Arkansas Demonstration Project:
The Use of Roller Compacted Concrete to Reconstruct a Segment of SH 213 in Fayetteville

Final Report
May 2015

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. "Innovations" is an inclusive term used by HfL to encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community's culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decision makers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is at www.fhwa.dot.gov/hfl.

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16. Abstract
As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, the Arkansas State Highway Transportation Department (ASHTD) was awarded a $420,000 grant to demonstrate the use of roller compacted concrete (RCC) as a durable and cost-effective alternative to traditional treatments. This report documents the rehabilitation/reconstruction of RCC pavement on Highway 213 in Conway County near Hattieville. The project is located in the Fayetteville Shale Play area, which houses more than 4,000 new gas wells. The pavement infrastructure in this area has rapidly deteriorated due to the recent increase in truck volume and loadings from the natural gas exploration activities.

This report details the innovation used to rehabilitate two segments of Highway 213 with RCC, cement treated reconstruction base, and SafetyEdge. This project met the Highways for LIFE goals for safety, queuing, and user satisfaction. The use of RCC technology required additional days for construction, but the increased time for road closures/detours during construction will be partly offset by lesser need for future maintenance activities.

Using RCC for pavement rehabilitation increased the construction costs, both initial and life cycle costs, over traditional asphalt overlay. However, considering the fact that the future natural gas exploration activities would result in higher truck volumes and heavier loadings, the cost of RCC can be justifiable over a 30-year period. The experience gained on this successful project will help the ASHTD use RCC more routinely on future projects.

17. Key Words
Roller Compacted Concrete, Safety Edge, Diamond Surface Grinding, Cement Treated Reconstructed Base

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
(none)	mil	25.4	micrometers	μm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2 (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in^2 (ksi)	kips per square inch	6.89	megaPascals	MPa
		DENSITY		
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
μm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	Newtons	0.225	poundforce	lbf
kPA	kiloPascals	0.145	poundforce per square inch	lbf/in^2 (psi)
MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)

ACKNOWLEDGMENTS

The project team would like to acknowledge the invaluable insights and guidance of Federal Highway administration (FHWA) Highways for Life (HfL) Team Leader Byron Lord, Contracting Officer's Representative Julie Zirlin, and Program Managers Ewa Flom, Mary Huie, and Kathleen Bergeron, who served on the technical panel on the demonstration project.

The team also is indebted to Lester Frank of the FHWA Arkansas Division for his effective coordination effort and to Arkansas Highway and Transportation Department Resident Engineer Gary Busbee, Construction Inspector Joe Knight and Research Engineer Sarah Tamayo for their efforts and cooperation on this project. Additionally we would like to thank Dr. Stacy Goad Williams of the University of Arkansas for her invaluable contribution to the completion of this report. The project team was instrumental in making this project a success and provided the information that helped shape this report.

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ABBREVIATIONS AND SYMBOLS

AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ASHTD	Arkansas State Highway and Transportation Department
CTRB	Cement Treated Reconstructed Base
dB	Decibel
DOT	Department of Transportation
ESAL	equivalent single axle load
FHWA	Federal Highway Administration
FDR	full depth reclamation
FSP	Fayetteville Shale Play
HfL	Highways for LIFE
IRI	International Roughness Index
LCCA	life cycle cost analysis
OBSI	onboard sound intensity
OSHA	Occupational Safety and Health Administration
PCC	portland cement concrete
RCC	Roller Compacted Concrete
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
vpd	vehicles per day

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—has provide incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than $5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how highway agencies can manage the highway project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

Project Solicitation, Evaluation, and Selection

FHWA issued open solicitations for HfL project applications in fiscal years since 2006. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, and contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

The project selection panel consisted of representatives of the FHWA's Offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management Team; the Division offices; and the HfL team. After evaluating and rating the applications and supplemental information, panel members convened to reach a consensus on the projects to recommend for approval. The panel gave priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one that the applicant State has never or rarely used, even if it is standard practice in other States.
- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.
- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.
- Demonstrate the willingness of the applicant department of transportation (DOT) to participate in technology transfer and information dissemination activities associated with the project.

