U.S. Department of Transportation
Federal Highway Administration

SUSTAINABLE PAVEMENTS PROGRAM

IMPROVED ASPHALT PAVEMENT SUSTAINABILITY THROUGH PERPETUAL PAVEMENT DESIGN

FHWA-HIF-19-080

The Iowa Department of Transportation constructed an innovative asphalt pavement project featuring perpetual pavement long-life design concepts in 2016. The award-winning project, located on a 3.5-mile stretch of State Highway 100 near Cedar Rapids, provided reduced life-cycle costs and reduced environmental impacts as compared to conventional design approaches.

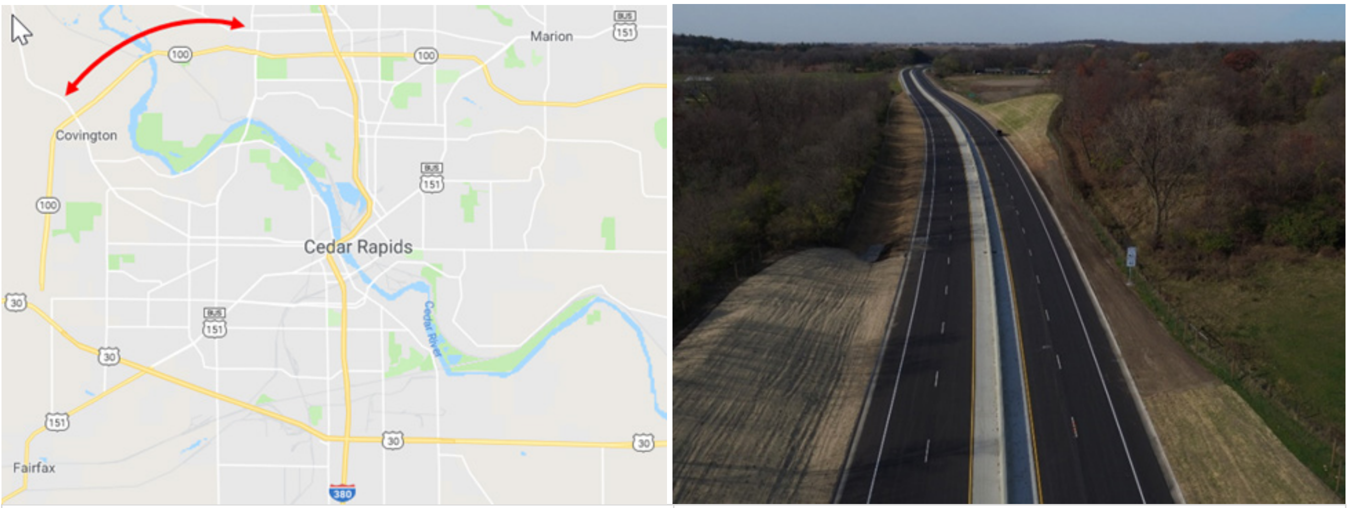
WHAT WAS THE MOTIVATION?

The Iowa Department of Transportation (Iowa DOT) is continuously looking for ways to improve the performance of its highway network while also reducing costs. The short service lives associated with many conventional asphalt pavements, along with their recurring maintenance and rehabilitation requirements and associated traffic disruptions, have led the Department to evaluate perpetual asphalt pavement designs offering extended service lives, lower life-cycle costs, and increased sustainability. With the perpetual pavement, the Iowa DOT expects to be able to limit future rehabilitation activities to the surface course while preserving the base and foundation. This will minimize the impacts to traffic by limiting long-term work zones and costly reconstruction alternatives in the future.

WHAT WAS DONE?

In 2016, the Iowa DOT constructed a perpetual pavement on a stretch of Iowa State Highway 100 (Iowa 100), a four-lane divided highway that loops around Cedar Rapids from Edgewood Road on the north and westward to Covington Road (see figures 1a and 1b). Perpetual pavements make use of a fatigue-resistant lower asphalt layer coupled with rut-resistant surface layers to produce a long-lasting pavement that can last for decades with only minimal maintenance to the surface layer (NAPA 2018). In the proper application, the enhanced performance and durability associated with perpetual pavements can result in significant economic (lower life-cycle costs), environmental (less material usage/ production), and social (fewer lane closures) benefits.

The portion of the Iowa 100 paving project featured in this case study was completed in 2016 and included a 12.5-inch asphalt pavement over a 15.5-inch modified subbase (see figure 2 [Schram 2018]), a design that is expected to carry the traffic on this stretch of highway for over 60 years with only minor periodic milling and resurfacing. The initial cost of the project was $15.1 million (including safety features and project management), with the pavement construction accounting for approximately $6.5 million. The $15.1 million cost was about $5 million less than the original engineer's estimate.



a) Project location

b) Overview photo

Figure 1. Iowa State Highway 100 project near Cedar Rapids.

