile strain was calculated using BISAR under the loading associated with the various pavement use factors. Based on this tensile strain, the number of axle loadings to failure was calculated. From the allowable total number of axle passes, the number of allowable axle passes per day was calculated based on a 20-year design life and a uniform distribution of axle passes over every day of the year. To provide an adequate factor of safety, the strains at the bottom of the asphalt layer must be low enough to allow for a minimum of ten axle passes per day for the design HMA thickness (traversed by a two-axle vehicle five times per day). All design recommendations presented in Table 9 are within the expected daily passes to failure.

Table 9. Axle Passes to Failure at Recommended Conventional HMA Thicknesses

Pavement Use Factor	Wheel Load (lb)	Tire Pressure (psi)	Asphalt Thickness (in)	Tensile Strain (in/in)	Lifetime Passes to Failure	Daily Passes to Failure
Light Duty	843	12	2.0	5.84e-5	2.51e7	3,435
Regular Duty	3,640	41	3.0	2.04e-4	5.87e5	80
Heavy Duty	9,000	100	5.0	3.94e-4	8.19e4	11

Agency discretion is used in determining the compacted mat thicknesses and combination of leveling binder (if needed) and surface course. The recommended minimum and maximum thicknesses discussed in Section 2.2.2.5 should be used.

2.2.4 Full-Depth Asphalt Thickness Design

To allow agencies additional design flexibility, a full-depth HMA pavement design is provided. The material and construction characteristics are the same as those used in conventional asphalt pavement design. Figure 2 presents the full-depth HMA pavement design and is subsequently discussed in greater detail.

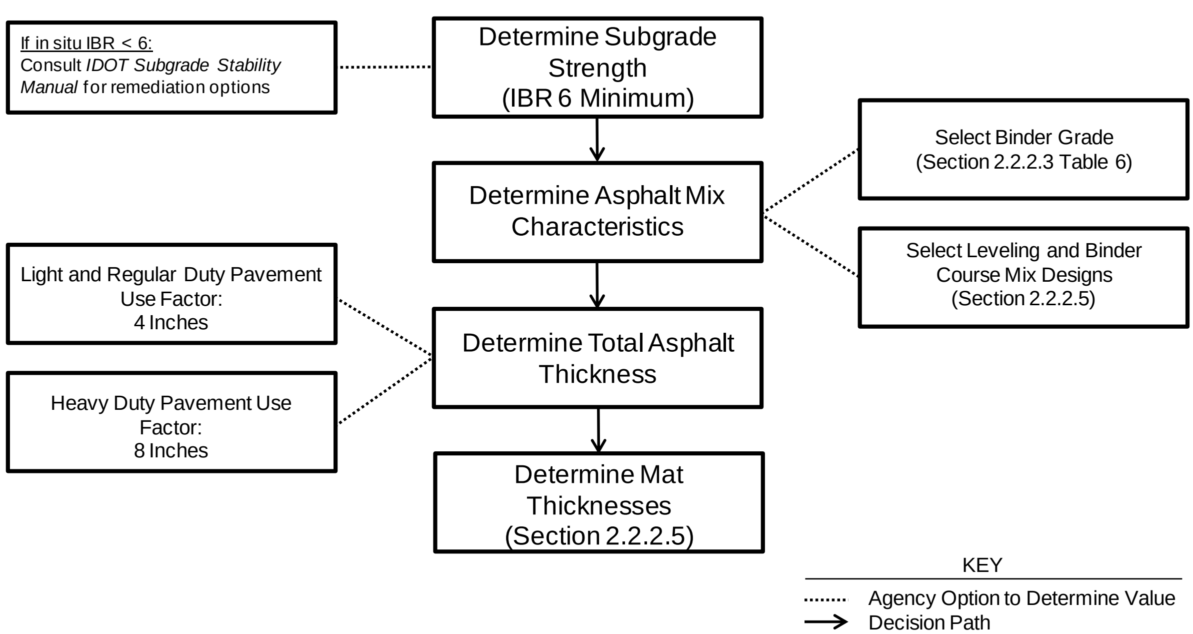

Figure 2. Full-depth HMA pavement design methodology.

2.2.4.1 Subgrade Strength Requirements

Differing from the conventional HMA pavement design, the full-depth design requires the subgrade to meet the minimum strength requirements outlined in the IDOT *Subgrade Stability Manual* to ensure that the subgrade will allow for proper asphalt compaction. Adequate subgrade strength is critical to ensure the proper constructability and performance of full-depth asphalt pavements. The *Subgrade Stability Manual* requires that subgrades have a minimum IBR of 6 if untreated. Subgrades that have an IBR below 6 must have an aggregate cover or depth of soil modification. The aggregate cover or soil modification must produce a material that has a minimum IBR of 10.

2.2.4.2 Allowable Stress in the Asphalt Layer

The process described in Section 2.2.3.2 was followed for the full-depth pavement.

2.2.4.3 Full Depth Hot-Mix Asphalt Pavement Thickness

The HMA properties in Table 8 were assumed for the full-depth design. It is assumed that the HMA pavement is placed on a subgrade with an elastic modulus (E) of 9,000 pounds per square inch, which corresponds to an IBR 6 material. The Poisson's ratio of the subgrade is assumed to be 0.40.

It has been determined that a 4-inch HMA surface is the thinnest constructible full-depth pavement. This relaxes the standards outlined in the IDOT *Bureau of Local Roads and Streets Manual*, Chapter 44 (2011), which requires a minimum HMA thickness of 6 inches for full-depth pavements. Similar to the process described in Section 2.2.3.3, the strains at the bottom of the asphalt layer must be low enough to allow for a minimum of ten axle passes per day for the design HMA thickness. All design recommendations presented in Table 10 are within the expected daily passes to failure.

Table 10. Axle Passes to Failure for Recommended Full-Depth HMA Thicknesses

Pavement Use Factor	Wheel Load (lb)	Tire Pressure (psi)	Asphalt Thickness (in)	Tensile Strain (in/in)	Lifetime Passes to Failure	Daily Passes to Failure
Light Duty	843	12	4.0	9.29e-5	6.24e6	854
Regular Duty	3,640	41	4.0	3.19e-4	1.13e5	15
Heavy Duty	9,000	100	8.0	3.92e-4	8.32e4	11

Agency discretion is used when determining the compacted mat thicknesses and combination of leveling binder (if needed) and surface course. The recommended minimum and maximum thicknesses discussed in Section 2.2.2.5 should be used.

2.3 PORTLAND CEMENT CONCRETE TRAIL DESIGN METHODOLOGY

2.3.1 Subgrade Preparation

Subgrade preparation should be in accordance with Section 2.2.1.

2.3.2 Material Specifications and Installation Requirements

2.3.2.1 Aggregate Base

Aggregate base materials and installation should be completed in accordance with Section 2.2.2.1.

2.3.2.2 Portland Cement Concrete

PCC should be class PV or SI and in accordance with SSRBC Section 1020. The agency will determine the strength gain and slump characteristics required for individual construction requirements and methods. Coarse and fine aggregate used in the PCC should meet the requirements for the applicable mix in SSRBC Sections 1004.02 and 1003.02, respectively.

Placement should be in accordance with SSRBC Section 420. However, due to the greater level of simplicity of bicycle trail pavements, the following portions can be omitted.

- Section 420.05—Joints: portions that pertain to dowel and tie bar installation. Dowel and tie bars can be used at the discretion of the agency; however, they are not considered necessary due to low axle loads and low load repetitions seen on bicycle trails.
- Section 420.08—Placement of Reinforcement: entire section. Reinforcement is not considered necessary due to low axle loads and low load repetitions seen on bicycle trails. Furthermore, if not installed properly, reinforcement can cause additional deterioration and increase maintenance requirements. Reinforcement can also increase the cost of major or end-of-life rehabilitation. However, reinforcement can be used if desired by the agency.
- Section 420.09—Strike Off, Consolidation, Finishing, Longitudinal Floating, Straightedging, Edging, and Final Finish, Subsection (e), Final Finish: A transverse broom finish or turf drag is recommended. Other finish techniques can be employed by the agency, if desired.
- Section 420.10—Surface Tests: entire section. The agency should check for compliance with its local specifications for bicycle trail construction and Americans With Disabilities Act (ADA) requirements, if applicable.

2.3.2.3 Structural Fibers

To reduce slab thicknesses and provide additional protection against joint misalignment and to improve performance in the event of mid-slab cracking, a structural fiber can be incorporated into the PCC mix at agency discretion. When properly incorporated into PCC, structural fibers increase the flexural strength while also bridging cracks (at both mid-slab and contraction joints), helping to keep cracks tight and provide some load transfer over the crack. Although structural fibers do not negate all issues with crack propagation in PCC slabs, they help maintain slab integrity after the crack has formed.

With the exception of slab thickness, all traditional construction methods, with exception of contraction joint spacing, should be followed. The structural fibers will bridge some of the sawed contraction joints, creating a “dominant” contraction joint approximately every 50 to 100 feet. At this dominant joint, the stresses within the concrete due to contraction will exceed the strength of the fibers, producing a slightly larger joint opening than would be observed with traditional concrete pavement. Increasing contraction joint spacing may seem like an attractive option, but since dominant joint spacing cannot accurately be estimated, it is better to provide regular planes of weakness to control cracking.

Structural fibers, if used, should meet the *Approved List of Synthetic Fibers* from the IDOT Bureau of Materials and Physical Research (2012). Fibers should be added at the dosage rate specified. Annual recertification of fibers by the manufacturer is required; therefore, the approved list is updated at least annually. The current approved list should be obtained from the IDOT website, on the “Doing Business” page, under the “Materials” heading, and the “Approved List for Materials” link.

2.3.2.4 Recycled Products

Materials identified in Section 2.2.2.6.1 for use in aggregate base can be applied on concrete-surfaced trails.

Recycled concrete aggregate can also be used in new PCC pavement. The properties of recycled concrete aggregate are different than those of virgin aggregate. Recycled concrete aggregate can also vary based on the source. It is recommended that an agency research current techniques and availability in its area, and consult an experienced contractor and material supplier.

2.3.2.5 Contraction Joints

Two rules of thumb apply to contraction joint spacing on conventional PCC pavement. Both are applicable to bicycle trails. First, joint spacing in inches is to be no more than 24 times the pavement thickness in inches. Second, the aspect ratio of the slabs (length of long side divided by length of short side) should be no greater than 1.25, with an ideal aspect ratio of 1 (square slabs) (Huang 2004).

For the structural fiber PCC, slab thickness will be reduced. It is not recommended that the contraction joint spacing be shortened if the slab thickness has been reduced, since the resulting concrete will have a higher flexural strength. Therefore, it is recommended that the structural fiber PCC have the same joint spacing as recommended for a conventional PCC pavement of the same pavement use factor.

The minimum contraction joint depth is required to be one quarter of the pavement thickness (Portland Cement Association, n.d.). A sawcut joint can be used for a smooth surface. However, if the contraction joints are to be sealed, the joint should be cut in a shape that accepts the sealant material without leaving excess material on the surface. The exact geometry will be determined by the agency based on its standard maintenance practices; however, the top of the sealant should be at or slightly below the surface of the pavement.

2.3.2.6 Construction Joints

Construction joints are used in between PCC placement (or any time there will be more than 30 minutes between placements) and should be fabricated using the process outlined in SSRBC Section 420.05. To avoid the addition of joints in the pavement, the construction joint should be placed where a contraction or expansion joint is required.

The lack of aggregate interlock at construction joints requires that load transfer be provided. For 5-inch-thick concrete pavement, a plate dowel should be used. Round dowels produce a large reduction in concrete thickness where placed, which can lead to pavement damage under loading. Plate dowels are generally diamond-shaped plates of steel that vary in thickness between 1/4 and 3/4 inch. Other than the shape, the placement within the slab and function of the plate dowel follows many of the same principles as a round dowel. Such products are available from suppliers that specialize in products for concrete flatwork.

Depending on the specific product chosen, it is recommended that manufacturer's recommendations for proper plate thickness, spacing, and installation be followed.

When 7-inch-thick concrete pavement is installed, smooth dowels with a 1-inch diameter should be placed on 18-inch centers across the width of the pavement. Dowels should be placed as indicated in SSBRC Section 420.

2.3.2.7 Expansion Joints

Regularly spaced expansion joints are not common in modern pavements. While there is a slight chance of joint blowups on a trail due to elimination of regularly spaced expansion joints, the concrete pavement has adequate strength to endure these expansion stresses without failing. Expansion joints can also allow for slab movement where the compression of an expansion joint leads to wider gaps at contraction joints. As a contraction joint becomes wider, the load-transfer capacity of aggregate interlock is reduced. Additionally, once expansion joints are installed, they become a recurring maintenance item. If not properly maintained, expansion joints can fill with incompressibles, causing pavement deterioration around the joint.

However, expansion joints are still needed to isolate the trail pavement from fixed features that the trail intersects, such as bridges, manholes, and other pavements running perpendicular to the trail.

Regularly spaced expansion joints are a common feature of many of the concrete trails observed, as discussed in Chapter 5 and Appendix D. Therefore, it is an agency decision whether to utilize regularly spaced expansion joints in pavement. While joint blowups due to the absence of regularly spaced expansion joints should be very infrequent, an agency may prefer to assume maintenance responsibilities and reduce aggregate interlock load transfer at contraction joints in order to further reduce the possibility of joint blowups.

Another option is requiring installation of regular expansion joints, depending on the temperature at the time of paving. A recently completed design for the U.S. Army Corps of Engineers Rend Lake Project Office contains a specification of this type. In this case, the specification does not require regularly spaced expansion joints if the concrete is installed during warm weather (defined as 60°F and above). If concrete is installed during cool or cold weather (below 60°F), 3/8-inch expansion joints are required at a maximum interval of 96 feet.

2.3.3 Conventional Portland Cement Concrete Thickness Design

Unlike HMA pavements, PCC pavements are primarily affected by temperature differentials between the top and bottom of the slab, as opposed to the environmental temperature. Therefore, no temperature input is required in the design. The design process for conventional PCC-surfaced trails is summarized in Figure 3 and is subsequently explained in further detail.

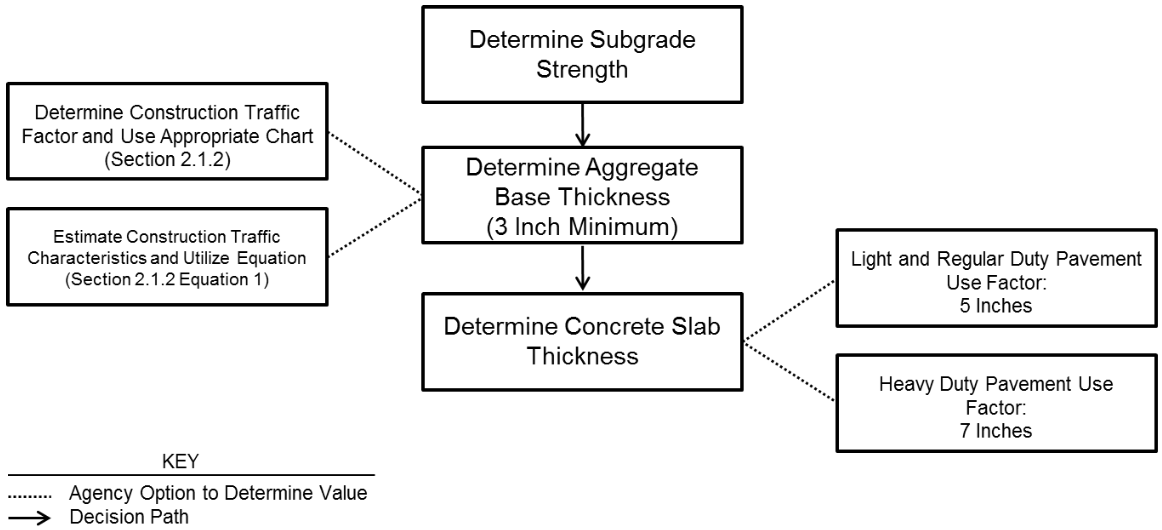

Figure 3. Conventional PCC trail design methodology.

2.3.3.1 Aggregate Base Thickness

The aggregate base should be determined based on subgrade strength and construction traffic factor, as discussed in Section 2.1.2. Minimum aggregate base thickness should be 3 inches in order to provide a working platform for paving equipment. There are numerous combinations of subgrade strength and aggregate base. An assumption is made that the PCC pavement is placed on a surface with a modulus of subgrade reaction (k-value) of 250 pounds per square inch per inch for all combinations of subgrade strength and corresponding aggregate base thickness.

2.3.3.2 Allowable Portland Cement Concrete Pavement Stress and Slab Sizes

Because of the traffic characteristics of bicycle trails, the PCC pavement design is based on applied load stresses and curling stresses in the concrete slab without regard to fatigue effects. The Westergaard equations are used to calculate these stresses. The load safety factor for roads, residential streets, and other streets that will carry small volumes of truck traffic is 1.0 (Huang 2004) .

With PCC pavements, a number of different environmental and construction influences can affect stresses. One influence is the temperature differential throughout the thickness of the slab. It is suggested that the temperature differential for concrete pavement is typically between 2.5°F and 3.5°F per inch of concrete thickness (Huang 2004). To allow for extreme conditions, it was assumed in this analysis that a reasonable temperature differential is 3.5°F per inch and that the differential is linear throughout the thickness of the slab. Additionally, joint spacing can affect PCC slab stresses. For this analysis, the maximum joint spacing and maximum aspect ratio were used to evaluate extreme conditions—which results in an 8- by 10-foot slab size for a 5-inch-thick pavement and 11.2 by 14 feet for a 7-inch-thick pavement. Given this guidance, it may seem that the smallest possible slab sizes are desired to minimize stresses. This is correct, assuming minimum stress is the only concern. Small joint spacing increases the number of joints, leading to decreased ride quality from a user's perspective and increased maintenance requirements and potential water infiltration into the pavement from an agency prospective.