HfL Project Performance Goals

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
  - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
  - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported via Occupational Safety and Health Administration (OSHA) Form 300.
  - Facility safety after construction—At least twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
  - Faster construction—At least 50 percent reduction in the time highway users are impacted, compared to traditional methods.
  - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
  - Queue length during construction—A moving queue length of less than 0.5 miles in a rural area or less than 1.5 miles in an urban area (in both cases at a travel speed 20 percent less than the posted speed).
- **Quality**
  - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile.
  - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.

- **User Satisfaction**
    - User satisfaction—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4-plus on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Arkansas State Highway and Transportation Department's (ASHTD) HfL demonstration project, which involved the reconstruction of approximately 2 miles of State Highway 213 in Conway County near Hattieville. The report presents project details relevant to the HfL program, including safety, construction congestion, and user satisfaction. HfL performance metrics and economic analysis lessons learned are also discussed.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

Changes in technology have allowed Arkansas to benefit from the large amount of natural gas located within the State. Since 2007, the Fayetteville Shale Play (FSP) area, the north central region of Arkansas (see Figure 1), has seen the development of more than 4,000 new gas wells. Each new well typically requires over 1,000 truck trips and 2,400 equivalent single axle loads (ESALs). Since these public roads were not designed to withstand such heavy traffic loadings, there has been accelerated pavement deterioration in the FSP area. More than 1,000 miles of highways have been adversely affected by this development, necessitating cost-effective rehabilitation strategies to maintain these highways vital to the economy of the region.