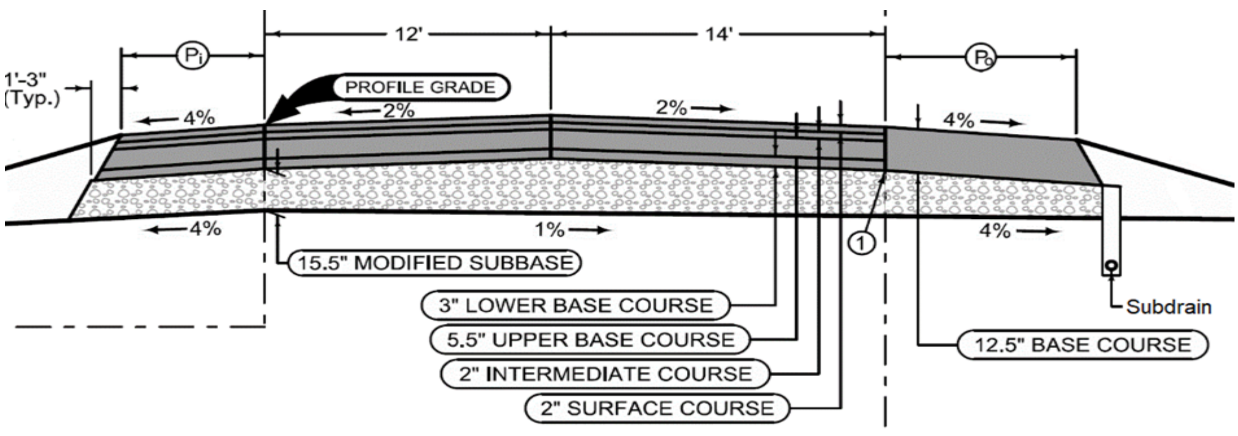


Figure 2. Iowa 100 pavement cross section design.

The projected traffic used in the development of the pavement design was 12,000 vehicles per day including 10 percent trucks. The properties of the asphalt materials used in the pavement cross section for the project are summarized in table 1. Some notable features of the pavement and materials designs include:

- The subbase course was built with 165,000 tons of material, composed mostly of a blend of 50 percent reclaimed asphalt pavement (RAP) and 50 percent virgin limestone aggregate.
- Most of the 120,000 tons of asphalt concrete (except for the lower base) included 12 to15 percent RAP.
- The lower base was built with 3 inches of a fatigue-resistant asphalt mixture designed at 3.5 percent air voids; it contained 5.2 percent asphalt binder and 100 percent virgin aggregate.

Table 1. Mixture properties of the asphalt materials used within each pavement layer.

Layer	Layer Thickness	No. of Lifts	Design Lab Voids	RAP Content	Binder Content and Grade	Cost Per Ton (including binder)
Surface	2 inches	1	4.0%	15%	5.0% PG 64-28	$54.00
Intermediate	2 inches	1	4.0%	12%	5.4% PG 64-28	$52.24
Upper base	5.5 inches	2	4.0%	15%	5.3% PG 64-28	$50.51
Lower base	3 inches	1	3.5%	None	5.2% PG 64-28	$50.07

The paving of the project, depicted in figure 3, went exceedingly well. Quality construction was highly emphasized and the construction processes included several innovative technologies, including intelligent compaction; paver-mounted, thermal profiling; and GPS ticketless paving. Because of this emphasis on quality, the contractor earned incentives for both air voids and smoothness.

Figure 3. Construction work on Iowa 100.

Although not a specification requirement, the response characteristics of the perpetual pavement design were verified by the Iowa DOT after construction using backcalculated results from falling weight deflectometer (FWD) deflection testing and mechanistic modeling. The verification determined an estimated maximum microstrain of approximately 24 at the bottom of the asphalt layer under a 34,000-lb tandem loading, well below the generally recommended maximum target values of 60 to 70 microstrain.

WHAT BENEFITS WERE ACHIEVED?

Although a formal benefit analysis was not conducted by the DOT, an independent assessment of the costs and environmental impacts of the perpetual pavement was performed for illustrative purposes only. In this assessment, the perpetual pavement design was compared to a conventional flexible pavement designed for the same design traffic loadings over a 50-year analysis period using the 1993 AASHTO Design Guide (AASHTO 1993). Only the primary traffic lanes and the pavement materials above the subbase were considered in the analysis. The maintenance and rehabilitation strategies for the perpetual and the conventional options are compared in tables 2 and 3; the Iowa DOT provided the schedule for the perpetual pavement and a "typical" schedule was assumed for the conventional pavement.