The completed stress analysis incorporated both the temperature and the load-induced (curling) stresses on the edge of the concrete slab. For the load stresses, a circular load shape was used in the analysis, as opposed to a semicircular load shape, since bicycle trails do not have a paved shoulder. The analysis considered stresses along the long side of the slab only, because the short side of the slab has comparatively lower curling stresses. Thus, the long side is the critical location.
The maximum curling stress at the mid-span of the slab is determined by Equation 7.

$$\sigma = \frac{CE\alpha_t \Delta t}{2} \tag{7}$$

where
C is the stress correction factor for a finite slab as determined from Figure 4
E is the modulus of elasticity of concrete in pounds per square inch
α_t is the coefficient of thermal expansion strain per degree Fahrenheit
Δt is the temperature differential in degrees Fahrenheit per inch of slab thickness

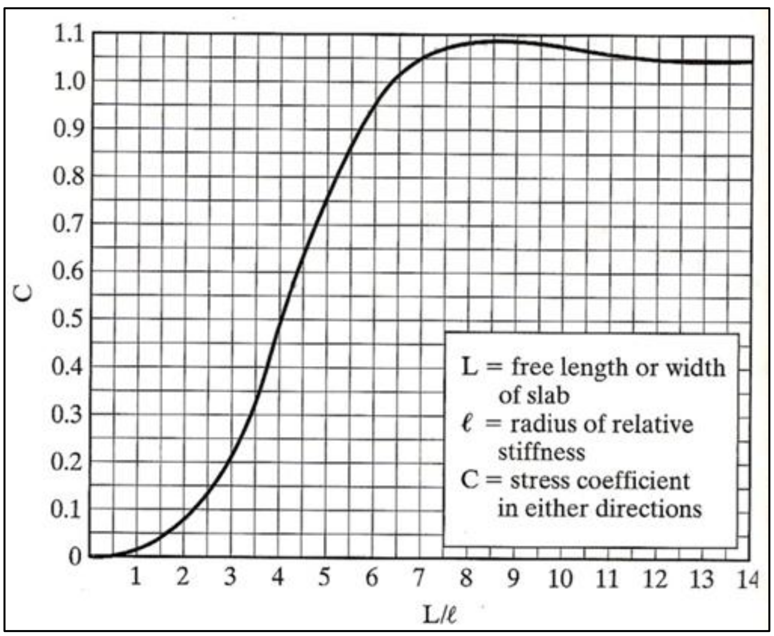

Figure 4. Finite slab stress correction factor (Huang 2004).

Figure 4 utilizes a ratio between the free length of the slab and the radius of relative stiffness, where L is the free length of the slab in inches and l is the radius of relative stiffness in inches, as calculated in Equation 8.

$$l = \left(\frac{Eh^3}{12(1-v^2)k} \right) \tag{8}$$

where
h is the thickness of the concrete slab in inches
v is Poisson's ratio
k is the modulus of subgrade reaction in pounds per square inch per inch

The edge stresses were determined for a circular load with Equation 9, which has been simplified for a Poisson's ratio of 0.15.

$$\sigma = \frac{0.803P}{h^2}\left[4\log\left(\frac{l}{a}\right) + 0.666\left(\frac{a}{l}\right) - 0.034\right] \tag{9}$$

where *P* is the load and *a* is the contact radius in inches. The variable *a* can be calculated with Equation 6.

2.3.3.3 Conventional Portland Cement Concrete Pavement Thickness

The flexural strength of both PV and SI classes of concrete is 675 pounds per square inch. Given the load safety factor of 1.0 for the traffic mix, the working flexural stress of bicycle trail pavements is 675 pounds per square inch.

To perform the stress analysis, the following values for the concrete were assumed, as shown in Table 11.

Table 11. Assumed PCC Properties

Property	**Value**
Modulus of Elasticity (psi)	4.0e6
Poisson's Ratio	0.15
Coefficient of Thermal Expansion (strain/°F)	5.00e-6
Temperature Differential (°F/inch)	3.5

In addition to the concrete properties, the load characteristics used in the analysis were selected from the control vehicles described by the pavement use factor discussed in Section 2.1.1.

A minimum slab thickness for this design will be 5 inches. A thinner concrete slab is susceptible to poor aggregate interlock (load transfer) at the joints and excessive damage if trafficked by a heavy vehicle.

Using the stress calculation process discussed in Section 2.3.3.2 and the concrete properties previously discussed in this section, appropriate concrete slab thicknesses for each pavement use factor can be determined. All design recommendations presented in Table 12 are within the allowable stress level of 675 psi.

Table 12. Conventional PCC Stresses at Recommended Slab Thicknesses

Pavement Use Factor	Wheel Load (lb)	Tire Pressure (psi)	Slab Thickness (in)	Curling Stress (psi)	Load Stress (psi)	Total Stress (psi)
Light Duty	843	12	5.0	164.5	71.8	236.3
Regular Duty	3640	41	5.0	164.5	288.7	453.2
Heavy Duty	9000	100	7.0	249.9	421.6	671.5

2.3.4 Structural Fiber Thickness Design

To reduce concrete slab thicknesses and improve bridging across cracks and joints, structural fibers can be added to PCC. The design process is similar to that used for conventional PCC pavement design, with the exception of the flexural strength improvement realized by the additional of structural fibers. The design process for structural fiber PCC–surfaced trails is summarized in Figure 5 and is subsequently explained in further detail.

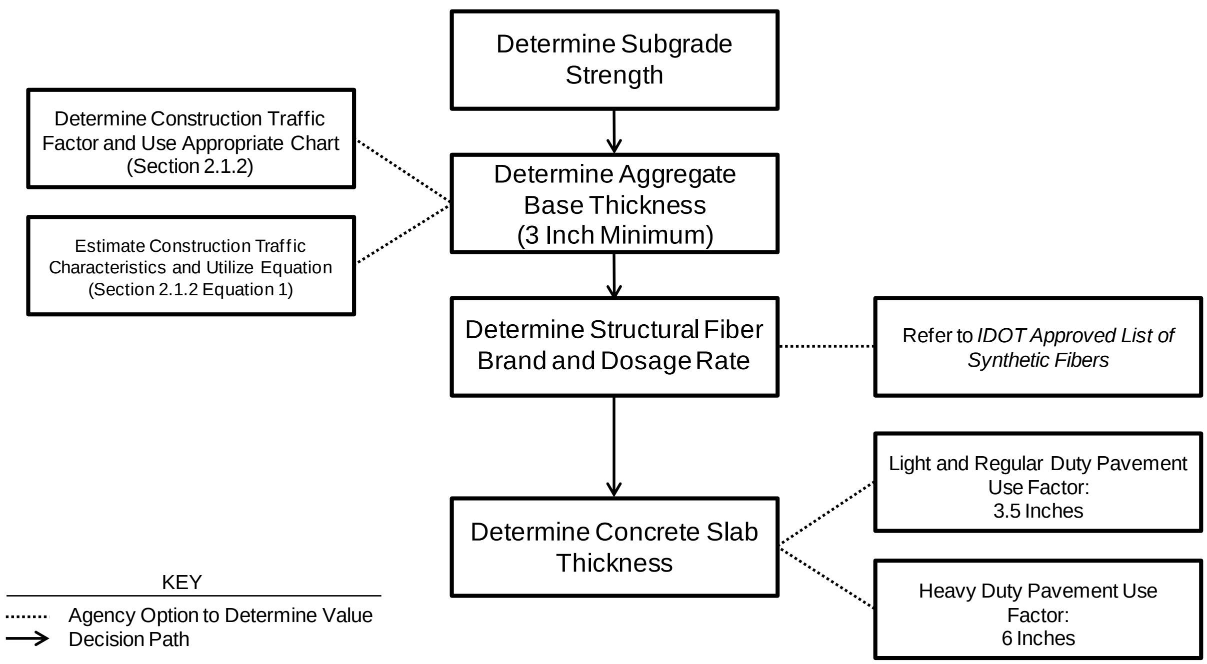

Figure 5. Structural fiber concrete trail design methodology.

2.3.4.1 Aggregate Base Thickness

The same recommendations and assumptions listed in Section 2.3.3.1 for conventional concrete pavement thickness design are applicable to structural fiber concrete thickness design.

2.3.4.2 Allowable Structural Fiber Portland Cement Concrete Stress and Slab Sizes

The contribution of structural fibers to the concrete is quantified with the residual strength ratio. Based on the residual strength ratio, the flexural strength of the concrete is modified by using Equation 10 (Roesler et al., 2008).

$$MR_{sf} = MR_{PCC}\left(1 + R_{150,3}\right) \tag{10}$$

where MR_{PCC} is the flexural strength of PCC without structural fibers and $R_{150,3}$ is the residual strength ratio of the structural fibers.

The addition of fibers at the dosage listed on the IDOT *Approved List of Synthetic Fibers* will provide for a 20% residual strength ratio. The same method and slab sizes described in Section 2.3.3.2 are used for the structural fiber thickness design.

2.3.4.3 Structural Fiber Portland Cement Concrete Pavement Thickness

Using the same load safety factor as used in Section 2.3.3.3, the acceptable level of load and curling stress is increased due to the inclusion of structural fibers. Therefore, the flexural strength of the PV or SI mix improves from 675 psi to 810 psi. The PCC slab thicknesses can be reduced to take advantage of the increase in flexural strength.

For the structural fiber PCC, a minimum slab thickness of 3.5 inches is used to ensure adequate structural fiber bridging across cracks.

To complete the stress analysis, the concrete properties as shown in Table 11 will be assumed. The appropriate concrete slab thicknesses for each pavement use factor can be determined. All design recommendations presented in Table 13 are within the allowable stress level of 810 psi. Note that the structural fiber PCC stress levels were calculated using the same maximum joint spacing and maximum aspect ratio as used for the conventional PCC pavement stress analysis.

Table 13. Structural Fiber PCC Stresses at Recommended Slab Thicknesses

Pavement Use Factor	**Wheel Load (lb)**	**Tire Pressure (psi)**	**Slab Thickness (in)**	**Curling Stress (psi)**	**Load Stress (psi)**	**Total Stress (psi)**
Light Duty	843	12	3.5	133.5	123.5	257.0
Regular Duty	3640	41	3.5	133.5	491.1	624.6
Heavy Duty	9000	100	6.0	222.6	536.8	759.4

2.4 AGGREGATE-SURFACED TRAIL DESIGN

2.4.1 Subgrade Preparation

Subgrade preparation should be in accordance with Section 2.2.1.

2.4.2 Material Specifications and Installation

2.4.2.1 Aggregate Base

Aggregate base materials and installation should be in accordance with Section 2.2.2.1.

2.4.2.2 Aggregate Surface

The Center for Dirt and Gravel Road Studies at Pennsylvania State University developed a trail mix aggregate (TMA) for use on bicycle trails and other recreational trails. This material was developed based on the gradation of their driving surface aggregate, which is a popular and proven aggregate for use on gravel roads. TMA is produced by blending three commonly available aggregates, including 4 parts of AASHTO #10 aggregate, 4 parts of AASHTO #8 aggregate, and 1 part minus 200 micron fines (Center for Dirt and Gravel Road Studies 2011).

To adjust AASHTO gradations to IDOT standard gradations, TMA should be composed of 4 parts CA-16, 4 parts FA-05, and 1 part minus 200 micron fines. Coarse aggregate quality should be Type C or better, as described in the SSBRC.

Obtaining adequate compaction during construction is key to ensuring good performance of a TMA surface. Proper, uniform compaction requires a material that is not segregated. For smaller jobs, the material can be end-dumped from haul vehicles; however, it is recommended that a paver or similar spreading device be used, when feasible, to keep segregation to a minimum. To achieve proper compaction, the TMA also should be at optimal moisture content during installation. Optimal moisture content varies based on the material properties and should, therefore, be determined on a job-by-job basis (Center for Dirt and Gravel Road Studies 2011).

2.4.2.3 Recycled Products

Materials identified in Section 2.2.2.6.1 for use in aggregate base can be applied with aggregate-surfaced trails.

Additionally, asphalt millings can be incorporated into the TMA. To maintain gradation requirements and ensure consistent material properties, the millings must be fractionated. Millings should not exceed 50% of virgin aggregate replacement. If too much binder is present in the TMA, a weak pavement will form, creating potholes and making blade maintenance more difficult (Skorseth and Selim 2000).

2.4.2.4 Geotextile

Over time, the aggregate base of the trail will begin to mix with the subgrade material. This issue is especially critical with aggregate-surfaced trails due to the increased moisture content in the pavement structure and the lack of load dissipation provided by a concrete or asphalt surface. It is recommended that a geotextile (either woven or nonwoven) be used as a separator between the subgrade and aggregate base for aggregate trails. The geotextile must be able to withstand construction traffic in order to be an effective part of the pavement structure.

Generally, nonwoven geotextiles are better for separation, drainage, and reinforcement. However, woven geotextiles are better for reinforcement layers, but they provide poor drainage compared to a similar nonwoven material.

2.4.2.5 Bituminous Surface Treatments

At the agency's discretion, a bituminous surface treatment can be used instead of a TMA surface. It is recommended that an A-2 or A-3 surface treatment be used, as described in SSBRC Section 403. An A-1 surface treatment can be used for maintenance purposes, but a more robust, thicker surface treatment should be applied over an aggregate base course. The agency can choose the emulsion types and aggregate type and size to achieve the desired surface on the trail.

2.4.3 Thickness Design

Unlike asphalt and concrete surfaces, aggregate surfaces have no significant temperature dependency. For the aggregate trail design, construction traffic and pavement use factors are considered. The aggregate-surfaced design methodology is summarized in Figure 6.

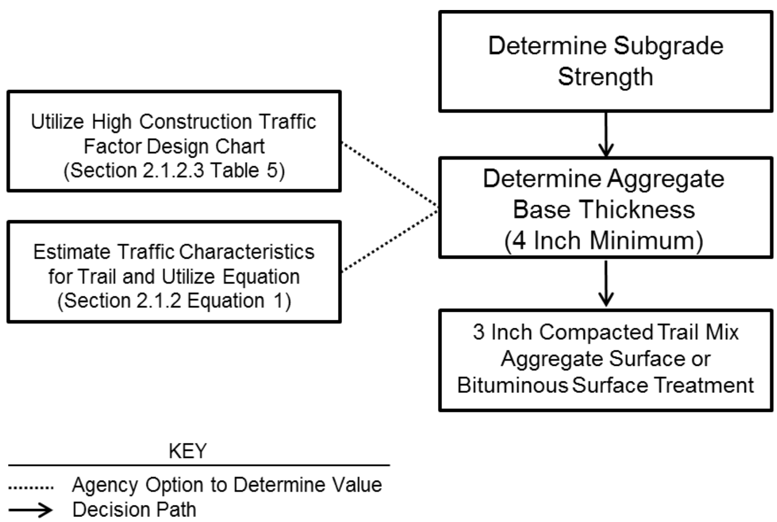

Figure 6. Aggregate trail design methodology.

2.4.3.1 Aggregate Base Thickness

A TMA or bituminous surface treatment provides minimal load dispersal; therefore, all traffic on the trail can be assumed to be construction traffic on the subgrade and aggregate base, as discussed in Section 2.1.2. It is recommended that the required aggregate base thickness be determined by Equation 1, with the agency estimating both the frequency and the characteristics of traffic on the trail. If these aspects are unknown, the subgrade thickness design table for the high-construction traffic factor (Table 5) can be used with a minimum aggregate base thickness of 4 inches.

2.4.3.2 TMA Thickness

TMA should be placed in a 3-inch compacted lift (Center for Dirt and Gravel Road Studies 2011). This recommendation is applicable to all pavement use factors because the aggregate base will be the main load-bearing element of the pavement structure. As discussed in Section 2.4.2.5, a bituminous surface treatment can be used in place of a TMA surface.

2.5 CROSS-SECTIONAL GEOMETRICS

2.5.1 Aggregate Base

To achieve adequate construction and future trail performance, it is important to extend the aggregate base beyond the planned edge of the trail surface. During construction, this additional width will aid in the compaction of both asphalt and TMA surfaces. For concrete pavements, the aggregate base must be wide enough to support paving equipment or formwork, depending on construction technique.

Additional aggregate base width provides better trail pavement performance by preventing edge degradation of the pavement surface. This is accomplished by providing adequate support for the entire width of the pavement and providing some protection from potential undercut by flowing water.

It is recommended that the aggregate base be extended 12 to 24 inches beyond the edge of the pavement surface. The final value will be an agency decision, based on past experience, pavement surface material chosen, and dimensions of paving equipment used.

2.5.2 Surface Cross Slope

Maintaining a cross slope prevents standing water on the trail surface, which enhances pavement performance. Since drainage times are not generally critical on trail surfaces (few users during adverse weather and relatively narrow pavement widths), it is recommended that the pavements have a constant slope to one side. Constant slopes are easier to construct, and they provide better surface thickness consistency compared to crowned surfaces. Depending on the surrounding land profile, a constant slope may also reduce the trail's drainage system requirements because ditches may be required on only one side. Additionally, a constant slope allows for easier snow removal and brooming.

Although a constant slope is recommended, the end goal is to prevent water from standing on the pavement. Therefore, the agency can choose whichever sloping method suits its needs. Care should be taken to follow local standards and ADA guidance, where applicable.

CHAPTER 3 TRAIL PAVEMENT MAINTENANCE STANDARDS

All pavement maintenance standards discussed in this section focus on the pavement from a structural standpoint and address topics that directly relate to the pavement structure or to factors that can affect the pavement structure. Foliage maintenance, signage, aesthetics, and other similar topics are not discussed. Discussion on these maintenance items can be found in Chapter 17 (Bicycle and Pedestrian Accommodations) of IDOT's *Bureau of Design and Environment Manual.*

3.1 ASPHALT-SURFACED TRAILS

3.1.1 Construction Characteristics to Prevent Maintenance Issues

3.1.1.1 Pop-ups

Pop-ups refer to small eruptions in the asphalt pavement surface, generally caused by weed growth. Weed growth can occur both underneath and within the pavement structure. An example of this distress can be seen in Figure 7.

Figure 7. Pop-ups through the HMA layer (ODOT).

The first step to preventing pop-ups and achieving a quality pavement is thorough grubbing to remove all vegetation from the projected trail site.

To further prevent pop-ups due to plant growth from underneath the pavement structure, a soil treatment placed on the prepared subgrade prior to base coarse installation may be effective. The Ohio Department of Transportation's (ODOT) *Design Guidance for Independent Bicycle Facilities* (2005) recommends use of herbicides/soil sterilants that reach approximately 1 foot below the surface of the subgrade.

In addition, a geotextile fabric can be used (with or without the soil sterilant) to provide protection against pop-ups. Before use, it must be ensured that the geotextile will survive construction and compaction of the aggregate base that will be placed over it. A nonwoven geotextile with a weight of 4 to 6 ounces is acceptable for use.

If pop-ups occur after construction, the affected area should be patched as described in Section 3.1.2.2, ensuring that the organic matter has been removed from the pavement structure and herbicide has been applied.

3.1.1.2 Organic Pop-Outs

Pop-outs are generally caused by organic matter being deposited into haul vehicles during construction. An example of this distress can be seen in Figure 8.

Figure 8. Pop-out caused by sweetgum ball within the HMA layer (Luttrell et al. 2004).

It is recommended that foliage in the proposed construction site be trimmed back to allow free passage of the proposed construction vehicles. Additionally, haul vehicles carrying asphalt should remain covered until they are ready to feed into the paver.