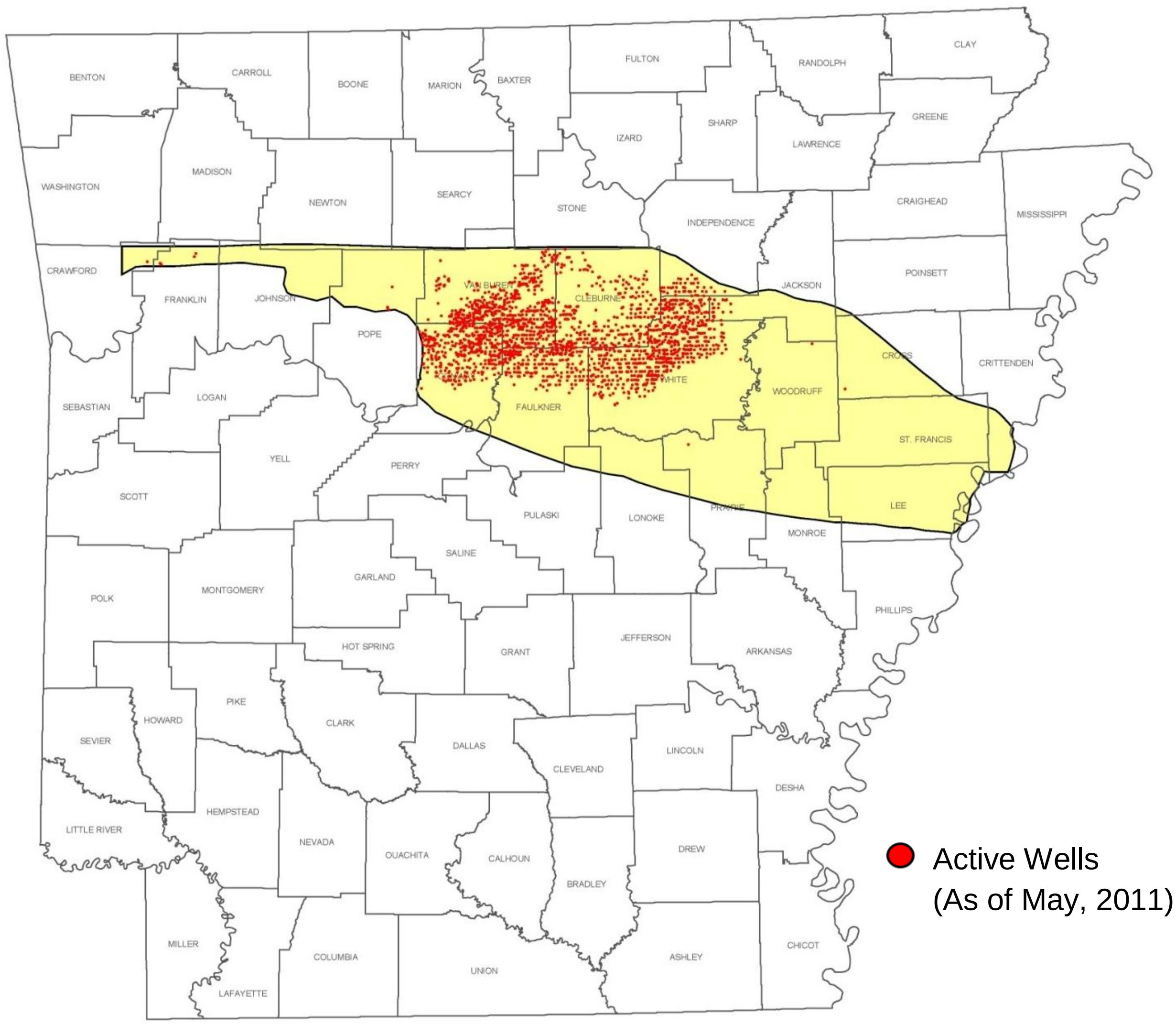

Figure 1. Map. Fayetteville Shale Play area (courtesy ASHTD).

PROJECT INNOVATIONS

The HfL project undertaken by the ASHTD involved several innovative technologies:

- Roller Compacted Concrete (RCC): RCC pavement was used on this project to shorten the construction time and reduce the costs generally associated with traditional concrete paving.
- Cement Treated Reconstruction Base (CTRB): The existing pavement and base were reconstructed to provide a platform for the roller compacted surface.
- SafetyEdge: A slipformed safety edge was provided to the pavement surface to allow vehicles to negotiate even steep differences between paved and unpaved surfaces, decrease highway fatalities and serious injuries, and provide an additional level of consolidation on the pavement edge to decrease raveling and improve pavement life.
- Pilot Cars: Pilot cars were used throughout the construction period to minimize the disruption to the road users in the project location, enhance road user safety, and reduce worker-related incidents during construction.

The experience gained through this project is expected to better enable the ASHTD to provide a safe, smooth, and long-term solution to the challenges related to maintaining the serviceability of their highway facilities.

HFL PERFORMANCE GOALS

The successful implementation of an HfL project was assessed with respect to how safety, construction congestion, quality, and user satisfaction were addressed during the construction of the project. On most HfL projects, data are collected before, during, and after construction, as appropriate, to demonstrate that the featured innovations can be deployed while simultaneously meeting the HfL performance goals in these areas.

- **Safety**
  - Work zone safety during construction—No motorist incidents were reported during construction. The ASHTD exceeded the HfL requirements for work zone safety. The use of a 24-hour per day pilot vehicle contributed greatly to the safety of the public and workers during the construction period.
  - Worker safety during construction—No worker injuries occurred during construction, which exceeded the goal of less than a 4.0 rating on the OSHA 300 form.
  - Facility safety after construction—The installation of SafetyEdge is expected to improve the safety of the facility after construction. However, the net effect of the expected improvement is yet to be determined.

- **Construction Congestion**

  - Faster construction—The RCC construction took 30 days to complete, whereas it is estimated that traditional concrete overlays would have taken 3 days to place. Considering the future maintenance activities and associated traffic impacts, the use of RCC on this project still would take 16 additional days. The HfL goal of 50 percent reduction in the time highway users are impacted, compared to traditional methods, was not met.

  - Trip time during construction—The average travel time measured during construction was 7.34 minutes, or 76.13 percent more than the corresponding travel time measured before construction. The HfL goal of less than 10 percent increase in trip time compared to the average preconstruction speed was not met. However, the use of the pilot vehicle limited delay and reduced queue length for traffic moving through the site.

  - Queue length during construction—Given the lower traffic level observed on this roadway segment, the use of a pilot vehicle helped meet the HfL performance goal of less than 0.5 miles queue length in a rural work zone.