Table 2. Maintenance and rehabilitation schedules for perpetual pavement alternatives on Iowa 100.

Activity	Year	Layer	Thick. (in)
New Construction	0	Surface	2
		Intermediate	2
		Upper base	5.5
		Lower base	3
		Subbase	15.5
Preservation	15	Mill & Fill	1.5
Thin Overlay	27	Overlay	2
Preservation	39	Microsurfacing	0.5
Minor Rehabilitation	47	Overlay	2
		CIR	4
End of Analysis	50	-	-

Table 3. Maintenance and rehabilitation schedules for conventional asphalt pavement alternatives on Iowa 100.

Activity	Year	Layer	Thick. (in)
New Construction	0	Surface	2
		Intermediate	2
		Upper base	5.5
		Subbase	15.5
Preservation	12	Mill & Fill	1.5
Medium Rehabilitation	20	Surface	2
		Intermediate	5
		Mill	-4
Preservation	28	Mill & Fill	1.5
Heavy Rehabilitation	35	Surface	2
		Intermediate	4
		Mill	-4
		CIR	4
Preservation	43	Mill & Fill	1.5
End of Analysis	50	-	-

As we switch our focus from growing our system to operating our system, perpetual pavement design provides us an advantage. We are able to limit our future rehabilitation activities to the surface course while preserving the base and foundation. This also minimizes our impacts to traffic and avoids long-term head-to-head work zones and costly reconstruction alternatives in the future.

–Scott Schram, Iowa DOT

LIFE-CYCLE COST ANALYSIS

A simplified life-cycle cost analysis (LCCA) was conducted assuming discount rates of both 2 and 4 percent and the maintenance and rehabilitation schedules shown in tables 2 and 3. The results of this analysis are summarized in table 4 in terms of both net present value (NPV) and equivalent uniform annual costs (EUAC). Even though the initial cost for the perpetual design was higher, the LCCA shows that its longer life offsets those higher initial costs. In terms of life-cycle costs, the perpetual pavement shows cost savings ranging from 17 to 28 percent, depending on the economic indicator (NPV or EUAC) and selected discount rate. As expected, the use of the lower discount rate favors the alternative with the higher initial costs. This cost analysis used typical asphalt pavement material and construction costs and is based on the maintenance and rehabilitation assumptions outlined in tables 2 and 3. Furthermore, it includes agency costs only, although the consideration of user costs would more strongly favor the perpetual design because of fewer lane closures and traffic disruptions.

Table 4. LCCA computations for perpetual and conventional pavements.

Economic Indicator	Discount Rate, %	Cost of Perpetual Pavement, $	Cost of Conventional Pavement, $	Cost Savings with Perpetual, $ (%)
NPV	2	5,273,053	7,366,294	2,093,241 (28)
EUAC	2	105,461	147,326	41,895 (28)
NPV	4	4,769,182	5,746,767	977,585 (17)
EUAC	4	95,384	114,935	19,552 (17)

LIFE-CYCLE ASSESSMENT

To assess the broader environmental impacts of the design and material choices, a life-cycle assessment (LCA) was conducted. The LCA compared the environmental impacts of the two design alternatives assuming similar use and performance throughout the analysis period and in accordance with the assumed schedules given in tables 2 and 3. The results of the LCA are annualized to enable a comparison and are presented in figure 4 for selected impact indicators as recommended in the FHWA LCA framework document (FHWA 2016). For each impact indicator, it is noted that the values for the conventional design were established as the baseline (set at 100 percent) and the impacts of the perpetual pavement are expressed as a percentage relative to that baseline amount.

As can be seen from figure 4, the perpetual pavement has significantly less impact in every selected category. The main contributor to the results is the use of the various paving materials throughout the design life of the two different pavement alternatives. The perpetual alternative uses less material over the design life that leads to lower environmental impacts. These environmental impacts are important to the State of Iowa under Iowa Code 455B.104 legislation requiring that greenhouse gas emissions be estimated for each year and forecasted for future years.