If pop-outs occur after construction, the affected area should be patched as described in Section 3.1.2.2, ensuring that the organic matter has been removed from the pavement structure.

3.1.1.3 Raveling of Pavement Edges

Raveling of asphalt surfaces on the edges of the pavement is a common concern in the use of HMA pavement. Generally, the most significant issues caused by raveling are increased rates of oxidation and stripping in the localized area. However, loose aggregate on the pavement surface, along with decreased aesthetics, make raveling an undesirable distress.

The main cause of edge raveling is lack of compaction on the edges of the pavement. Obtaining proper compaction in a HMA layer requires the underlying material to have sufficient strength. Therefore, it is recommended that the compacted subgrade and base exceed the width of the asphalt layer and that the prepared subgrade and base extend on either side of the planned asphalt layer (West 2005). As discussed in Section 2.5, an aggregate base should be extended between 12 and 24 inches from the planned pavement edge.

3.1.1.4 Root Infiltration

Tree roots can cause upheaval in asphalt pavements. There are three methods to reduce or eliminate the impact of tree roots on pavements. Two of the methods are implemented during construction of the trail, while the final method is a recurring maintenance item.

The first method is simply keeping the trail horizontally separated from trees. It is recommended that the trail be located at least 1 foot away for each inch of mature trunk diameter from the nearest tree, with a minimum of 6 feet (Luttrell et al. 2004). This method might not be possible if a sufficient right-of-way is not available. This technique is also difficult to implement in areas with immature trees because final trunk diameter and extent of root growth may be difficult to estimate.

The second method involves installing a root barrier at the edge of the pavement. The top edge of the root barrier should be slightly above the ground surface and extend to a depth of at least 1 foot (Luttrell et al. 2004). A diagram of this method can be seen in Figure 9. A number of different rigid root barrier products are available on the market. These generally are available from 12 inches to 48 inches in depth, if additional protection is desired. Additionally, many are manufactured from recycled polyethylene, which can increase the amount of recycled materials used on the project. Root barriers can generally be obtained from landscape supply companies.

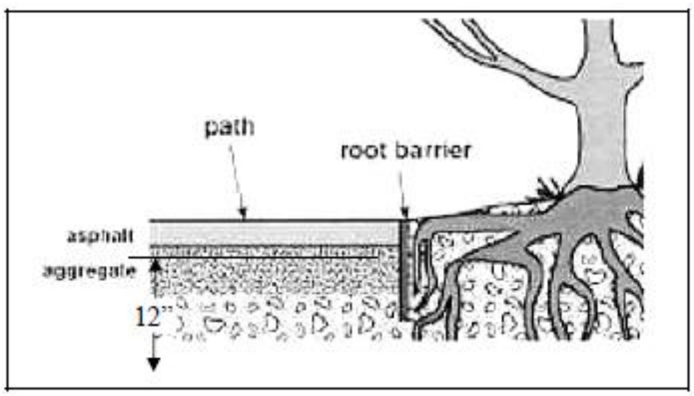

Figure 9. Root barrier installation diagram (Luttrell et al. 2004).

The final method involves physically cutting tree roots at the trail edge on a regular basis. Cutting should occur vertically along the edge of the shoulder pavement “every couple of years” to prevent tree roots from penetrating the base (ODOT 2005). This method, however, is not recommended because it requires recurring maintenance and can harm the trees.

Root barriers are suggested as the best option, with physically separating the trail from trees as an alternative if space exists. Root barriers should be installed according to the manufacturer’s instructions.

3.1.2 Recurring Maintenance Recommendations

3.1.2.1 Crack Sealing

Cracks that have an opening wide enough to accept a bike tire pose a safety hazard. Crack sealing offers the same advantages on bicycle trails as it does on highway pavements and should be performed with the same materials and methods as used on road pavements. Details about proper installation and equipment are detailed in SSBRC Section 451.

Acceptable materials are listed in SSBRC Section 1050.02 (which specifies ASTM D6690 Type II material).

3.1.2.2 Patching

Areas where cracks in the pavement exceed 0.5 inch or where HMA pavement degradation has occurred should be patched. Since HMA thicknesses are relatively thin on bicycle trails, full-depth patches are recommended. Patch sizes should be determined based on equipment used to compact the patch and surrounding distresses. A single large patch repair is generally more cost effective and of higher quality than a repair made with numerous small patches.

The patch perimeter should be sawcut to ensure a relatively straight, smooth, uniform edge for patch construction. If available, a tack coat material should be applied to the patch edges prior to placing the patch material. Under no circumstances should the edges of the pavement be heat treated or torched prior to the installation of patching material. Upon HMA removal, if it is determined that the distress stems from an issue within the base material or subgrade, the problem should be investigated and rectified prior to patch installation.

A patch size with dimensions no smaller than 2 by 3 feet is recommended to ensure adequate compaction can be completed with a plate tamper. The use of larger compaction equipment will require a larger patch size. Lift thickness will also be dependent on the compaction equipment used. Lift thickness should not exceed 3 inches for plate tampers to ensure that adequate compaction is obtained throughout the entire patch depth.

While cold-mix emulsified asphalt can be used, a hot-mix material is recommended. Cold-mix products often rapidly degrade due to difficulty of compaction and low-quality materials, producing loose material on the trail surface and potentially leaving large drop-offs where the patch and existing pavement intersect. Cold mix should be used only in emergency situations until a HMA patch can be installed.

The final patch surface should be slightly above the surrounding pavement. Due to the low traffic and load levels, little compaction under traffic of the patch material is likely to occur. However, excessive patch settlement will create areas where water could pond, resulting in potential user safety issues as well as an increased rate of pavement deterioration in that area.

Ideally, the patch perimeter should be filled with joint sealant upon completion; however, doing so may be cost prohibitive. In that case, the patch perimeter should be sealed at the next scheduled joint sealing.

3.1.2.3 Surface Sealing

Controlling oxidation and surface distresses, along with filling small cracks, is the primary goal of surface sealing. A variety of products are recommended by a number of different agencies.

ODOT recommends an emulsified, gilsonite-modified, pavement sealer and rejuvenator. Immediately after the sealer is applied, black silica sand is distributed over the emulsion to fill minor voids and provide increased friction. ODOT suggests that a seal coat be applied every 5 years.

The City of Davis, California, suggests a “cold applied composition of a refined petroleum asphalt emulsion, mineral fibers, and inert fillers.” It is suggested that this seal coat product be applied “as soon after paving as is practical” (City of Davis 2009).

In addition to these products, any product that meets the seal coat specifications in SSRBC Section 1032.06-1032.09 could be used.

While it is recommended that surface sealing is completed on bicycle trails, no particular product is recommended. From a pavement standpoint, any product that helps rejuvenate the pavement and prevent oxidation is desired. How this product affects trail users is outside of the scope of this study. Therefore, it is suggested that the jurisdiction in charge of maintenance select a material that provides the desired final surface texture and friction.

3.1.2.4 Surface Treatments

While chip sealing and slurry sealing are maintenance options on bicycle trails, they should be used with caution. Chip seals have the potential to produce a number of undesirable effects, including loose aggregate on the pavement surface, rough pavement surface, and tracking of emulsion on hot days. Slurry seals may not provide the necessary friction characteristics for users and might track emulsion excessively during hot weather.

From a pavement maintenance standpoint, both of these techniques will extend the life of asphalt pavement. Once again, the jurisdiction in charge of maintenance can use these techniques if desired, assuming potential user drawbacks are also considered. Because of the possible undesirable affects associated with surface treatments, they are not considered in the recurring maintenance schedule or the life cycle cost analysis.

3.1.2.5 Major/End-of-Life Rehabilitation

Thin bicycle trail pavements are not good candidates for mill and overlay operations. First, any distress visible on the surface of the pavement generally will be present throughout the pavement layer. Second, the weight of the milling machine and subsequent construction traffic associated with mill and overlay operations will likely destroy the remaining milled surface.

Three major rehabilitation options are presented in this section. Note, however, that if widespread subgrade issues are suspected, removal and replacement (including remediation of the subgrade) is the only option. All other rehabilitation methods can only treat issues in the base material or pavement layer. If only localized base and subgrade issues are observed, they must be corrected through removal and replacement before any other major rehabilitation option is undertaken.

First, assuming the existing pavement is in good condition, a HMA overlay can be completed. Distresses in the existing pavement (underlying the overlay) must first be repaired and cracks sealed. A minimum 2-inch HMA layer, meeting the same mix characteristics for new pavements, as suggested in this report, should be placed. The minimum 2-inch design thickness is to ensure adequate overlay depth, taking construction variability into consideration, and it will minimize problems associated with debonding of thin, poorly bonded overlays. Once again, this is a viable option only if the existing pavement is in good condition.

An issue with the overlay option is that reflective cracking will eventually propagate through the overlay. As a result of low loading, reflective cracks will not propagate as quickly as in roadway pavements because there will be little vertical pavement movement as loads traverse the cracks and distresses. Instead, most crack movement will be horizontal, due to thermal effects. The softer binder grade used on bicycle trails will also extend reflective crack propagation times.

A number of methods are available to further counteract reflective cracking with the overlay option. If existing cracks are relatively straight, their locations can be identified and the overlay can be sawed and sealed to help control reflective cracking. Additionally, a number of interlayer systems could be used, such as an interlayer stress-absorbing composite to achieve base separation. Agency experience with reflective crack control on roadway pavements can also be used to identify possible techniques.

Any method used to minimize reflective cracking will only delay their propagation—there is no way to prevent reflective cracking. In spite of the reflective crack issue, however, a HMA overlay may still be a desirable solution. An overlay will result in a thicker asphalt layer, which will improve the structural capacity of the trail. The overlay method also does not require removal of the original pavement surface, thereby reducing construction time and expense.

Second, ultra-thin whitetopping can be used to overlay the distressed HMA. Ultra-thin whitetopping typically involves the use of a 2- to 3-inch-thick fiber composite concrete. Joints are sawn into the concrete to create small square slabs, generally with the length of a side between 2 and 6 feet, depending on overlay thickness. When utilizing this method for a low-volume, low-load pavement such as a bicycle trail, sweeping is the only preparation needed for the asphalt pavement prior to concrete overlay placement. Additional information on design and placement can be found in the National Concrete Pavement Technology Center's *Guide to Concrete Overlays* (Harrington 2008). Additionally, design and construction of ultra-thin whitetopping is discussed by Roesler et al. in *Design and Concrete Material Requirements for Ultra-Thin Whitetopping* (2008).

Finally, the HMA layer can be completely removed and replaced. This option will remove all pavement distresses and allow for base and subgrade repairs to be completed as needed. Costs could be reduced with this method by recycling the existing pavement. Once the RAP has been fractionated and its properties have been determined, the material can be used in a new HMA mix.

An overview of the distress sources and their major rehabilitation methods discussed in this section is presented in Table 14.

Table 14. HMA Pavement Major Rehabilitation Method Based on Distress Source

Rehabilitation Method	Asphalt Surface Distresses	Asphalt Structural Distress	Base Material Failure	Subgrade Failure
Asphalt Overlay	X			
Ultra-Thin Whitetopping	X	X	X	
Removal and Replacement	X	X	X	X

3.1.3 Recurring Maintenance Schedule

Regular maintenance is recommended to keep trails in good condition and provide for the best long-term performance of the infrastructure. Ultimately, the level of maintenance to be performed will be an agency decision, based on the desired level of serviceability, available funding, and long-term plans.

Table 15 outlines the proposed trail maintenance schedule for HMA-surfaced trails. Time frames for completing the maintenance tasks for the first time are outlined in the middle column. After that, the maintenance tasks should be completed at the regular interval indicated in the far right column. Should material quality or construction issues cause cracking (i.e., thermal cracking) or patch areas (i.e., localized weak spots), these distresses will generally appear in a relatively short time frame—approximately 2 years. Once these initial distresses have been repaired, subsequent distresses should occur at a much slower rate.

Table 15. HMA-Surfaced Trail Maintenance Recommendations

Maintenance Task	First Maintenance Application (years)	Subsequent Maintenance Applications (years)
Check drainage components for proper function	1	1
Identify and complete crack sealing	2	6
Identify and complete patching	2	6
Perform seal coating	4	4

Pavement drainage features, such as ditches and culverts, are not discussed in this report; however, their ability to remove moisture from the vicinity of the pavement is critical to well-performing pavement. Additionally, it is recommended that the maintenance activities take place in a logical order. For example, completing patch work prior to crack sealing will allow for sealant to be installed around the patches. Likewise, completing both patching and crack sealing prior to seal coating will provide the best level of pavement preservation.

The time lines shown for the maintenance tasks are recommendations. A number of real-world factors, such as construction materials, construction technique, trail usage, and environmental conditions, may dictate completion of these tasks more or less frequently than outlined. The time frames shown in Table 15 are used to determine the life-cycle cost of the asphalt-surfaced trail construction option.

3.2 PORTLAND CEMENT CONCRETE–SURFACED TRAILS

3.2.1 Construction Characteristics to Prevent Maintenance Issues

3.2.1.1 Clearing and Grubbing

Vegetation infiltration into the pavement is less of a concern with PCC surfaces than HMA surfaces; however, it is prudent to ensure that all organic materials are grubbed from the proposed trail subgrade prior to construction. The use of herbicides and geotextiles, as described in Section 3.1.1.1, is not as critical with PCC pavements but can be used at the agency's discretion.

3.2.1.2 Root Infiltration

Tree roots can cause faulting of joints in PCC pavements along with disrupting the transverse and longitudinal grade of slabs. Therefore, the same considerations and recommendations described for asphalt trails in Section 3.1.1.4 are valid for PCC trails and should be implemented.

3.2.1.3 Joint Sealing

Joint sealing of PCC pavements is recommended. Any measure to prevent moisture penetration into the pavement structure will increase the serviceable life. If installed properly, joint sealing reduces moisture penetration. Additionally, the sealant will prevent incompressibles from entering the joint, which can cause deterioration. However, the cost versus benefit will need to be determined by the constructing agency. Details about proper installation and equipment are detailed in SSBRC Section 452. Acceptable materials are listed in the SSBRC Section 1050.02 (which specifies ASTM D6690 Type II material).

3.2.2 Recurring Maintenance Recommendations

3.2.2.1 Crack and Joint Sealing

Cracks should be filled as they appear and progress. Especially critical are cracks with a width that could accept a bicycle tire. Additionally, joint material should be removed and replaced during crack-sealing efforts if areas of failure are observed. The methods and materials identified in Section 3.2.1.3 should be used.

3.2.2.2 Patching

In areas where cracks in the pavement exceed 0.5 inch or where there is significant PCC pavement degradation, patching needs to be completed. Since PCC thicknesses are relatively thin on bicycle trails, full-depth patches are recommended. Patch sizes should be determined based on equipment used to compact the aggregate base and/or subgrade and the surrounding distresses. A higher-quality and more cost-effective repair is achieved with a single large patch as opposed to numerous small patches.

The patch perimeter should be sawcut to ensure a relatively straight, smooth, uniform edge for patch construction. Upon concrete removal, if it is determined that the distress stems from an issue within the base material or subgrade, the problem should be investigated and rectified prior to patch installation.

A patch size with dimensions no smaller than 2 by 3 feet is recommended to ensure that adequate aggregate base and/or subgrade compaction can be completed with a plate tamper. The use of larger compaction equipment will require a larger patch size.

The patch should be completed in a manner that does not promote water ponding. This includes proper compaction of subgrade and base materials. Additionally, care should be taken to ensure that the patch is finished in a manner which discourages ponding water.

Ideally, the patch perimeter should be filled with joint sealant upon completion; however, doing so may be cost prohibitive. In that case, the patch perimeter should be sealed at the next scheduled joint sealing.

3.2.2.3 Major/End of Life Rehabilitation

PCC pavements have a number of rehabilitation options, many of which are similar to those proposed for HMA pavement. The options discussed include HMA overlay, in-place rubbilization, and removal and replacement. If widespread subgrade issues are suspected, removal and replacement (including remediation of the subgrade) is the only option. All other rehabilitation methods can only treat issues in the base material or pavement layer. If only localized base and subgrade issues are observed, they must be corrected through removal and replacement before any other major rehabilitation option is undertaken.

Similar to HMA trail pavements, PCC pavements in relatively good condition can be overlaid with HMA. Good candidate pavements include those that have very little faulting or movement at the joints, few full-depth cracks, and no distresses that suggest aggregate base or subgrade failure. Therefore, a HMA overlay will best rectify issues that stem from PCC surface defects, such as spalling and aggregate pop-outs. However, reflective cracking will again be an issue with this approach; therefore, crack control methods discussed in Section 3.1.2.5 should be used, and the agency needs to be aware of the possible increased rate of deterioration of the asphalt overlay.

The existing PCC pavement can also be rubbilized, thus turning the pavement into additional base material. After rubbilization, the material must be compacted. Then a new PCC or HMA pavement can be installed. This method eliminates the reflective cracking issues with a HMA overlay directly on the existing concrete pavement. Additionally, it eliminates the expense of hauling the existing pavement off-site for disposal or processing into recycled materials. However, if subgrade problems are suspected, rubbilization should not be completed. These subgrade problems will manifest themselves in the rubbilized layer and again cause failure in the new pavement layer.

An overview of the distress sources and their major rehabilitation methods discussed in this section is presented in Table 16.

Table 16. PCC Pavement Major Rehabilitation Method Based on Distress Source

Rehabilitation Method	**Concrete Surface Distresses**	**Concrete Structural Distress**	**Base Material Failure**	**Subgrade Failure**
Asphalt Overlay	X			
Rubbilization	X	X	X	
Removal and Replacement	X	X	X	X

3.2.3 Recurring Maintenance Schedule

The following trail maintenance schedule is recommended to keep trails in good condition and provide for the best long-term performance of the infrastructure. Ultimately, the level of maintenance to be performed will be an agency decision, based on the desired level of serviceability, available funding, and long-term plans.
Table 17 outlines the proposed trail maintenance schedule for PCC-surfaced trails.

Table 17. PCC-Surfaced Trail Maintenance Recommendations

Maintenance Task	**Maintenance Interval (years)**
Check drainage components for proper function, no pooling water	1
Identify and complete joint and crack sealing	6
Identify and complete patching	6

Pavement drainage features, such as ditches and culverts, are not discussed in this report; however, their ability to remove moisture from the vicinity of the pavement is critical to well-performing pavement. Additionally, it is recommended that the maintenance activities take place in a logical order. For example, completing patch work prior to crack sealing will allow for sealant to be installed around the patches.