- **Quality**

  - Smoothness—The average post-grinding IRI was measured to be 69.5 inches/mile. The HfL goal of IRI less than 48 inches/mile was not met on this project. A pay deduction of $40,893.22 was applied to the contractor for not meeting the smoothness criteria.

  - Noise—Noise was not measured on this project.

- **User satisfaction**

  - User satisfaction—The traveling public gave the project high marks for overall satisfaction and recognized the importance of keeping traffic flowing during construction. Eighty-seven percent of the respondents believed the project resulted in a high-quality roadway surface. Satisfaction with the finished product is high and meets the HfL user satisfaction criteria of 4-plus on a 7-point Likert scale.

ECONOMIC ANALYSIS

The costs of delivering this HfL project were compared to the most likely traditional alternative technique, in this case a 2-inch asphalt concrete (AC) overlay applied every 5 years. While historically it would not have been an option to provide a portland cement concrete surface on a low-volume highway such as this, the condition of the existing pavement due to the increased loading, and the necessity to provide for these loads far into the future, makes this comparison reasonable.

LESSONS LEARNED

There were several issues identified that could help provide for more successful application of this technology in the future:

- It is critical to have a thorough understanding of the paver to be used on the project. Extensive use of test strips is recommended before placement of the actual surface.
- Fly ash should be avoided, as it tended to reduce the early strength of the concrete.
- Care must be taken at the plant to ensure the consistent addition of cement to maintain consistent mix properties. High humidity can cause clumping of cement.
- Higher temperature limits should be required to ensure adequate strength. Lower nighttime temperatures in the 30s °F seemed to reduce the strength on the west segment.
- Due to the observed raveling of the bare or ground surface, it may be advisable to apply a thin AC wearing surface at the time of construction.

CONCLUSIONS

In spite of the significant additional cost, there may be locations where RCC technology is appropriate, given the future development of natural gas wells or other development that increases heavy loads far above those anticipated by the original pavement design. It is believed that much of the additional cost was due to the unfamiliarity with the technology and the short nature of the project.

It was also noted that, in some cases, failure of the traditional thin overlays occurred in as little as 6 months after construction. If even one additional overlay is required in the 30 year analysis period, the cost of the two alternatives becomes nearly the same. The ASHTD believes that RCC can provide a good, long-lasting surface for roads under heavy load conditions.

PROJECT DETAILS

PROJECT BACKGROUND

The project involved reconstruction/rehabilitation of two segments on State Highway 213 in Conway County near Hattieville. Each section, approximately 0.86 miles in length, has been adversely affected by the construction of nearby natural gas wells. This project is located in the FSP area, the north central region of Arkansas, which houses more than 4,000 new gas wells.

State Highway 213 has experienced significant traffic growth, from 770 vehicles per day (vpd) in 2007 to 1,100 vpd in 2010. This increase in traffic volumes translates to a growth rate of more than 12 percent per year, which is significantly higher than the average annual statewide growth rate of 2 percent per year. This growth in traffic is primarily a result of the increase in the number heavy trucks used to develop and maintain the natural gas facilities around the project location. The heavy vehicles have been employed not only for the drilling phase of well development, but also for trucking the water used during the ongoing fracking operations to the approved sites for disposal.

PROJECT DESCRIPTION

The increased truck traffic and loading have resulted in rapid deterioration of the pavement infrastructure—more than 2,500 miles of roadways, including the lower volume highways. The typical pavement structure in the FSP area is hot mix asphalt surface over a crushed stone base. The pavements in the FSP area exhibit several load-related distresses, including rutting, fatigue cracking, potholes, slippage cracking, and edge failures.(1) Structural enhancements are needed in many areas to prevent recurrent failures; however, because of budgetary constraints, traditional alternatives, such as a complete reconstruction or major rehabilitation, are not feasible on a widespread basis. On the other hand, routine minor rehabilitation with typical asphalt overlays has failed within 6 months of service.(1)

Given the limitations with traditional rehabilitation alternatives, ASHTD opted to use RCC pavement to reconstruct or rehabilitate two deteriorated roadway segments on State Highway 213. The project location and project limits are presented in Figure 2 and Figure 3, respectively. This project involved the reconstruction of two 1-mile sections of RCC pavement over differing base treatments.