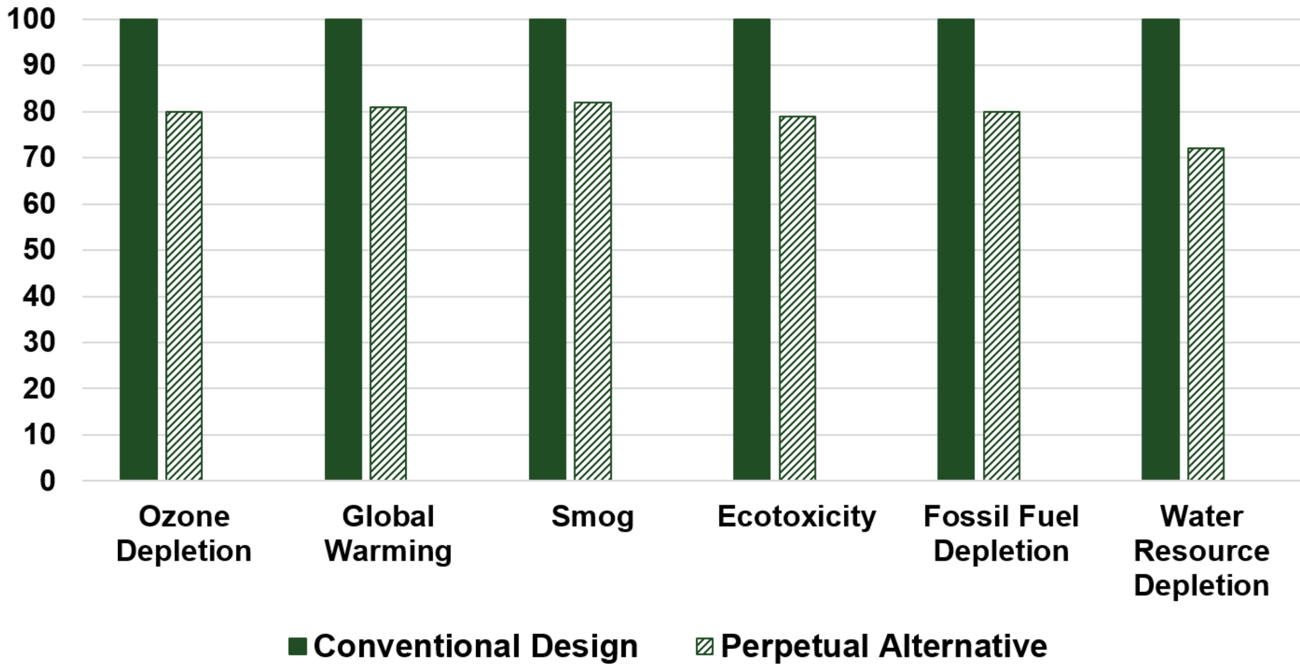


Figure 4. LCA results for the conventional design and the perpetual alternative.

RESILIENCE

Although not quantified in this project, the perpetual asphalt pavements design offers a level of resiliency for the roadway facilities on which they are used. The thicker asphalt pavement structure is resistant to moisture damage and more likely to remain serviceable after a flooding event. This is important to the Iowa DOT because it has a program examining the resiliency of its transportation infrastructure.

WHAT WERE THE KEY OUTCOMES AND LESSONS LEARNED?

Some of the key outcomes and lessons learned from this project are:

- The Iowa DOT selected a perpetual pavement for this project to reduce overall life-cycle costs and to increase the sustainability of the pavement. This design limits future rehabilitation activities to the surface course and minimizes the impacts to traffic by limiting long-term work zones and costly reconstruction alternatives in the future.
- A significant amount of RAP was used in the construction of the perpetual pavement, eliminating disposal costs and demonstrating the suitability of reusing pavement materials. The subbase course was built with 165,000 tons of material, composed mostly of a blend of 50 percent reclaimed asphalt pavement (RAP) and 50 percent virgin limestone aggregate. Most of the 120,000 tons of asphalt concrete (except for the lower base) included 12 to15 percent RAP.
- The use of innovative construction technologies—including intelligent compaction, thermal scanning, and GPS ticketless paving—allowed the contractor to earn incentives for both field air voids and smoothness.
- A simple LCCA based on an assumed maintenance and rehabilitation schedule indicated that the perpetual pavement had lower NPV and EUAC costs (ranging from 17 to 28 percent less, depending on the selected discount rate) compared to a conventional asphalt pavement. The initial cost for the project came in 25 percent below the engineer's estimate.
- The perpetual pavement exhibited better environmental performance than the conventional pavement design because it used significantly less material over the life cycle.
- Although not a stated goal, the perpetual pavement offers the potential for increased resiliency in the case of an extreme flooding event as the pavement structure will be less susceptible to moisture damage.

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KEY WORDS

asphalt concrete, sustainability, perpetual pavement, long-life pavement, life-cycle assessment, cost savings.

CREDITS

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