The time lines shown for the maintenance tasks are recommendations. A number of real-world factors, such as construction materials, construction technique, trail usage, and environmental conditions, may dictate completion of these tasks more or less frequently than outlined. The time frames shown in Table 17 are used to determine the life-cycle cost of the PCC-surfaced trail construction option.

3.3 AGGREGATE-SURFACED TRAILS

3.3.1 Construction Characteristics to Prevent Maintenance Issues

As with paved trails, it is necessary to ensure that aggregate trails are crowned or have a consistent cross-slope to facilitate water drainage from the surface of the pavement. A 4% crown is suggested on gravel roads (Skorseth and Selim 2000). However, that may be extreme for bicycle trail construction. First, the ADA specifies that the maximum cross-slope be 2%. Additionally, a 4% slope might not be necessary, since aggregates used to surface bicycle trails are generally smaller than aggregates used for gravel roads, allowing for adequate drainage at a lower cross-slope. It is critical to keep water from ponding on the trail surface by directing water from the surface to the ditches along the trail or other drainage infrastructure.

3.3.2 Recurring Maintenance Recommendations

While most distresses on aggregate trails can be addressed with “spot fixes,” or localized aggregate placement and compaction, occasionally a larger-scale project may be needed. Over time, erosion, standing water, and traffic will distort the surface of the aggregate trail. These distortions will both accelerate degradation and decrease user satisfaction. Proper grading, shaping, and addition of surface material may be required to combat this issue. Additionally, the agency may choose to re-compact the surface of the trail, depending on the depth of disturbed material during grading operations or the amount of new surface material added. A higher level of compaction will reduce moisture infiltration into the pavement structure and decrease surface erosion.

3.3.3 Recurring Maintenance Schedule

The following trail maintenance schedule is recommended to keep trails in good condition and provide for the best long-term performance of the infrastructure. Ultimately, the level of maintenance to be performed will be an agency decision, based on the desired level of serviceability, available funding, and long-term plans.

Table 18 outlines the proposed trail maintenance schedule for aggregate-surfaced trails.

Table 18. Aggregate-Surfaced Trail Maintenance Recommendations

Maintenance Task	Maintenance Interval (years)
Check drainage components for proper function, no pooling water	1
Spot fixes/localized grading and shaping	1

Pavement drainage features, such as ditches and culverts, are not discussed in this report; however, their ability to remove moisture from the vicinity of the pavement is critical to well-performing pavement. Additionally, it is recommended that the maintenance activities take place in a logical order. For example, ditch maintenance will cause degradation of the traffic surface and profile. Therefore, to provide the highest level of trail service, ditch maintenance should be performed prior to grading and shaping of the trail.

The time lines shown for the maintenance tasks are recommendations. A number of real-world factors, such as construction materials, construction technique, trail usage, and environmental conditions, may dictate completion of these tasks more or less frequently than outlined. The time frames shown in Table 18 are used to determine the life cycle cost of the aggregate-surfaced trail construction option.

CHAPTER 4 LIFE-CYCLE COST ANALYSIS

Bicycle trails are constructed in a variety of locations. Based on construction location and site conditions, construction costs vary widely. Studies of asphalt trails show costs in the range of $45,000 to $833,000 per mile, while studies on aggregate trails found costs ranging from $23,000 to $370,000 (Luttrell et al. 2004). Obviously, very poor subgrade materials, intense grubbing with tree removal, and difficult site access increase the per-mile cost. Therefore, the costs and quantities involved in the life-cycle cost analysis follow “average” trail construction requirements and maintenance needs.

This chapter first presents a discussion of quantities and costs and then presents the life-cycle cost analyses. The analyses include only those aspects discussed in this report, which focus solely on the pavement system. The analyses do not consider costs for drainage components, shoulders, signage, trail heads, intersections, or traffic control markings.

For tasks that closely correspond to an SSBRC coded pay item, costs were determined based on the most recent IDOT pay item report available with sufficient quantities to calculate a realistic, representative cost. Costs were estimated for those tasks that did not have a closely corresponding SSBRC coded pay item based on material, labor, and equipment components of the task.

4.1 COST ANALYSIS OF DIFFERENT SURFACE TYPES

Some surface types have a lower initial construction cost, but the initial savings may be overcome by increased maintenance costs associated with the trail surface. This section examines the 20-year costs associated with each trail type, without considering an end-of-life rehabilitation method. This analysis assumed that the trail surface will either be in satisfactory condition after the 20-year period or the reduced level of surface is allowable.

Design inputs for pavement design vary based on factors discussed in Chapter 2. However, for all the analyses in this section, the following inputs were used:

- Regular-duty pavement use factor
- Medium subgrade traffic factor
- Subgrade = IBR 3
- High water table (within 20 inches of the bottom of the aggregate base)
- 10-foot trail width
- 1 mile (5280 feet) trail length segment

The following construction assumptions were used for all analyses in this section:

- The top of the constructed pavement layer matches the existing grade. For example, if the pavement structure (aggregate base and surface material) is 7.5 inches thick, the top 7.5 inches of in situ material on the trail alignment will be removed.
- No additional grubbing or material removal is required beyond the depth of removal necessary for the constructed pavement layer to match the existing grade.
- Trees are within close proximity to the trail for 20% of its overall length. For this example, 1056 feet of root barrier will need to be installed for the 1-mile trail segment.

- Mobilization and demobilization were estimated at 10% of the project value for both the initial construction and maintenance actions.
- Site engineering and construction management tasks were estimated at 5% of the initial construction value. No site engineering and construction management costs were applied to the maintenance items.

The life-cycle cost analysis used a 3% discount rate. The salvage value was based on the remaining life of a maintenance procedure at the end of the analysis period. A prorated value of the maintenance procedure was used as the salvage value.

Present worth was determined by Equation 11.

$$PW = MC_k\left(\frac{1}{(1+i)^{n_k}}\right) \tag{11}$$

where MC_k is the maintenance cost in year k, i is the discount rate, and n_k is the year of expenditure.

4.1.1 Conventional Hot-Mix Asphalt Surface

Based on the design inputs for this cost analysis, the pavement is composed of 4.5 inches of aggregate base with a 3-inch HMA surface. The following assumptions were used when calculating the initial construction cost:

- Prime coat will be applied to the aggregate base at a rate of 0.50 gallons per square yard.
- The HMA surface will be constructed in one lift on top of the aggregate base. This requires the use of the IL-9.5L mix asphalt.
- The compacted HMA mat will have a density of 112 pounds per square yard per inch of thickness.

The following assumptions were made about maintenance:

- Patching—1% of the pavement surface area will require patching after the first 2 years. For each subsequent 6-year period, 1% of the pavement surface area will require patching. For this analysis, all patches will be Class D, Type II patches as described in the SSBRC.
- Crack Sealing—After the first 2 years, a length equal to 10% of the pavement length will require crack sealing. For each subsequent 6-year period, a length equal to 7% of the pavement length will require crack sealing. All cracks will be routed prior to sealing. Sealant material will be installed at 0.4 pounds per linear foot.
- Seal Coat—Application will be at 0.2 gallons per square yard.

Since all maintenance actions will have no life remaining at the end of the analysis period, no salvage value is included in the analysis.

4.1.2 Conventional Portland Cement Concrete Surface

Based on the design inputs for this cost analysis, the pavement is composed of 4.5 inches of aggregate base with a 5-inch slab thickness. The following assumptions were used when calculating the initial construction cost:

- Dowel bars at construction joints and expansion joints (if needed) are included in the unit cost for the PCC pavement.

The following assumptions were made about maintenance:

- Patching—For each 6-year period, 1% of the pavement surface area will require patching. For this analysis, all patches will be Class C, Type II patches as described in the SSBRC.
- Crack Sealing—For each 6-year period, a length equal to 10% of the pavement length will require crack sealing. All cracks will be routed prior to sealing. Sealant material will be installed at 0.4 pounds per linear foot.

A salvage value was included, since the final set of maintenance tasks performed at year 18 will still have 4 years of life at the end of the analysis. Therefore, the salvage value was equal to 67% of the year 18 maintenance costs.

4.1.3 Aggregate Surface

Based on the design inputs for this cost analysis, the pavement is composed of 7 inches of aggregate base with a 3-inch TMA surface. The following assumptions were used when calculating the initial construction cost:

- The aggregate surface will have a compacted density of 100 pounds per square yard per inch.
- No root barrier will be installed because surface irregularities caused by tree roots will be negligible compared to surface irregularities caused by other environmental factors.

The following assumptions were made about maintenance. Since maintenance on aggregate paths consists primarily of manual labor, the following assumptions include personnel, vehicular, and material costs:

- It will require 4 man hours of labor per month to keep the 1-mile length of trail in satisfactory condition. The manual labor will be provided by a single person. This equates to 48 man hours per year. Personnel costs are based on the March 2012 prevailing wage for Champaign County, which includes the base rate, health and welfare insurance, pension, and training (Illinois Department of Labor, n.d.).
- Five hundred pounds of aggregate surface material will be required for maintenance per year.
- One pickup truck will be required during these maintenance activities. Vehicle cost is based on the 2004 IDOT *Schedule of Average Annual Equipment Ownership Expense*, using the 2011 calendar-year index factor (most current available).

Since no maintenance actions will have life remaining at the end of the analysis period, no salvage value was included in the analysis.

4.1.4 Conclusion

Detailed spreadsheets entailing quantities, unit prices, and present values can be found in Appendix A. For convenience, the final cost figures for each trail type are summarized in Table 19.

Table 19. Pavement Type Cost Analysis Summary

Pavement Surface Type	Initial Cost ($)	Present Worth Rehab Cost ($)	Present Worth Total Cost ($)
Conventional HMA Concrete	173,679.96	21,436.88	195,116.83
Conventional Portland Cement Concrete	306,141.80	10,143.53	314,524.18
Aggregate Surface	158,084.96	38,401.53	196,486.49

4.2 COST ANALYSIS OF DIFFERENT PAVEMENT USE FACTORS

Some trail locations might dictate the pavement use factor used for design. Cost savings can be realized if traffic types on the trail pavement can be limited. This section examines the potential savings from a lower pavement use factor.

Design inputs vary from area to area. However, the following inputs were used for all analyses in this section:

- Medium subgrade traffic factor
- Subgrade = IBR 4
- Low water table (deeper than 20 inches from the bottom of the aggregate base)
- 10-foot trail width
- 1 mile (5280 feet) trail length segment

The following construction assumptions were used for all analyses in this section:

- The top of the constructed pavement layer matches the existing grade. For example, if the pavement structure (aggregate base and surface material) is 7.5 inches thick, the top 7.5 inches of in situ material on the trail alignment will be removed.
- No root barrier is needed.
- Mobilization and demobilization were estimated at 10% of the project value, for the initial construction.
- Site engineering and construction management tasks were estimated at 5% of the initial construction value.

For this comparison, a conventional PCC surface was evaluated for both a mile of trail built under the regular-duty pavement use factor and a mile of trail built under the heavy-duty pavement use factor. Since the same surface material was used for this analysis, the maintenance costs were the same. Therefore, only initial costs were examined.

Using the design procedure outlined in Chapter 2, 3 inches of aggregate base are needed based on the subgrade traffic factor, IBR, and water table location. A 5-inch-thick PCC slab is needed for the regular-duty pavement use factor, and a 7-inch-thick PCC slab is needed for the heavy-duty pavement use factor.

Detailed spreadsheets entailing quantities, unit prices, and present values can be found in Appendix B. For convenience, the final cost figures for each trail type are summarized in Table 20.

Table 20. Conventional PCC Surface
Pavement Use Factor Cost Analysis Summary

Pavement Use Factor	**Initial Cost ($)**
Light Duty/Regular Duty	295,302.69
Heavy Duty	377,972.58

4.3 COST ANALYSIS OF DIFFERENT CONSTRUCTION TRAFFIC FACTORS

The trail alignment and surroundings may dictate the construction traffic factor. In some locations, innovative thinking about construction sequences and processes may allow an agency to use a lower construction traffic factor.

Design inputs vary from area to area. However, the following inputs were used for all analyses in this section:

- Regular-duty pavement use factor
- Subgrade = IBR 2
- Low water table (deeper than 20 inches from the bottom of the aggregate base)
- 10-foot trail width
- 1 mile (5280 feet) trail length segment

The following construction assumptions were used for all analyses in this section:

- The top of the constructed pavement layer matches the existing grade. For example, if the pavement structure (aggregate base and surface material) is 7.5 inches thick, the top 7.5 inches of in situ material on the trail alignment will be removed.
- No root barrier is needed.
- Mobilization and demobilization were estimated at 10% of the project value, for the initial construction.
- Site engineering and construction management tasks were estimated at 5% of the initial construction value.

For this comparison, a conventional HMA surface was evaluated for both a mile of trail built under the medium construction traffic factor and a mile of trail built under the high construction traffic factor. Since the same surface material was used for this analysis, the maintenance costs were the same. Therefore, only initial costs were examined.

Using the design procedure outlined in Chapter 2, 4.5 inches of aggregate base are needed for the medium construction traffic factor and 7 inches of aggregate base are needed for the high construction traffic factor. A 3-inch HMA mat is placed over both aggregate bases.

Detailed spreadsheets entailing quantities, unit prices, and present values can be found in Appendix C. The final cost figures for each trail type are summarized in Table 21.

Table 21. Conventional Asphalt Surface
Construction Traffic Factor Cost Analysis Summary

Construction Traffic Factor	Initial Cost ($)
Medium	169,186.68
High	212,536.34

CHAPTER 5 REVIEW OF EXISTING BICYCLE TRAILS

A concise discussion comparing the existing trails that were observed with the proposed design and maintenance recommendations is presented in this chapter. More detailed discussion on the existing trail visits, with pictures, is provided in Appendix D.

5.1 CENTRAL REGION

Three different trail surface types were observed in the central region: PCC, HMA, and aggregate/bituminous surface treatment trails. Agencies responsible for construction and maintenance included a city public works department, a city park district, and a community group. For additional details, see Section D.1.

5.1.1 Portland Cement Concrete Surface

The three PCC surface trails fell under the low construction traffic factor and regular-duty pavement use factor. The structural pavement section of all three trails was similar, with a 5-inch-thick PCC slab placed on top of compacted subgrade. The design methodology outlined in this document calls for a 5-inch-thick PCC slab on a 3- to 4-inch-thick compacted aggregate base.

The trails were in good condition overall. Patching at joints was evident on one of the trails. All three trails had low severity misalignment at transverse joints. The trail design provided poor drainage away from the trail pavement structure. The addition of aggregate base to the existing trail structure, along with better drainage, would likely reduce the joint misalignment issues.

Small aggregates were broken away from the concrete matrix during the sawcutting of contraction joints. Better construction techniques and quality assurance/quality control would have minimized this problem.

Minimal scheduled maintenance has occurred on the trail. The majority of maintenance has been completed on an as-needed basis.

5.1.2 Asphalt Surface

The existing HMA surface trail fell under the medium construction traffic factor and a light or regular-duty pavement use factor. The exact structural design of the pavement was unknown; however, the HMA thickness was thick enough to withstand a 1.25-inch mill and overlay. Therefore, it can be assumed that the HMA layer was at least 3.5 to 4 inches. The aggregate base thickness was also unknown. Other trails constructed by the agency were 6-inch, full-depth HMA; thus, it is possible that the trail was built on compacted subgrade.

Based on the design methodology presented in this document, a conventional pavement design of a 3-inch HMA layer with a 3- to 6-inch aggregate base would be used in this situation. If an IBR 6 subgrade is assumed, full-depth pavement design would require a 4-inch HMA layer.

The existing trail was overlaid using an IL-9.5L mix with PG 58-22 binder, allowing 30% RAP. The design methodology outlined in this document would have called for an IL-9.5L mix design or a combination of an IL-4.75 surface with either IL-9.5L or IL-19.0L leveling binder course. Based on the binder selection table provided in this report, a binder grade of PG 58-28 would be required, with a maximum of 15% RAP.

A myriad of cracking-type distresses were observed on this trail. Thermal cracking had occurred at regular intervals. This was likely due to the combined effects of using a stiff binder along with a relatively high level of RAP. In addition to the thermal cracking, there was also consistent longitudinal cracking along one edge of the pavement. This longitudinal cracking was likely due to either poor drainage or poor compaction. Improved edge compaction could be achieved if the aggregate base was extended 12 to 24 inches beyond the proposed edge of the pavement. Finally, there was some localized centerline cracking, likely due to paver segregation. This highlights the need for good construction practices and use of quality equipment in a good state of repair.

Since the overlay was placed, no maintenance has occurred on the trail.

5.1.3 Aggregate/Bituminous Treatment Surface

The aggregate trail observed was composed of a 6-inch aggregate base and a 2-inch FA-20 aggregate surface on some portions of the trail and an A-2 bituminous surface treatment on other portions of the trail.

Based on the design methodology presented in this report, an aggregate trail would consist of a woven or nonwoven geotextile, a 4- to 9-inch aggregate base, and a 3-inch TMA surface or an A-2 surface treatment.

The aggregate portion of the existing trail was in good condition; however, like all aggregate surfaces, the FA-20 surface was being displaced by water. It is expected that the TMA blend proposed in this report, with a greater percentage of plastic fines along with a larger top aggregate size than an FA-20 material, would help to prevent some of the aggregate migration due to flowing water and other environmental effects.

The bituminous surface treatment portion of the trail was performing well. No maintenance had been performed on the surface treatment, and there was no evidence of any structural issues or excessive bleeding of the emulsion. However, like all bituminous surface treatments, a rough and sometimes uneven surface was present on the trail, along with some loose gravel.

Good shoulder support was present on both the aggregate and surface treatment portions of the trail, which helped to prevent excessive displacement or deterioration of the surface material at the edges of the trail. Extending the aggregate base 12 inches to 24 inches beyond the planned edge of the trail surface, as recommended in this report, should ensure performance in this area.

Maintenance on the aggregate portion involved the use of hand tools to replace and spread the aggregate surface that had been eroded. This was completed on an as-needed basis.

5.2 SOUTH REGION

Three different trail surface types were observed in the south region: Portland cement concrete, hot-mix asphalt, and aggregate/bituminous surface treatment trails. Agencies responsible for construction and maintenance included a regional mass transit district, a state park, and the federal government. For additional details, see Section D.2.

5.2.1 Portland Cement Concrete Surface

The observed PCC trail fell under the medium to high construction traffic factor and the regular-duty pavement use factor. The structure consisted of a 6-inch aggregate base and a 4-inch concrete slab. Contraction joints were tooled at approximately12-foot intervals, and expansion joints were installed every 100 to 120 feet. The design methodology outlined in this report calls for a 5-inch slab with a 3- to 9-inch aggregate base, depending on subgrade conditions and construction traffic factor.