ASHTD had a research contract with the University of Arkansas, Fayetteville, to thoroughly evaluate the RCC technology and prepare recommendations for incorporating RCC into the AHTD Standard Specifications. This study included a life cycle cost analysis to explore the feasibility of using RCC in Arkansas. The results indicated that the RCC was the least expensive option over a 40-year analysis period. (2)

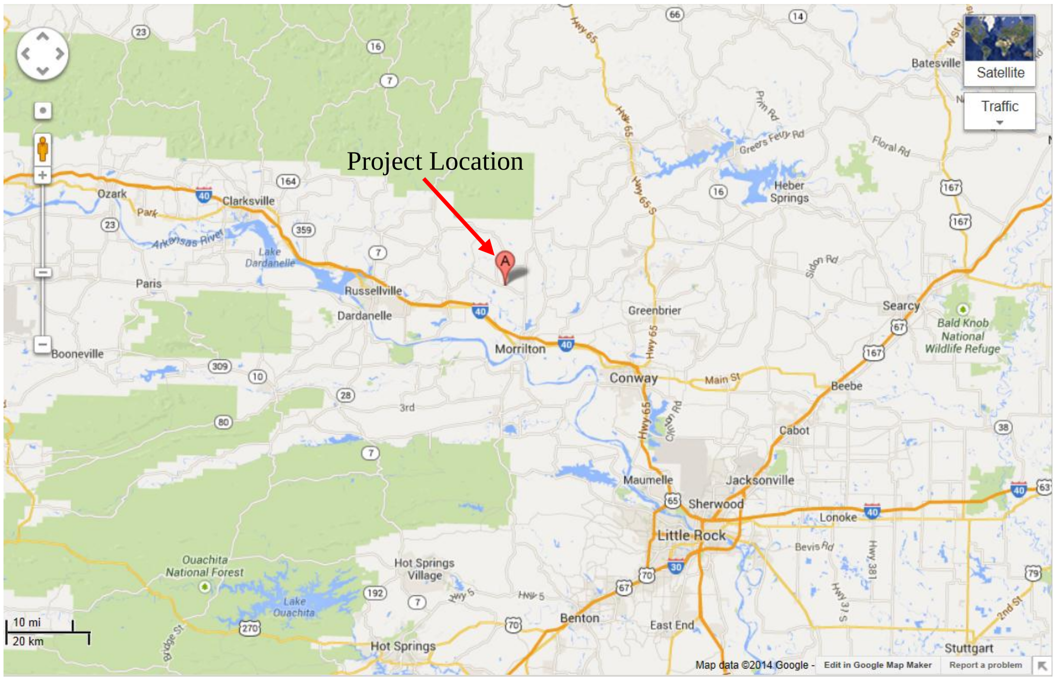

Figure 2. Map. Project location.