Overall, the trail was performing very well. Although the expansion joints were not sealed, they were in good condition. The tooled contraction joints were in good condition; however, tooling as opposed to sawcutting joints makes for a somewhat rougher riding surface.

The only issues were an occasional shattered slab due to the heavy equipment used for removing trees that fell across and blocked the trail. In most cases, these slabs had been patched. However, if a high number of downed trees are expected, along with frequent use of heavy equipment, the heavy-duty pavement use factor could have been used in this area to reduce the need for repairs.

No maintenance had been completed on the trail since construction.

5.2.2 Asphalt Surface

Two hot-mix asphalt trails were observed, each with a different pavement structure. However, both trails fell under the high construction traffic factor and regular-duty pavement use factor based on their location (atop railroad beds) and the agency's maintenance vehicles.

The first trail observed was completed in 1995. It was composed of a 6-inch aggregate base placed on the graded existing ballast material. A 2-inch-thick HMA layer was then placed. A mix comparable to an IL-9.5 mix with 50 design gyrations and a PG 64-22 binder grade was used.

The second trail observed was built in 2003 and incorporated changes to the agency's standard design. It was composed of a geogrid placed over the graded existing ballast. A 6-inch aggregate base was placed over the geogrid and was topped with a 3-inch-thick HMA layer. An IL-9.5 mix with 50 design gyrations and a PG 64-22 binder grade was used. Additionally, the agency extended the aggregate base 12 inches on either side of the HMA surface.

Based on the methodology in this report, both trails would consist of a 4- to 9-inch aggregate base and a 3-inch HMA layer. Likewise, the PG 64-22 binder used would match the current recommended binder grade.

Both trails were maintained with similar practices. Crack sealing with a hot-applied bituminous sealant was completed on an as-needed basis. Sealing occurred when the crack reached a thickness of 1/8 inch or greater. Patching had been completed where necessary. Patch dimensions were sufficient (smallest observed dimension was 3 feet) to allow for adequate compaction of the patch.

The main issues with the trail built in 1995 were tree root infiltration and some areas with inadequate shoulder support. Overall, the trail was in good condition. Because the trail alignment was fixed, additional tree removal or installation of a root barrier would have helped to prevent this issue. Extending the aggregate base would have helped to prevent the shoulder support issues.

The design used for the 2003 trail was modified based on the performance of the older trails. The 2003 trail showed no major distresses. There were some low-severity longitudinal cracks that had been sealed. Additionally, binder bleeding had occurred in one small area.

Maintenance performed on these trails closely matched the maintenance recommendations discussed in this report.

5.2.3 Aggregate/Bituminous Treatment Surface

In the south region, the aggregate and bituminous surface treatment trails were on two different networks. The aggregate surface trail consisted of a woven geotextile on the compacted subgrade, with a 6-inch aggregate base and a 2-inch surface composed of FA-20 in some areas and FA-21 in others. Based on the design methodology presented in this report, an aggregate trail would consist of a woven or nonwoven geotextile, a 4- to 9-inch aggregate base, and a 3-inch TMA surface.

Similar to the description in Section 5.1.3, the majority of distresses were due to erosion of the surface material. Additionally, sections of this trail did not have the aggregate base extended beyond the planned edge of the trail surface, thus causing the erosion of surface material off the sides of the trail and leading to a humped trail surface. Again, the extension of the aggregate base would have helped to prevent this occurrence.

Maintenance on the aggregate portion involved the use of hand tools to replace and spread the aggregate surface that had been eroded. This was completed on an as-needed basis.

The bituminous surface treatment trail consisted of a 6-inch aggregate base, a thin leveling lift of FA-20, and an A-1 surface treatment. Based on the design methodology presented in this report, a bituminous surface treatment trail would consist of a geotextile, 4- to 9-inch aggregate base, and an A-2 surface treatment. The primary distress on this trail involved rutting due to high vehicular traffic and structural collapses caused by animal burrows in the subgrade.

As evidenced, a bituminous surface treatment is not a good option if there is a potential for high vehicular traffic or for animal activity in the trail structure. However, use of a geotextile and a more substantial surface treatment , as recommended in this report, should help the trail withstand these environmental effects with a higher level of serviceability.

5.3 NORTH REGION

Two different trail surface types were observed in the north region: Portland cement concrete and hot-mix asphalt trails. The agency responsible for construction and maintenance is a regional park district. For additional details, see Section D.3.

5.3.1 Portland Cement Concrete Surface

The PCC section fell under the regular-duty pavement use factor and the low construction traffic factor. The structure consisted of 4 inches of aggregate base and a 5-inch slab thickness. This was very similar to the design proposed by this report, which recommends 3 to 4 inches of aggregate base and a 5-inch slab thickness.

Overall, the PCC portion of the trail was in good condition. No major distresses were present. Contraction joints were tooled and have some minor spalling. This spalling is likely due to overfinishing when the joint was tooled and use of snow removal equipment. No expansion joints were installed in the pavement.

5.3.2 Hot-Mix Asphalt Surface

The HMA trail section fell under the regular-duty pavement use factor and the medium construction traffic factor. The structure consisted of 8 inches of aggregate base and a 2-inch HMA layer. An IL-9.5 mix was used with a binder grade of PG 64-22, with a maximum of 15% RAP. The recommended design void content was 4% at 50 gyrations.

The recommendations in this report would produce a pavement section composed of 4 to 6 inches of aggregate base with a 3-inch HMA layer, consisting of PG 58-28 binder and a maximum of 15% RAP.

The trail was in overall good condition and was one of the few that had been seal coated at 4- to 5-year intervals since its construction. The seal coat appeared to have kept the asphalt surface in good condition and provide some sealant for small cracks that could not be effectively sealed with a bituminous crack sealant material. The sealant material and application rates allowed the trail to maintain a satisfactory level of frictional characteristics. However, some of the traffic control markings were ghosting through the seal coat, as seal coat often does not adhere well to paint or thermoplastic. This ghosting is not an issue from a pavement performance standpoint; however, it may cause issues from an aesthetic standpoint.

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APPENDIX A: LIFE-CYCLE COST ANALYSIS DETAILED TABULATIONS

Table A.1. Conventional Asphalt Pavement Cost Tabulations

Analysis period, years	20
Initial year of construction	2012
Discount rate, %	3.0%

Project Length, ft	5,280
Number of Lanes	1
Lane width, ft	10
Total pavement area, sq.yd	5,867
Total shoulder area, sq.yd	0

ITEM	YEAR	QUANTITY	UNIT	UNIT PRICE	COST	PRESENT WORTH
INITIAL CONSTRUCTION COST						
Removal & Disposal of Unsuitable Matl	0	1220	CUYD	$ 22.34	$ 27,254.80	$ 27,254.80
Aggregate Base Crse, Type B 4.5"	0	5867	SQYD	$ 4.81	$ 28,220.27	$ 28,220.27
Bituminous Materials (Prime Coat)	0	2934	GAL	$ 2.67	$ 7,833.78	$ 7,833.78
Hot-Mix Asphalt Surface Crse, Mix "C", N 30, 3" Mat	0	986	TON	$ 85.00	$ 83,810.00	$ 83,810.00
Root Barrier, 12" depth	0	1056	LF	$ 3.70	$ 3,907.20	$ 3,907.20
Mobilization/Demobilization	0	10%	LSUM	$ 151,026.05	$ 15,102.61	$ 15,102.61
Engineering and Construction Inspection	0	5%	LSUM	$ 151,026.05	$ 7,551.30	$ 7,551.30
REHABILITATION COSTS						
Crack Routing	2	528	FOOT	$ 0.01	$ 5.28	$ 4.98
Crack Filling	2	211	POUND	$ 2.42	$ 510.62	$ 481.31
Class D Patches, Type II, 3"	2	59	SQYD	$ 61.02	$ 3,600.18	$ 3,393.51
Mobilization/Demobilization	2	10%	LSUM	$ 4,116.08	$ 411.61	$ 387.98
Bitumionus Matls (Seal and Cover Coat)	4	1173	GAL	$ 2.80	$ 3,284.40	$ 2,918.15
Mobilization/Demobilization	4	10%	LSUM	$ 3,284.40	$ 328.44	$ 291.81
Crack Routing	8	370	FOOT	$ 0.01	$ 3.70	$ 2.92
Crack Filling	8	148	POUND	$ 2.42	$ 358.16	$ 282.73
Class D Patches, Type II, 3"	8	59	SQYD	$ 61.02	$ 3,600.18	$ 2,842.02
Bitumionus Matls (Seal and Cover Coat)	8	1173	GAL	$ 2.80	$ 3,284.40	$ 2,592.74
Mobilization/Demobilization	8	10%	LSUM	$ 7,246.44	$ 724.64	$ 572.04
Bitumionus Matls (Seal and Cover Coat)	12	1173	GAL	$ 2.80	$ 3,284.40	$ 2,303.61
Mobilization/Demobilization	12	10%	LSUM	$ 3,284.40	$ 328.44	$ 230.36
Crack Routing	14	370	FOOT	$ 0.01	$ 3.70	$ 2.45
Crack Filling	14	148	POUND	$ 2.42	$ 358.16	$ 236.79
Class D Patches, Type II, 4"	14	59	SQYD	$ 61.02	$ 3,600.18	$ 2,380.14
Mobilization/Demobilization	14	10%	LSUM	$ 3,962.04	$ 396.20	$ 261.94
Bitumionus Matls (Seal and Cover Coat)	16	1173	GAL	$ 2.80	$ 3,284.40	$ 2,046.73
Mobilization/Demobilization	16	10%	LSUM	$ 3,284.40	$ 328.44	$ 204.67
SALVAGE VALUE	20				N/A	N/A
				INITIAL CONSTRUCTION COST	$ 173,679.96	$ 173,679.96
				REHABILITATION COST	$ 27,695.54	$ 21,436.88
				TOTAL LIFE CYCLE COST	**$ 201,375.49**	**$ 195,116.83**

Table A.2. Conventional Portland Cement Pavement Cost Tabulations

Analysis period, years	20
Initial year of construction	2012
Discount rate, %	3.0%

Project Length, ft	5,280
Number of Lanes	1
Lane width, ft	10
Total pavement area, sq.yd	5,867
Total shoulder area, sq.yd	0

ITEM	YEAR	QUANTITY	UNIT	UNIT PRICE	COST	PRESENT WORTH
INITIAL CONSTRUCTION COST						
Removal & Disposal of Unsuitable Matl	0	1549	CUYD	$ 22.34	$ 34,604.66	$ 34,604.66
Aggregate Base Crse, Type B, 4.5"	0	5867	SQYD	$ 4.81	$ 28,220.27	$ 28,220.27
Portland Cement, 5"	0	5867	SQYD	$ 34.00	$ 199,478.00	$ 199,478.00
Root Barrier, 12" depth	0	1056	LF	$ 3.70	$ 3,907.20	$ 3,907.20
Mobilization/Demobilization	0	10%	LSUM	$ 266,210.13	$ 26,621.01	$ 26,621.01
Engineering and Construction Inspection	0	5%	LSUM	$ 266,210.13	$ 13,310.51	$ 13,310.51
REHABILITATION COSTS						
Crack Routing	6	528	FOOT	$ 1.28	$ 675.84	$ 566.01
Crack Filling	6	211	POUND	$ 3.37	$ 711.07	$ 595.51
Class C Patches, Type II, 6"	6	59	SQYD	$ 50.00	$ 2,950.00	$ 2,470.58
Mobilization/Demobilization	6	10%	LSUM	$ 4,336.91	$ 433.69	$ 363.21
Crack Routing	12	528	FOOT	$ 1.28	$ 675.84	$ 474.02
Crack Filling	12	211	POUND	$ 3.37	$ 711.07	$ 498.73
Class C Patches, Type II, 6"	12	59	SQYD	$ 50.00	$ 2,950.00	$ 2,069.07
Mobilization/Demobilization	12	10%	LSUM	$ 4,336.91	$ 433.69	$ 304.18
Crack Routing	18	528	FOOT	$ 1.28	$ 675.84	$ 396.98
Crack Filling	18	211	POUND	$ 3.37	$ 711.07	$ 417.68
Class D Patches, Type II, 4"	18	59	SQYD	$ 50.00	$ 2,950.00	$ 1,732.81
Mobilization/Demobilization	18	10%	LSUM	$ 4,336.91	$ 433.69	$ 254.75
SALVAGE VALUE	20				$ (3,180.56)	$ (1,761.00)

INITIAL CONSTRUCTION COST	$ 306,141.65	$ 306,141.65
REHABILITATION COST	$ 14,311.80	$ 10,143.53
TOTAL LIFE CYCLE COST	**$ 317,272.89**	**$ 314,524.18**

Table A.3. Aggregate Surface Cost Tabulations

Analysis period, years	20
Initial year of construction	2012
Discount rate, %	3.0%

Project Length, ft	5,280
Number of Lanes	1
Lane width, ft	10
Total pavement area, sq.yd	5,867
Total shoulder area, sq.yd	0

ITEM	YEAR	QUANTITY	UNIT	UNIT PRICE	COST	PRESENT WORTH
INITIAL CONSTRUCTION COST						
Removal & Disposal of Unsuitable Matl	0	1631	CUYD	$ 22.34	$ 36,436.54	$ 36,436.54
Geotextile	0	5867	SQYD	$ 1.93	$ 11,323.31	$ 11,323.31
Aggregate Base Crse, Type B, 7.0"	0	5867	SQYD	$ 11.99	$ 70,345.33	$ 70,345.33
Trail Mix Aggregate, 3"	0	880	TON	$ 22.00	$ 19,360.00	$ 19,360.00
Mobilization/Demobilization	0	10%	LSUM	$ 137,465.18	$ 13,746.52	$ 13,746.52
Engineering and Construction Inspection	0	5%	LSUM	$ 137,465.18	$ 6,873.26	$ 6,873.26
REHABILITATION COSTS						
Manpower	1	48	HOUR	$ 43.39	$ 2,082.72	$ 2,022.06
Vehicle	1	48	HOUR	$ 11.63	$ 558.24	$ 541.98
Material	1	0.50	TON	$ 80.00	$ 40.00	$ 38.83
Manpower	2	48	HOUR	$ 43.39	$ 2,082.72	$ 1,963.16
Vehicle	2	48	HOUR	$ 11.63	$ 558.24	$ 526.19
Material	2	0.50	TON	$ 80.00	$ 40.00	$ 37.70
Manpower	3	48	HOUR	$ 43.39	$ 2,082.72	$ 1,905.98
Vehicle	3	48	HOUR	$ 11.63	$ 558.24	$ 510.87
Material	3	0.50	TON	$ 80.00	$ 40.00	$ 36.61
Manpower	4	48	HOUR	$ 43.39	$ 2,082.72	$ 1,850.47
Vehicle	4	48	HOUR	$ 11.63	$ 558.24	$ 495.99
Material	4	0.50	TON	$ 80.00	$ 40.00	$ 35.54
Manpower	5	48	HOUR	$ 43.39	$ 2,082.72	$ 1,796.57
Vehicle	5	48	HOUR	$ 11.63	$ 558.24	$ 481.54
Material	5	0.50	TON	$ 80.00	$ 40.00	$ 34.50
Manpower	6	48	HOUR	$ 43.39	$ 2,082.72	$ 1,744.25
Vehicle	6	48	HOUR	$ 11.63	$ 558.24	$ 467.52
Material	6	0.50	TON	$ 80.00	$ 40.00	$ 33.50
Manpower	7	48	HOUR	$ 43.39	$ 2,082.72	$ 1,693.44
Vehicle	7	48	HOUR	$ 11.63	$ 558.24	$ 453.90
Material	7	0.50	TON	$ 80.00	$ 40.00	$ 32.52
Manpower	8	48	HOUR	$ 43.39	$ 2,082.72	$ 1,644.12
Vehicle	8	48	HOUR	$ 11.63	$ 558.24	$ 440.68
Material	8	0.50	TON	$ 80.00	$ 40.00	$ 31.58
Manpower	9	48	HOUR	$ 43.39	$ 2,082.72	$ 1,596.23
Vehicle	9	48	HOUR	$ 11.63	$ 558.24	$ 427.84
Material	9	0.50	TON	$ 80.00	$ 40.00	$ 30.66

Table A.3 Continued. Aggregate Surface Cost Tabulations

Manpower	10	48	HOUR	$	43.39	$	2,082.72	$	1,549.74
Vehicle	10	48	HOUR	$	11.63	$	558.24	$	415.38
Material	10	0.50	TON	$	80.00	$	40.00	$	29.76
Manpower	11	48	HOUR	$	43.39	$	2,082.72	$	1,504.60
Vehicle	11	48	HOUR	$	11.63	$	558.24	$	403.28
Material	11	0.50	TON	$	80.00	$	40.00	$	28.90
Manpower	12	48	HOUR	$	43.39	$	2,082.72	$	1,460.78
Vehicle	12	48	HOUR	$	11.63	$	558.24	$	391.54
Material	12	0.50	TON	$	80.00	$	40.00	$	28.06
Manpower	13	48	HOUR	$	43.39	$	2,082.72	$	1,418.23
Vehicle	13	48	HOUR	$	11.63	$	558.24	$	380.13
Material	13	0.50	TON	$	80.00	$	40.00	$	27.24
Manpower	14	48	HOUR	$	43.39	$	2,082.72	$	1,376.92
Vehicle	14	48	HOUR	$	11.63	$	558.24	$	369.06
Material	14	0.50	TON	$	80.00	$	40.00	$	26.44
Manpower	15	48	HOUR	$	43.39	$	2,082.72	$	1,336.82
Vehicle	15	48	HOUR	$	11.63	$	558.24	$	358.31
Material	15	0.50	TON	$	80.00	$	40.00	$	25.67
Manpower	16	48	HOUR	$	43.39	$	2,082.72	$	1,297.88
Vehicle	16	48	HOUR	$	11.63	$	558.24	$	347.88
Material	16	0.50	TON	$	80.00	$	40.00	$	24.93
Manpower	17	48	HOUR	$	43.39	$	2,082.72	$	1,260.08
Vehicle	17	48	HOUR	$	11.63	$	558.24	$	337.74
Material	17	0.50	TON	$	80.00	$	40.00	$	24.20
Manpower	18	48	HOUR	$	43.39	$	2,082.72	$	1,223.38
Vehicle	18	48	HOUR	$	11.63	$	558.24	$	327.91
Material	18	0.50	TON	$	80.00	$	40.00	$	23.50
Manpower	19	48	HOUR	$	43.39	$	2,082.72	$	1,187.75
Vehicle	19	48	HOUR	$	11.63	$	558.24	$	318.36
Material	19	0.50	TON	$	80.00	$	40.00	$	22.81
SALVAGE VALUE	20						N/A		N/A
			INITIAL CONSTRUCTION COST			$	158,084.96	$	158,084.96
			REHABILITATION COST			$	50,938.24	$	38,401.53
			TOTAL LIFE CYCLE COST			**$**	**209,023.20**	**$**	**196,486.49**