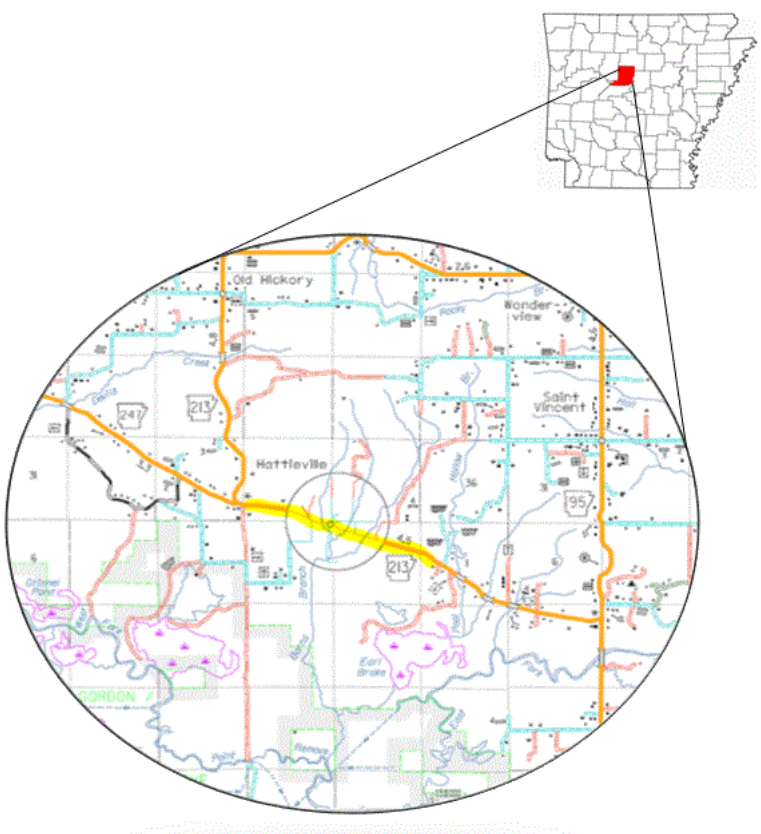

Figure 3. Map. Project limits.

Figure 4 shows the annual average daily traffic (AADT) volumes for the project location and surrounding areas. On this section of roadway, 2010 AADT volumes were estimated to be approximately 1,100 vpd. The traffic volume consistently increased from 740 to 1,100 between 2005 and 2009.