APPENDIX B: PAVEMENT USE ANALYSIS DETAILED TABULATIONS

Table B.1. Conventional Concrete Pavement, Regular-Duty
Pavement Use Factor Cost Tabulations

ITEM	YEAR	QUANTITY	UNIT	UNIT PRICE	COST	PRESENT WORTH
INITIAL CONSTRUCTION COST						
Removal & Disposal of Unsuitable Matl	0	1302	CUYD	$ 22.34	$ 29,086.68	$ 29,086.68
Aggregate Base Crse, Type B, 3"	0	5867	SQYD	$ 4.81	$ 28,220.27	$ 28,220.27
Portland Cement, 5"	0	5867	SQYD	$ 34.00	$ 199,478.00	$ 199,478.00
Mobilization/Demobilization	0	10%	LSUM	$ 256,784.95	$ 25,678.50	$ 25,678.50
Engineering and Construction Inspection	0	5%	LSUM	$ 256,784.95	$ 12,839.25	$ 12,839.25
		INITIAL CONSTRUCTION COST			$ 295,302.69	$ 295,302.69

Table B.2. Conventional Concrete Pavement, Heavy-Duty
Pavement Use Factor Cost Tabulations

ITEM	YEAR	QUANTITY	UNIT	UNIT PRICE	COST	PRESENT WORTH
INITIAL CONSTRUCTION COST						
Removal & Disposal of Unsuitable Matl	0	1631	CUYD	$ 22.34	$ 36,436.54	$ 36,436.54
Aggregate Base Crse, Type B, 3"	0	5867	SQYD	$ 4.81	$ 28,220.27	$ 28,220.27
Portland Cement, 7"	0	5867	SQYD	$ 45.00	$ 264,015.00	$ 264,015.00
Mobilization/Demobilization	0	10%	LSUM	$ 328,671.81	$ 32,867.18	$ 32,867.18
Engineering and Construction Inspection	0	5%	LSUM	$ 328,671.81	$ 16,433.59	$ 16,433.59
		INITIAL CONSTRUCTION COST			$ 377,972.58	$ 377,972.58

APPENDIX C: CONSTRUCTION TRAFFIC ANALYSIS DETAILED TABULATIONS

Table C.1. Conventional Asphalt Pavement, Medium Construction Traffic Factor Cost Tabulations

ITEM	YEAR	QUANTITY	UNIT	UNIT PRICE	COST	PRESENT WORTH
INITIAL CONSTRUCTION COST						
Removal & Disposal of Unsuitable Matl	0	1220	CUYD	$ 22.34	$ 27,254.80	$ 27,254.80
Aggregate Base Crse, Type B 4.5"	0	5867	SQYD	$ 4.81	$ 28,220.27	$ 28,220.27
Bituminous Materials (Prime Coat)	0	2934	GAL	$ 2.67	$ 7,833.78	$ 7,833.78
Hot-Mix Asphalt Surface Crse, Mix "C", N 30, 3" Mat	0	986	TON	$ 85.00	$ 83,810.00	$ 83,810.00
Mobilization/Demobilization	0	10%	LSUM	$ 147,118.85	$ 14,711.89	$ 14,711.89
Engineering and Construction Inspection	0	5%	LSUM	$ 147,118.85	$ 7,355.94	$ 7,355.94
		INITIAL CONSTRUCTION COST			$ 169,186.68	$ 169,186.68

Table C.2. Conventional Asphalt Pavement High Construction Traffic Factor Cost Tabulations

ITEM	YEAR	QUANTITY	UNIT	UNIT PRICE	COST	PRESENT WORTH
INITIAL CONSTRUCTION COST						
Removal & Disposal of Unsuitable Matl	0	1631	CUYD	$ 22.34	$ 36,436.54	$ 36,436.54
Aggregate Base Crse, Type B 7"	0	5867	SQYD	$ 9.67	$ 56,733.89	$ 56,733.89
Bituminous Materials (Prime Coat)	0	2934	GAL	$ 2.67	$ 7,833.78	$ 7,833.78
Hot-Mix Asphalt Surface Crse, Mix "C", N 30, 3" Mat	0	986	TON	$ 85.00	$ 83,810.00	$ 83,810.00
Mobilization/Demobilization	0	10%	LSUM	$ 184,814.21	$ 18,481.42	$ 18,481.42
Engineering and Construction Inspection	0	5%	LSUM	$ 184,814.21	$ 9,240.71	$ 9,240.71
		INITIAL CONSTRUCTION COST			$ 212,536.34	$ 212,536.34

APPENDIX D: DETAILED REVIEW OF EXISTING TRAILS

D.1 CENTRAL REGION

D.1.1 Meadowbrook Park Trails

D.1.1.1 History

Meadowbrook Park is a 130-acre park in south Urbana. Within the park are paved trails and “mowed” trails, which feature a grass surface. The paved trail network consists of three separate trails: the Prairie Trail, Sculpture Garden Trail, and Hickman Wildflower Walk. Figure D.1 is the park’s trail map. Table D.1 shows the corresponding trail color depicted in the figure, along with the trail length and date the construction plans were finalized.

The design and construction management for all three segments was completed by a consulting engineer firm, which was not contacted as part of this project. Therefore, the exact construction dates are unknown.

The dashed lines in Figure D.1 indicate portions of the trails that were built and are maintained by the Urbana Public Works Department; those portions are not included in this analysis.

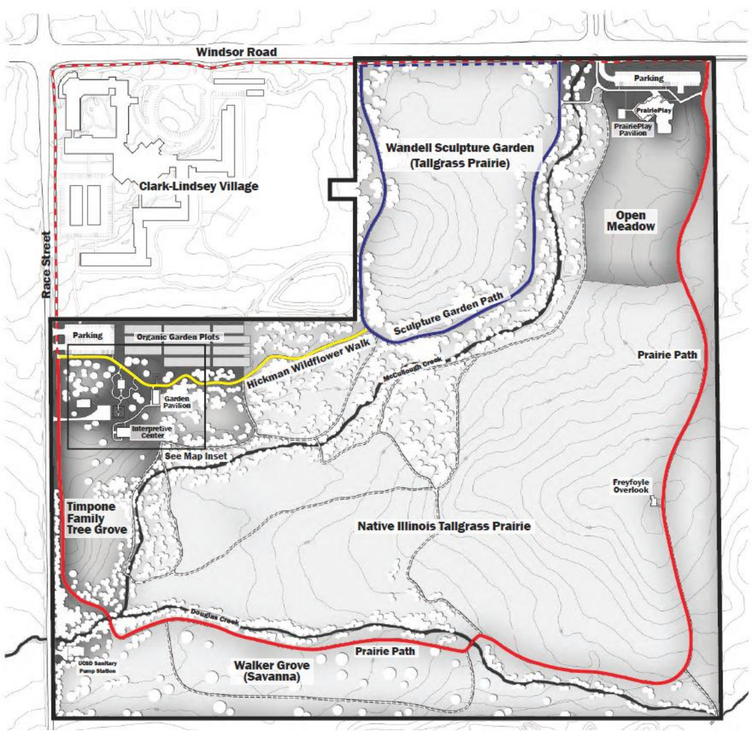

Figure D.1. Meadowbrook Park trail map (Urbana Park District).

Table D.1. Meadowbrook Park trail information.

Trail	Figure D.1 Color	Length (mi)	Plans Finalized
Sculpture Garden Trail	Blue	0.50	Aug. 1995
Prairie Trail	Red	1.10	Feb. 1996
Wildflower Walk	Yellow	0.25	May 1997

D.1.1.2 Construction

All three designs were completed by the same consulting engineer and feature similar pavement elements. Initially, all topsoil was removed, which extended to a depth of 12 to 24 inches based on soil profiles. After the topsoil was excavated, an earthen embankment was installed in the excavation. If no suitable earth material was available, the plans allowed for substitution with CA-6 or CA-10. The embankment thickness extended from the bottom of the excavation to 5 inches below the surrounding elevation. The earthen embankment (or substituted aggregate material) was to be compacted to 95% standard proctor density.

The PCC pavement was constructed directly on the embankment. All trails are 10 feet wide. All of the Sculpture Garden and Prairie Trail trails have a 5-inch thickness, while the Wildflower Trail has some sections that are 5 inches thick and some that are 6 inches thick. The 6-inch-thick section extends for 250 feet in the middle section of the Wildflower Trail. The rationale for the thickness variation was not provided in the plans; however, the surface water flow path indicated on the plans suggests that the 6-inch trail thickness crosses a low area prone to surface water flow during rainfall events.

The PCC did not follow a standard IDOT mix design; however, it was specified to have a 14-day compressive strength of 3500 pounds per square inch, 460 pounds per cubic yard of cement, and 145 pounds per cubic yard of fly ash. Air was entrained at 5% to 8%. The majority of the pavement was slipformed. In areas where slipform paving could not be completed, forms and vibrators were used. The pavement had a “heavy” broom finish transverse to the direction of travel.

Transverse joints were spaced every 10 feet with no longitudinal joint. Transverse joints were sawcut. Expansion joints were noted for installation around installed structures (a bridge). Pavement was to be thickened to 6 inches for 2 feet on either side of construction joints. Construction joints were to have 30-inch, #4 deformed reinforcement bars installed on 30-inch centers at the mid-depth of the pavement.

D.1.1.3 Maintenance

No records of maintenance tasks were available for these trails. However, the park district did indicate that intermittent patching had been completed to correct joint deterioration, such as blow-ups and cracking caused by the deformed reinforcement bar installed for load transfer at construction joints. After field observation, the patching work was completed only on the Prairie Trail. It appears that patches were installed under two different projects, as evidenced by differences in concrete color and slight differences in the finishing technique.

Also, some new joint sealant material had been installed at certain points on the trail. Most of the sealant appears to have been installed on the expansion joints that surround the bridges used within the trail network.

D.1.1.4 Observations

Based on discussions with the Urbana Park District, the three trails would fall under the regular pavement use factor. The majority of the district’s maintenance vehicles are pickup trucks. The trails appear to fall under the low subgrade traffic factor. Compacted soil would not hold up well to repetitive construction traffic. Additionally, the site is relatively flat and accessible to construction vehicles outside of the trail subgrade and base material.

Overall, all trails are in good condition. There were only two slabs that displayed uncontrolled cracking.

All three trails had instances of minor faulting. The majority of faults resulted in a grade difference between slabs of 0.5 inch or less, as shown in Figure D.2. These faults also led to increased spalls at the joint due to contact with snow removal equipment.

Figure D.2. Joint faulting leading to further deterioration.

As shown in Figure D.3, trees are a minimum of 10 feet from the edge of the trail, both when the trail traverses a previously wooded area and when the trees were planted after trail construction. Thus, there is no evidence of the faulting being caused by tree roots. The proper spacing from trees is necessary since no root barrier product was used during construction. However, as shown in Figure D.4, there was little consideration for drainage away from the trail pavement structure. This excess moisture, combined with a lack of aggregate base, is likely the cause of faulting.

Some joint deterioration was also present on all three trails. As seen in Figure D.5, the contraction joints were sawcut after paving. The jagged edges of the sawcut suggest that the joints were sawed too early, as the paste had not had time to achieve proper strength and prevent small aggregate from being broken away from the concrete matrix. Evidence of organic growth from the contraction joints was also apparent. While some of the joint sealant had been replaced on expansion joints, much of it was in poor condition, as seen in Figure D.6. This is leading to incompressibles entering the joint, causing additional spalling and degradation.

Figure D.3. Standoff between trees and trail.

Figure D.4. Lack of trail drainage.

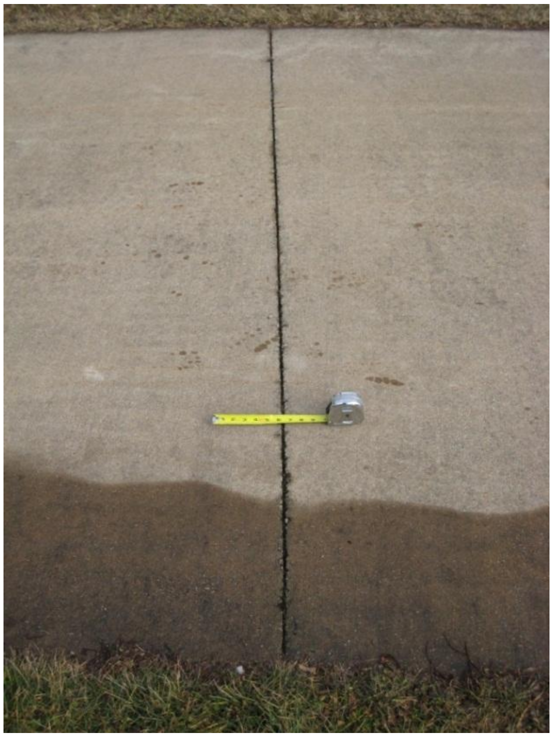

Figure D.5. Small aggregate broken away from concrete matrix during sawcutting.

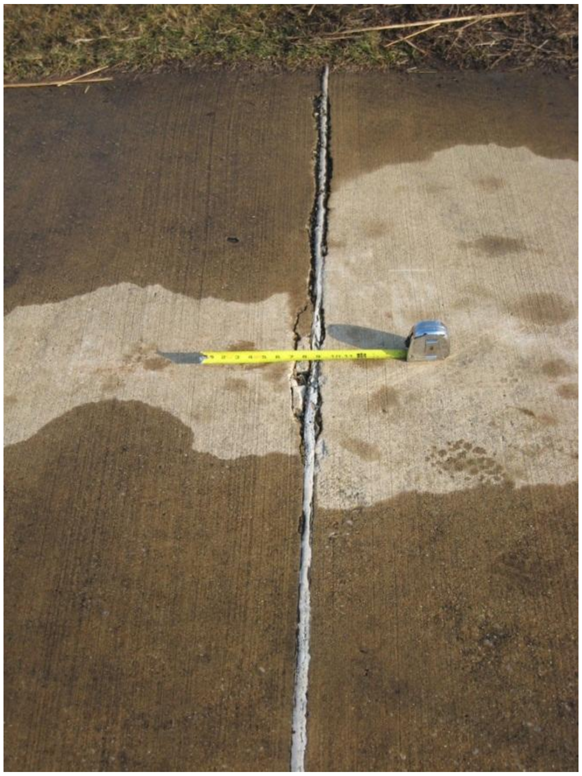

Figure D.6. Joint deterioration due to failing sealant.

The most interesting observation about the three trails was the differences in the use of expansion joints and their spacing. The Sculpture Garden Trail had no expansion joints and no evidence of any patching. The Wildflower Walk had expansion joints installed approximately every 100 feet. There was no evidence of any patching on the Wildflower Walk, which means that the expansion joints were installed during original construction. In the plans for the Prairie Trail, there were no specifications on regular intervals for expansion joint installation. However, there was either a patch (with an expansion joint installed with the patch) or an expansion joint (possibly installed as part of a previous patching project or at a longer interval during original construction) at almost exact 100-foot intervals.

D.1.2 General Dacey Trail

D.1.2.1 History

Planning for the General Dacey trail started in the early 1980s by a local Shelbyville businessman. After thorough planning, a grant with matching private funding was received to build the first phase of this trail in 2005. Construction on phases 2, 3, and 4 followed in 2007, 2008, and 2010, respectively. Currently, plans are complete and funding is available to build the sixth phase of this project. The fifth phase is currently on hold due to the sensitivity of its planned location passing over the Lake Shelbyville dam. A map of the system is shown in Figure D.7, with the red lines indicating completed trials and the orange lines indicating planned trails. Additionally, Figure D.7 shows the aggregate portion of the network (rather than the bituminous surface treatment portion) and Phase 4, which was completed after the map was published.

The trail primarily passes over land owned by the City of Shelbyville and the U.S. Army Corps of Engineers. Construction plans, bidding, and inspection were performed by the Shelby County Highway Department. Maintenance is performed by a local group of volunteers and trail users.

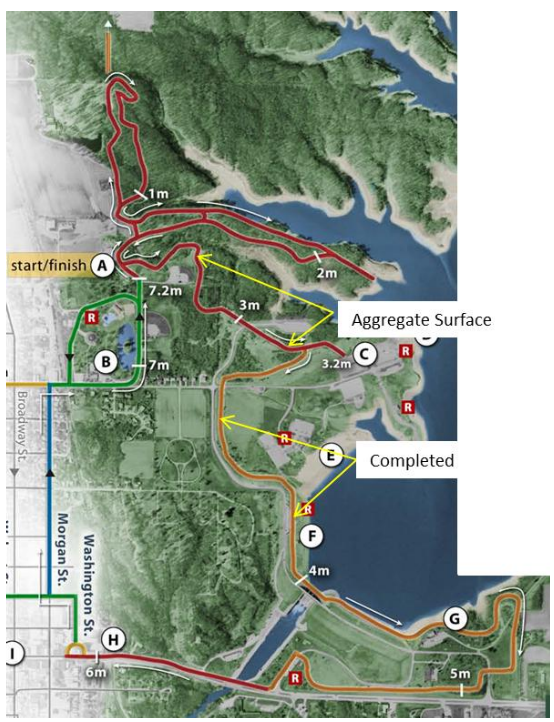

Figure D.7. General Dacey Trail map.

D.1.2.2 Construction

Phase 1 of the project was built with an aggregate surface. A 6-inch CA-6 or CA-10 aggregate base (the specifications allowed either material) was placed on cleared, grubbed, and compacted subgrade. A 2-inch FA-20 aggregate surface was placed over the aggregate base.

Due to the softness of the aggregate surface, a bituminous surface treatment was used on all remaining phases. The portions that received the bituminous surface treatment were built on cleared, grubbed, and compacted subgrade with 6-inch CA-6 or CA-10 aggregate base. After proof rolling the aggregate base, an A-2 bituminous surface treatment was applied which consisted of an MC-30 prime coat, HFE-150 seal coat, and CA-16 chip.

A bituminous surface treatment was selected to provide a harder trail surface at a total cost that did not greatly exceed that of the planned aggregate surface. Additionally, the trail planner had seen some poorly performing asphalt trails and knew that a good level of service could not be maintained with an asphalt surface by a volunteer group with minimal equipment resources and maintenance funding. It is important to note that the trail planner knew that use of a bituminous surface treatment excluded some user groups (primarily roller bladers and skate boarders).

D.1.2.3 Maintenance

As previously mentioned, trail maintenance is performed solely by a volunteer group. There is no direct funding through any agency to pay for maintenance tasks. When washouts occur on the aggregate portion, the aggregate is replaced using hand tools. Minimal amounts of new FA-20 have been required for repairs. No maintenance has been performed on the bituminous surface treatment portions.

D.1.2.4 Observations

The aggregate portion of the trail has seen some displacement of the surface aggregate, as shown in Figure D.8. A higher level of fines in the aggregate may help to reduce water displacement of the surface. Very few sections of the trail were humped, likely due to the construction of adequate shoulders and drainage facilities along the edges of the trail, as seen in Figure D.9.

On the portions of the trail that were constructed with a bituminous surface treatment, the aggregate base extended beyond the edge of the treatment in many locations, as seen in Figure D.10. An extended base course width was not specifically called for in the plans. The additional aggregate base width, combined with low vehicular traffic, has led to good performance of the surface treatment. The only surface distresses present are a very few minor cracks in the bituminous surface treatment. As shown in Figure D.11, there are some grade variations (high spots and low spots) in the surface treatment, which can be expected with this material.

Figure D.8. Water displacement of the surface aggregate.

Figure D.9. Adequate shoulders prevent humping, and separation of the trail from drainage components prevents surface degradation.

Figure D.10. Aggregate base extended beyond the edge of the surface treatment.

Figure D.11. Grade variation in the bituminous surface treatment.

D.1.3 Race Street Bike Trail

D.1.3.1 History

This trail runs along the west side of Race Street, which travels north to south, in Urbana. Within the road right-of-way, the trail is maintained by the Urbana Public Works Department. The trail runs through a primarily residential area, with housing developments on the east side of the road and University of Illinois graduate student apartments and agricultural land on the west side of the road, as denoted with a red line in Figure D.12.

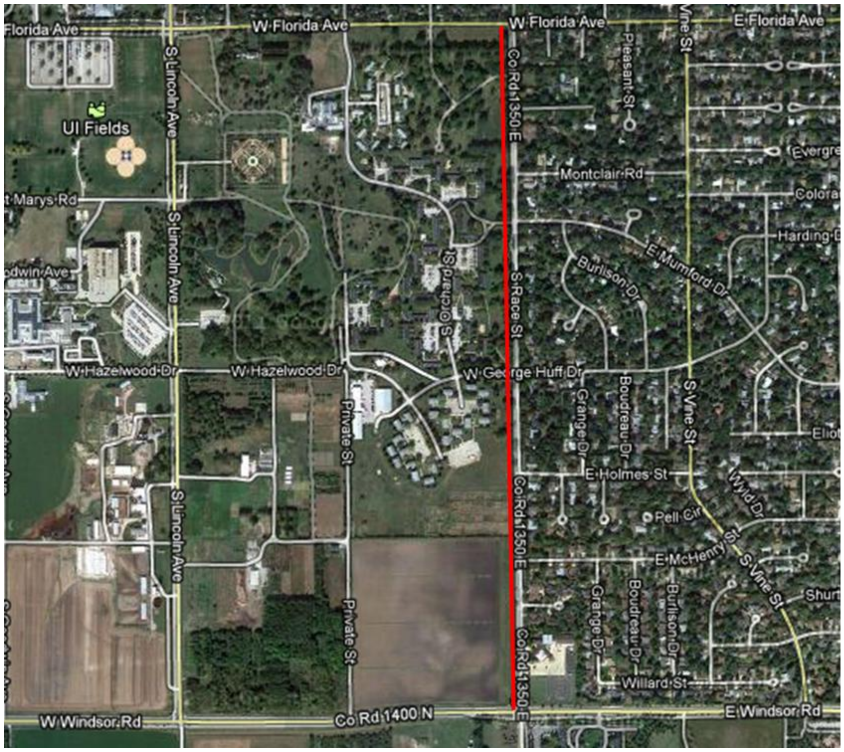

Figure D.12. Race Street bike trail map.

D.1.3.2 Construction

The trail was originally constructed with a HMA surface. No original construction records are available for the trail. The focus of this discussion will be the mill and overlay performed in 2007.

D.1.3.3 Maintenance

In 2007, the majority of this trail was milled and overlaid as part of a larger HMA rehabilitation project within the city. Surface distresses and non-structural/non-fatigue cracking were present in the trail, which warranted the mill and overlay project. Although the thickness of the original HMA surface was unknown, a mill depth of 1.25 inches was selected. Damage caused by construction traffic to the milled surface is the primary concern; however, the inspector on the project indicated that the milled surface sustained no damage.

The overlay consisted of a 1.25-inch-thick compacted mat with an IL-9.5L mix design with 3% air voids at 30 gyrations, PG 58-22 binder, and a maximum of 30% RAP to be included in the mix.

D.1.3.4 Observations

This trail would fall under the medium subgrade traffic factor with a low pavement use factor. A road parallels the trail on the west side. On the east side of the trail, there is ample open area for haul vehicles. Additionally, the trail sees little vehicular traffic because it parallels the road.

A number of different types of cracking were evident on the trail. The thermal cracking shown in Figure D.13 was a regular occurrence along the overlaid sections. Some centerline cracking was also present in localized areas for limited lengths. The localized nature suggests that there were some segregation issues with the mix as it was placed by the paver—perhaps when the paver wings were up.

If 30% RAP was used in the asphalt for this trail, it would have increased the low-temperature rating of the PG 58-22 binder.

Figure D.13. Typical thermal crack.

Longitudinal cracking was also present; however, the vast majority of the cracking was only on the east side of the pavement, as shown in Figure D.14. In many areas, the pavement sloped away from the road, and the shoulder material was higher than the pavement. Therefore, water could be ponding on this side of the trail and causing the distress. Also, the longitudinal cracking could be due to poor compaction. The edges of a HMA mat are generally difficult areas to compact. While one might expect compaction issues on both sides of the mat, perhaps the west side of the trail (closer to the roadway) was over some granular material placed during the original construction of the road, thus improving subgrade and base stability and improving compaction.

As seen in Figure D.15, there was a only short standoff between the trees lining the trail. This has caused several locations where roots have disrupted the asphalt surface. Installation of a root barrier or use of additional standoff would have helped to prevent this problem.

Figure D.14. Typical edge cracking on the east side of the trail.

Figure D.15. Inadequate standoff and tree root infiltration.

D.2 SOUTH REGION

D.2.1 Wayne Fitzgerrell State Park Trail

D.2.1.1 History

Wayne Fitzgerrell State Park is located on the east side of Rend Lake in southern Illinois. The park features an aggregate-surfaced bike trail that travels from the north to the south of the park. On the north end of the park, the trail connects with another trail leading to Rend Lake Community College. The original portion of the trail was constructed under contract in the late 1990s starting from the Rend Lake resort and heading south.

Over time, the park has continued to construct portions of the trail using in-house labor. The current extents of the trail are shown in Figure D.16, along with several unmapped spurs to other facilities within the park, including day-use areas and campsites. The portions of the trail built by in-house labor are structurally similar to the original portion; however, no formal plans were created.

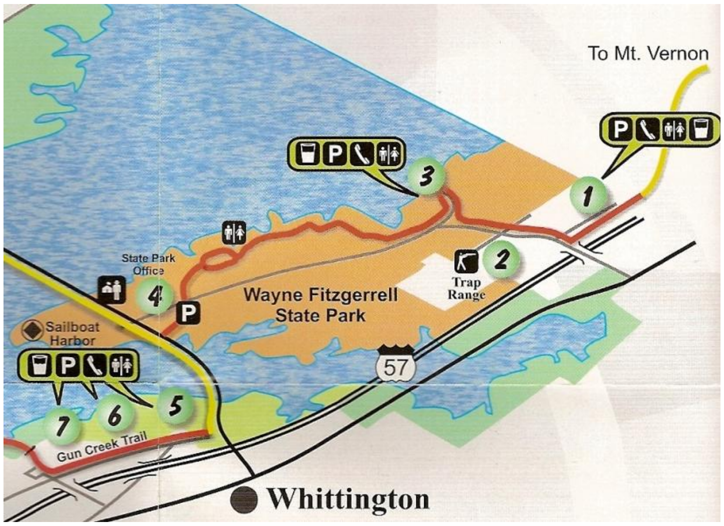

Figure D.16. Fitzgerrell State Park trail map.

D.2.1.2 Construction

The original portion of the trail was constructed mostly on the base material of an abandoned county road. However, for the areas not built over this base material, no information was provided on the plans regarding subgrade material properties or subgrade preparation. It appears that the subgrade was cleared and grubbed, with the topsoil removed and in situ material compacted.

The original section specified use of a geotextile fabric when the trail was built using new base course material, but the fabric weight and type were not specified in the plans. Geotextile was used for the trails constructed by in-house workers, but technical information was not available. However, a small portion of the geotextile was exposed, showing that a woven material at an approximate weight of 6 ounces was used.

Whether built over the abandoned road or on prepared subgrade, the original portion called for a 6-inch CA-10 aggregate base layer. On top of the aggregate base, a 2-inch surface layer of FA-20 was installed. No information was provided in the original plans about compaction of the aggregate layers, but it is assumed that SSBRC compaction specifications were used.

For the sections constructed by in-house workers, similar layer thicknesses and materials were used. FA-21 was selected for use as the surface layer, based on the increased fines content.

D.2.1.3 Maintenance

All maintenance is completed in house; therefore, formal records are not available. Weed killer is applied once a year to curb weed encroachment (with two applications a year during wet years). Grading is done only after heavy rains, on localized areas that have eroded due to moving water. Washouts are minimal, with most areas being re-graded with hand tools. Using heavy equipment to re-grade the trail is not common. Finally, the trail is generally rolled in the spring, to knock down on the “fluffy” surface created by the freeze–thaw effects in the fine aggregate surface layer.

D.2.1.4 Observations

Portions of the trail over the former county road base were performing well. The old road base provided both good support and well-planned drainage facilities, as shown in Figures D.17 and D.18. However, regardless of drainage and base material, some displacement of the surface material due to heavy precipitation and small flooding events is expected, and occurred, as shown in Figure D.19.

Figure D.17. Road bed offers support across trail width.

Figure D.18. Good separation between trail surface and culvert.

Figure D.19. Displacement of surface aggregate due to water.

Trail sections that were not built on the old road base showed some additional distresses. First, drainage components were not always installed when needed, as shown in Figure D.20. In other locations, a small area of separation between the culvert pipe and trail surface required additional erosion control to be installed after trail construction, as seen in Figure D.21. Figure D.22 shows these trail portions also experienced “humping,” or the gradual erosion and displacement of material from the edges of the trail. This issue could have likely been prevented by extending both the compacted subgrade and aggregate base at least 12 inches on either side of the trail aggregate surface. Additionally, this extension of the base would help to prevent water from undercutting the pavement structure. Installing proper shoulders will also help to prevent humping, along with providing a safer environment for users.

Figure D.20. Additional drainage elements needed in some locations.

Figure D.21. Fortification of drainage components after installation.

Figure D.22. Trail humping due to lack of shoulder material and no extension of aggregate base beyond aggregate surface.

As shown in Figure D.23, the trail surface was quite soft. While freeze–thaw action is likely a cause, it also appeared that there was a low level of fines in the aggregate surface, thus cutting down on the self-cementing nature of the surface aggregate. Additionally, some of this softness could be caused by a relatively uniformly graded material. The TMA proposed would help alleviate both these issues by providing a well-graded aggregate blend with adequate fines content.

Figure D.23. Soft surface aggregate.

D.2.2 U.S. Army Corps of Engineers Rend Lake Trail

D.2.2.1 History

The Rend Lake bicycle trail has been in development since the 1990s by the U.S. Army Corps of Engineers. The first section, approximately 3 miles long, was built by the Corps in-house without formal plans being developed. The second section, which extends along the south and west sides of the lake, was constructed in 2001. The 2001 section will be the basis of this discussion.

In 2010, the Corps funded design for additional bicycle trails to complete the loop with the currently constructed portions. These portions of the trail involve significant engineering challenges and construction effort, including an extension of the causeway that carries Illinois Route 154 and a bridge over the southeast branch of the lake.

Along with the construction efforts to complete the trail loop, there is additional interest from other local agencies to develop trails that connect the Rend Lake trail network with local urban areas. The network is shown in Figure D.24, with existing trails indicated by red lines and planned trails indicated by yellow lines.

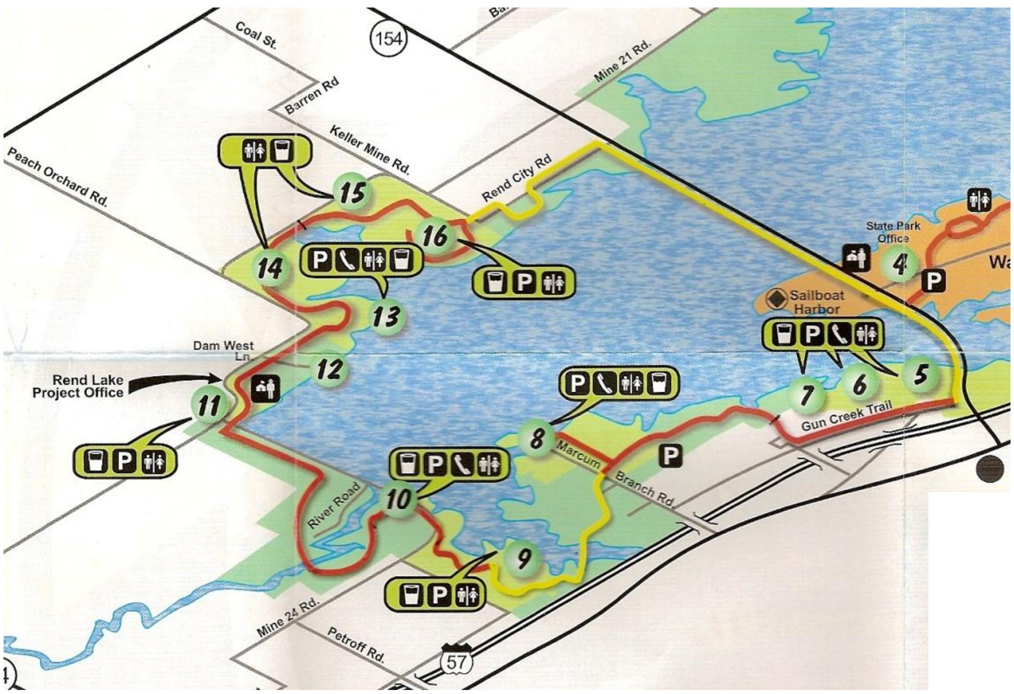

Figure D.24. U.S. Army Corps of Engineers Rend Lake trail system map.

D.2.2.2 Construction

The trail was constructed on compacted existing subgrade material. The original plans called for a 6-inch Type B, CA-10 aggregate base to be placed on top of the compacted subgrade. On top of the aggregate base, a thin (leveling) layer of FA-20 material was to be placed. The pavement structure was to be capped with an A-1 bituminous surface treatment.

At the time of construction, the local Corps project office opted to install 4-inch-thick PCC pavement on top of the CA-10 aggregate base as opposed to the FA-20 and bituminous surface treatment. However, due to funds, it was not possible to upgrade the entire trail. Therefore, an approximately 0.5-mile section of bituminous pavement was constructed in order to connect the new trail into the existing network.

The PCC pavement was added using the Corps' Indefinite Delivery/Indefinite Quantity contract; therefore, the concrete used met the specifications of that contract. Unfortunately, those specifications were not available for review. However, it is safe to assume that the concrete mix design is similar to IDOT PV or SI mixes.

The PCC pavement had tooled contraction joints spaced approximately every 12 feet. Expansion joints were unsealed (fiberboard material was exposed at the pavement surface) and were located every 100 to 120 feet. No special treatments were applied at construction joints.

D.2.2.3 Maintenance

The PCC trail was reported to need a low level of maintenance. Some patching had been completed, but this was mainly due to heavy equipment operating in localized areas for tree removal. The trail travels through some heavily wooded wetland areas, making downed trees a common occurrence.

The bituminous surface treatment portion of the pavement has required more maintenance. In numerous areas, animal burrows under the trail caused collapses and sinkholes in the surface. A CA-6 type aggregate was then used to fill the holes in the trail and the animal burrows to maintain a safe operating surface.

D.2.2.4 Observations

Conversations with the Corps rangers indicated that vehicles traversed most parts of the trail daily. Along with Corps vehicles, the Illinois Department of Natural Resources uses it to access some wetland areas. The vehicles that traverse the trail are exclusively 1-ton and smaller trucks and truck chassis–based vehicles. The alignment of the trail suggests that there was a medium or high subgrade traffic factor, depending on location. In some areas, the trail was built on a fill area with marsh on either side. In other locations, it would have been possible to have construction vehicles travel off the trail surface.

Overall, the PCC pavement sections of the trail were in very good condition. As seen in Figure D.25, there was the occasional shattered slab, though the tree debris in the background suggests that heavy equipment was needed to remove a tree from the trail and might have caused that damage. The tooled contraction joints showed no distresses (Figure D.26), and the unsealed expansion joints were in good condition (Figure D.27), with exception of some vegetation growth. There is essentially no faulting at joints, likely due to the substantial aggregate base under the pavement.

The bituminous surface treatment portion of the trail was in poorer condition. As seen in Figure D.28, rutting of the bituminous surface treatment had formed due to the regular vehicular traffic, and some breakdown of the bituminous surface was occurring at the edges. The trail also sustained some surface damage due to impressions from downed trees. Figure D.29 shows the damage caused by animal burrows under the bituminous treatment. As seen in this application, bituminous surface treatments are not considered to be a structural layer. A consideration of both the positives and negatives of the options should be undertaken before selecting it as a trail surface.

Figure D.25. Slab shattered by tree removal equipment.

Figure D.26. Typical tooled contraction joint.

Figure D.27. Typical unsealed expansion joint.

Figure D.28. Rutting and breakdown at the edge
of the bituminous surface.

Figure D.29. Animal burrows causing surface collapses.

D.2.3 Madison County Transit Nature Trail

D.2.3.1 History

Madison County Transit (MCT) is one of the only transit districts in the country that maintains a network of bicycle trails in conjunction with its traditional bus services. Old railroad right-of-way was purchased by MCT and preserved for future light rail development. The planned interim use was as bicycle trails. The majority of trails have been constructed over time with grants from numerous agencies. Currently, the district operates and maintains over 100 miles of trails in Madison County.

The majority of trails that MCT operates are HMA. However, they also have some bituminous surface treatment trails and some aggregate trails. The bituminous surface treatment is used in areas where the bicycle trail traverses a levy, as the potential for damage during Mississippi River flood conditions was too great to warrant an investment in HMA. The limestone trails are located in remote areas, where trails provide access to small towns in central and eastern portions of the county.

The Nature Trail was MCT's first paved trail. It originates in Edwardsville and heads southwest to Granite City via Pontoon Beach. The trail is 13.5 miles long and was built in 1995. Figure D.30 shows the Nature Trail highlighted in green.

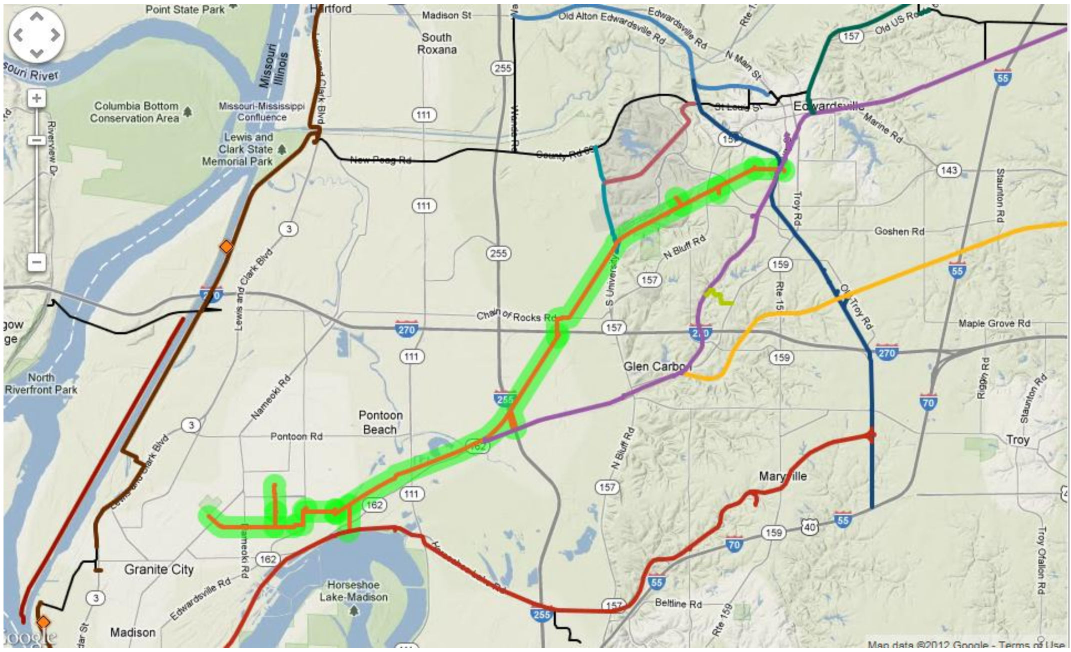

Figure D.30. Nature Trail map.

D.2.3.2 Construction

Prior to starting construction, MCT performed borings on the railroad right-of-way at 500-foot intervals to determine in situ conditions. Areas with problematic in situ materials received some remedial treatment. On top of the right-of-way, a 6inch aggregate base was placed. Prime coat was applied, and the trail was capped with a 2-inch-thick HMA surface.

Due to the age of the trail, some specific construction information was not available. However, the asphalt surface is roughly equivalent to what would currently be considered an IL-9.5 mix with 50 gyration design using PG 64-22 binder.

D.2.3.3 Maintenance

MCT performs regular maintenance in-house, including vegetation control, mowing, and crack sealing. No strict maintenance schedule is followed. Since maintenance personnel regularly traverse the trails during mowing season, areas in need of crack sealing and vegetation control are identified.

Crack sealing is completed with a typical bituminous sealant material. Generally, cracks are sealed only when they exceed 1/8 inch. The cracks are not routed; however, they are cleaned with compressed air. Care is taken during crack sealing to maintain as smooth a riding surface as possible.

Regularly occurring vegetation control aims to identify weak or dead trees that threaten to block the trail if fallen. Additionally, MCT maintains a 15-foot clearance above the trail surface and 10 to 30 feet laterally from the trail surface to allow for free operation of service vehicles.

If needed, patching of the trail surface is completed by a contractor.

D.2.3.4 Observations

Based on maintenance discussions, the Nature Trail would fall under the regular-duty pavement use factor. MCT uses pickup trucks and small tractors to provide maintenance. Because trails are predominately located on old railroad beds with limited access in most areas, it can be assumed that the trail would have a high subgrade traffic factor.

Overall, the Nature Trail was in good condition and should not require anything other than regular maintenance to reach its expected 20-year lifespan in 2015 at a good level of serviceability. The most common distress was tree root infiltration, as shown in Figure D.31. In addition, there were some areas where the railroad bed was very narrow, not allowing for extension of the aggregate base beyond the HMA edge. In these localized areas, there was some edge cracking issues as shown in Figure D.32. Some patching had been completed, to address areas severely distressed by tree root infiltration and edge cracking. These areas can be seen in Figures D.33 and D.34, respectively. In both cases, patches were a minimum of 3 feet wide and had crack sealant installed around the perimeter of the patch.

There was one location with significant longitudinal cracking. As shown in Figure D.35, this area was very localized and therefore is likely due to a lens of plastic soil. It should be noted that there was no thermal cracking present in the trail.

Figure D.31. Tree root infiltration.

Figure D.32. Area of edge cracking and fall-off.

Figure D.33. Patch correcting tree root infiltration.

Figure D.34. Patch correcting edge cracking.

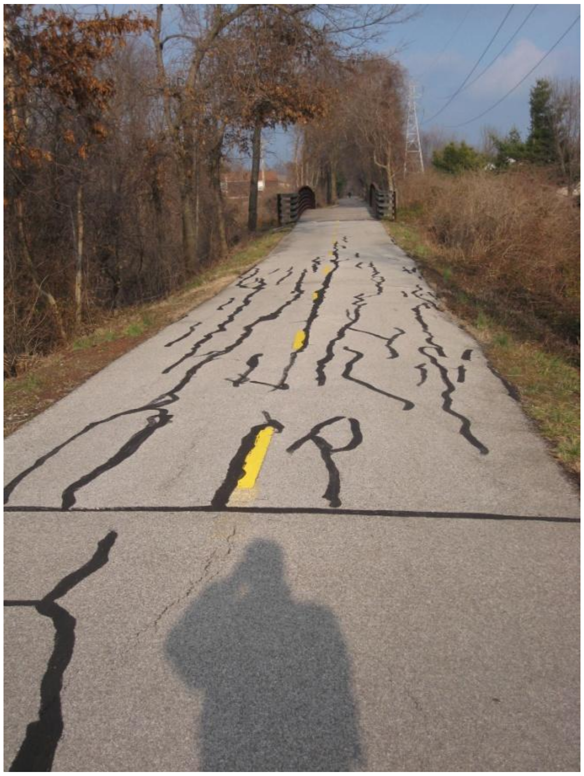

Figure D.35. Localized extreme longitudinal cracking.

D.2.4 Madison County Transit Goshen Trail

D.2.4.1 History

The Goshen Trail was an addition to the MCT system, built in 2003. The trail runs primarily north and south, starting on the northern edge of Edwardsville and extending 8.5 miles to Interstate 55. Figure D.36 shows the Goshen Trail highlighted in green.

Figure D.36. Goshen Trail map.

D.2.4.2 Construction

To improve HMA trail performance and further reduce the potential for cracking, MCT improved their HMA trail design from that used in 1995. A subgrade investigation consisting of boring at 500-foot intervals was again completed.

A Tensar BX-1100 geogrid was placed on top of the prepared railroad bed. A 6-inch aggregate base was then placed, followed by a 3-inch HMA layer. The aggregate base was extended for 1 foot on either side of the planned asphalt edge. No prime coat was used. The asphalt was an IL-9.5 mix with 50 design gyrations and PG 64-22 binder. Up to 10% RAP was allowed in the HMA mix.

This trail had some crossings with farm access roads, as shown in Figure D.37. In addition to widening the pavement at the road crossing to reduce the amount of gravel being tracked onto the trail, the pavement is thickened at the road crossing. Generally, the road crossing is constructed with 5 inches of HMA or 6 inches of PCC.

Figure D.37. Typical asphalt farm road crossing.

D.2.4.3 Maintenance

The same maintenance tasks as described in Section D.2.3.3 were completed on the Goshen Trail.

D.2.4.4 Observations

Similar to the discussion in Section D.2.3.4, this trail would fall in the regular-duty pavement use factor and a high construction traffic factor.

This trail was in outstanding condition. Like the Nature Trail, there were no thermal cracks present. As shown in Figure D.38, there was good vegetation clearance and pavement edge support. Some areas had low-severity longitudinal cracking, as shown in Figure D.39. One localized area of binder bleeding was observed, as shown in Figure D.40.

Figure D.38. Good edge support and vegetation clearance.

Figure D.39. Low-severity longitudinal cracking.

Figure D.40. Localized binder bleeding.

D.3 NORTH REGION, FOX RIVER TRAIL

D.3.1 History

The Fox River Trail is a multi-jurisdictional trail that follows the Fox River through several northern Illinois counties, primarily Kane, McHenry, and Kendall. Each jurisdiction is responsible for the construction and maintenance of the trail through their area..

For the HMA pavement analysis, a portion of the trail under the control of Oswegoland Park District, which is located in Kendall County, was studied. Oswegoland Park District performs its construction and maintenance in accordance with the 2004 Kendall County Trails and Greenways Plan. The goal of the Kendall County plan is to provide some construction uniformity for all trails within the county, regardless of the agency responsible for construction and maintenance.

The portion of the trail within the Oswegoland Park District is primarily asphalt; however, there is portion of concrete pavement as the trail goes through Elgin, in Kane County. A map of the portion of the trail studied is shown in Figure D.41, where the trail is denoted with a dashed red line. This portion of trail was constructed in 1999.

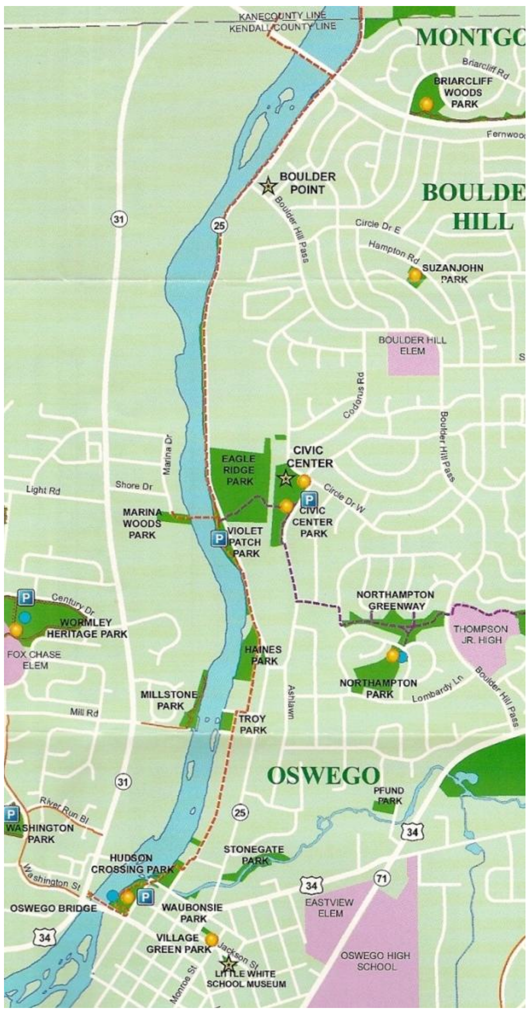

Figure D.41. Oswegoland Park District portion of the Fox River Trail.

D.3.2 Construction

The asphalt portions of the trail consist of a compacted subgrade, 8 inches of aggregate base course, and 2 inches of HMA. An IL-9.5 mix was used with a binder grade of PG 64-22, with a maximum of 15% RAP. The recommended void content is 4% at 50 gyrations.

Portland cement concrete portions of the trail consist of a compacted subgrade, 4 inches of aggregate base, and a 5-inch slab thickness. Transverse jointing is performed at 10-foot spacing with no longitudinal joint.

For all pavement types, both the subgrade and base course are proof rolled with a 25-ton, three-axle truck. A maximum rut depth of 1 inch is allowed on the subgrade, and a maximum rut depth of 0.5 inch is allowed on the aggregate base. A 5-ounce geotextile is used in areas with unstable subgrade.

General construction designs and requirements follow the Kendall County Trails and Greenways Plan. Typical trail cross sections from this plan are shown in Figure D.42.

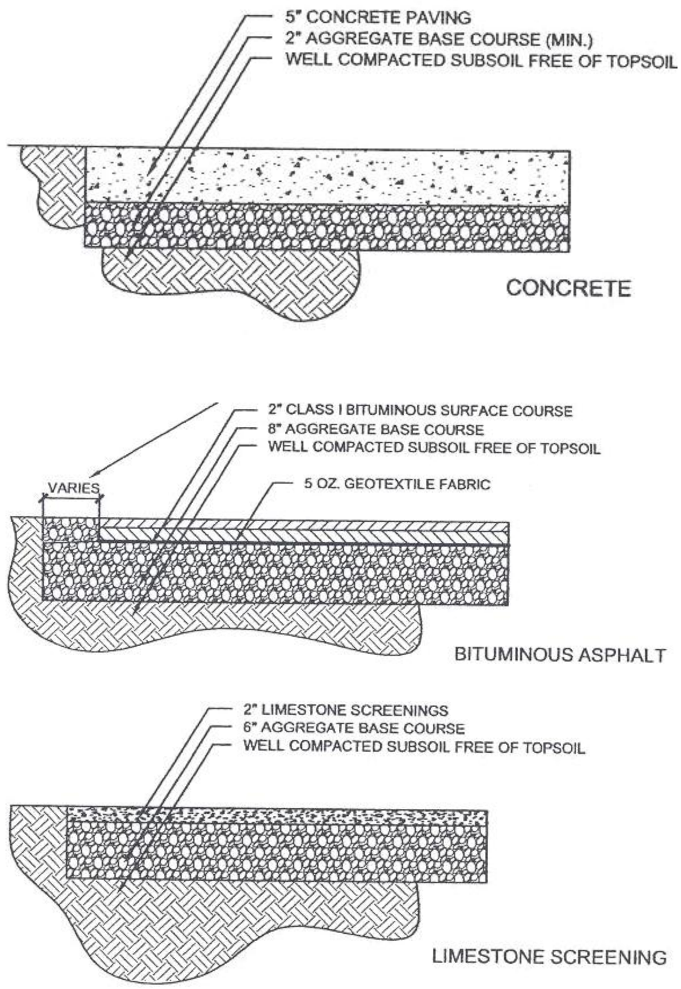

Figure D.42. Typical trail cross sections outlined by the Kendall County Trails and Greenways Plan.

Figure D.43 shows a cross-sectional view of the HMA trail design for the portion of the Fox River Trail passing through Violet Patch Park.

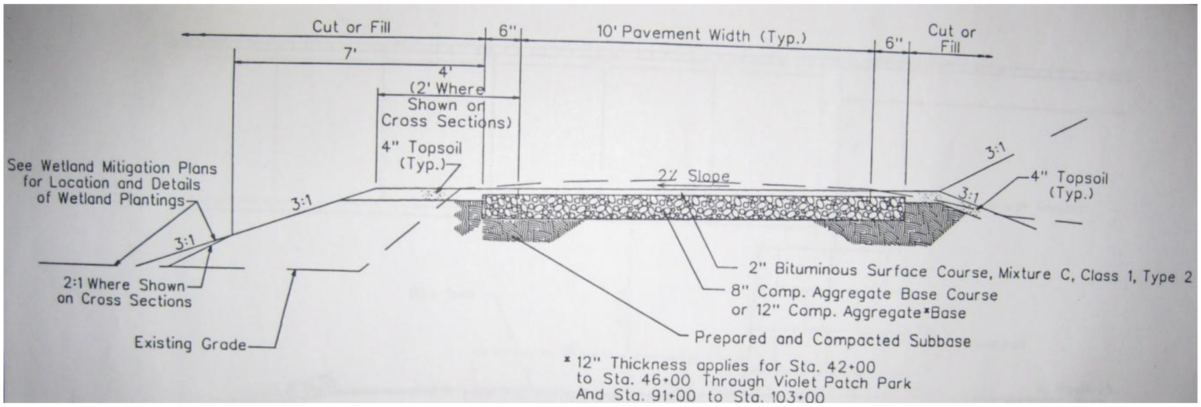

Figure D.43. Asphalt trail pavement cross section through Violet Patch Park.

D.3.3 Maintenance

The park district applies a seal coat on asphalt pavement every 4 to 5 years. Specifications require a “coal tar emulsion or rubberized coal tar sealer with hardening agents blended in as required to comply with manufacturer’s specifications and recommendations.” In addition to the sealant, 4 to 6 pounds of black silica sand is added to each gallon of sealer applied. After the trail surface has been properly prepared, two coats of the sealer are applied to the pavement. The first application is applied by hand or machine squeegee at an application rate of 50 to 60 square feet per gallon. The second application can be sprayed, applying the product at 60 to 70 square feet per gallon.

Additionally, some patching has been performed on the asphalt portion of the trail. Most patching has been to repair damage from tree roots (the park district found that cottonwood and willow are the two tree species that cause the majority of the pavement upheavals). Generally, the asphalt used for patching matches the specifications for asphalt used for the original trail construction.

No maintenance has been performed on the Portland cement concrete section.

D.3.4 Observations

Conversations with the park district indicate that all regular maintenance, including snow removal and garbage service, is completed with 1-ton and smaller pickup trucks. This suggests that the trail would fall into the regular-duty pavement use factor. Based on the asphalt surface, the trail would have at least a medium subgrade traffic factor. Due to the trail’s alignment, some areas would have a high subgrade traffic factor.

Overall, the trail was in excellent condition, with little evidence of durability problems such as damage from thermal and frost effects or damage caused by traffic loads.

The regular seal coat applications seem to be providing a good level of pavement preservation. A seal-coated trail can be seen in Figure D.44, with a close-up of the trail’s surface shown in Figure D.45. As evident in the figures, seal coats generally do not adhere well to pavement paint or thermoplastic marking products; therefore, traffic control markings applied before the seal coat may start to ghost the surface as the seal coat weathers and ages.

Figure D.44. Typical seal-coated path appearance.

Figure D.45. Seal-coated asphalt trail surface.

The PCC portion of the trail was also in good condition. Contraction joints were tooled. Some spalling was evident where the joints were tooled, likely due to overfinishing and snow removal equipment. Figure D.46 shows a typical PCC pavement section. Contraction joints were placed at 10-foot intervals. No expansion joints were installed in the pavement. No patching had occurred.

Figure D.46. Typical PCC pavement section with some joint spalling.

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