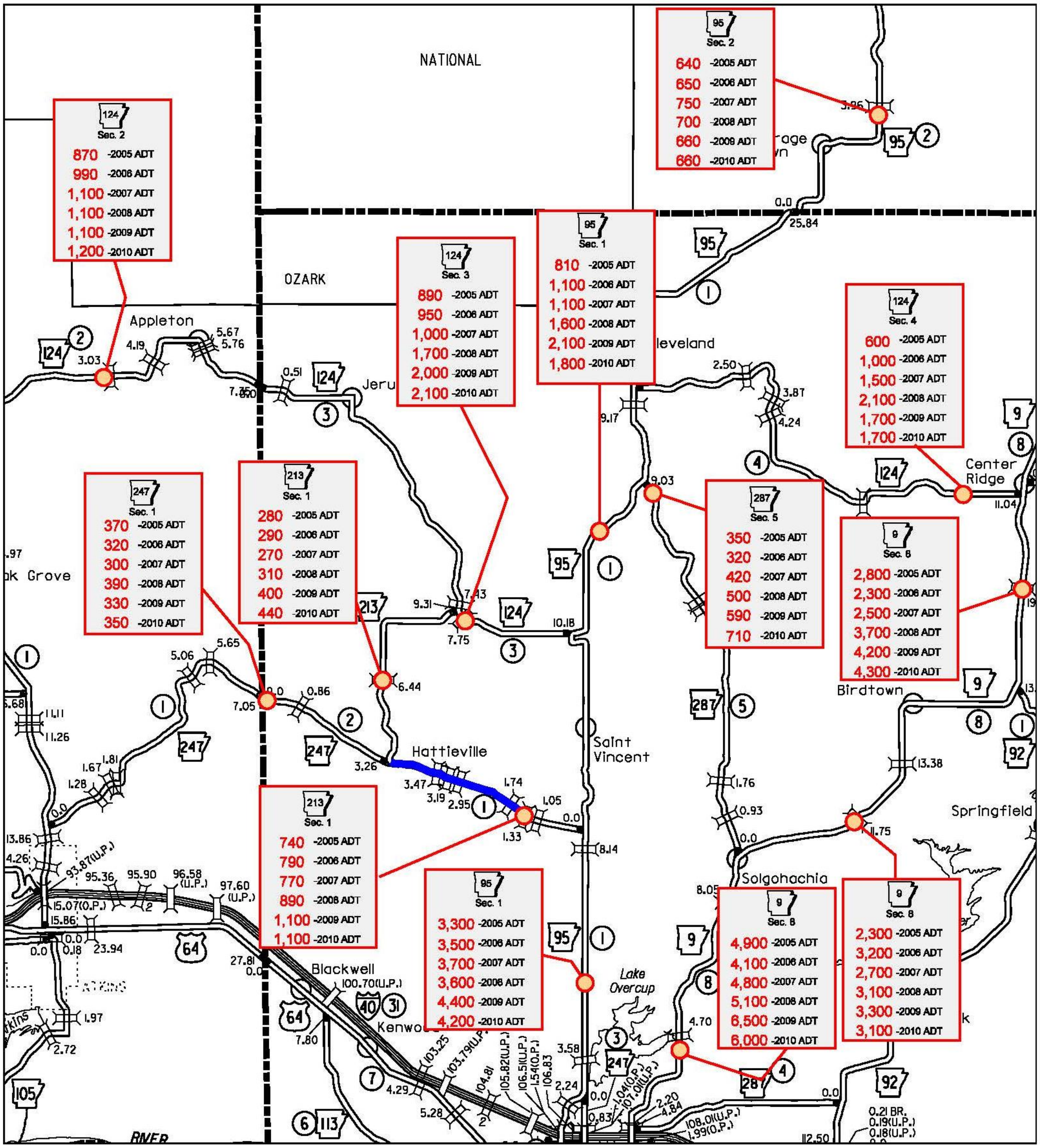

Figure 4. Map. AADT histories for the project location and surrounding areas (courtesy ASHTD).

Roller Compacted Concrete

RCC is a stiff, no-slump concrete mixture. It contains less paste than conventional concrete but provides similar structural support. RCC is a much drier mixture compared to the traditional concrete. RCC is usually constructed without forms, dowels, reinforcing, or finishing, and does not require jointing. Some of the benefits of using RCC pavements include:

- Reduced construction duration.
- Reduced construction costs.
- Reduced maintenance.
- Increased energy savings.
- Increased recycling potential.

Paving Schedule

The project paving lasted for about 1.5 months, with around 2 weeks of paving for each of the pavement sections. The paving schedule is shown in Table 1.

Table 1. Paving schedule.

Date	Activity	Station
11/1/2012	CTRB	Westbound Station 187 to 232
11/2/2012	CTRB	Eastbound Station 187 to 232

Section 1 – West End – RCC over CTRB

11/5/2012	RCC	Westbound Station 187 to 197
11/6/2012	RCC	Westbound Station 197 to 205
11/7/2012	RCC	Westbound Station 205 to 210
11/8/2012	RCC	Westbound Station 210 to 232
11/9/2012	RCC	Eastbound Station 187 to 194
11/14/2012	RCC	Eastbound Station 194 to 205
11/15/2012	RCC	Eastbound Station 205 to 218
11/16/2012	RCC	Eastbound Station 218 to 232

Section 2 – East End – RCC Overlay

11/26/2012	RCC	Westbound Station 106 to 117
11/27/2012	RCC	Westbound Station 117 to 134
11/29/2012	RCC	Westbound Station 134 to 152
12/3/2012	RCC	Eastbound Station 106 to 129
12/4/2012	RCC	Eastbound Station 129 to 135
12/5/2012	RCC	Eastbound Station 135 to 152

Section 1 – Replacement of Bad Areas

12/8/2012	RCC	Westbound Station 210 to 232
12/11/2012	RCC	Eastbound Station 187 to 199
12/12/2012	RCC	Eastbound Station 199 to 218
12/13/2012	RCC	Eastbound Station 218 to 232

Bid Information

ASHTD received three bids for the construction of this project that was let out on July 25, 2012.

The bid prices ranged between $1,723,266.64 and $1,942,418.66, and the low bidder was chosen. The Engineer's estimate was $1,983,072.33 or 13 percent more than the lowest bid.

Structure Information

On this project, two sections were designed and constructed using RCC pavement as the wearing course. Each section, 1 mile in length, included hot mix asphalt transitions, thus resulting in an actual RCC pavement length of approximately 0.86 miles in each section. ASHTD used the 1993 American Association of State Highway and Transportation Officials (AASHTO) pavement design method, ASHTD's standard during the reconstruction process, for design on this project. The reconstructed structure had the following specifications:

1. Section 1 – 7-inch RCC pavement with diamond ground surface over a 6-inch CTRB.
2. Section 2 – 8-inch RCC pavement with diamond ground surface over a leveled existing pavement.

In addition to the RCC surface, the new facility will provide 11-foot lanes and a 3-foot shoulder with safety edge, an improvement over the previous 10-foot lanes with no paved shoulder. ASHTD also developed special provisions to govern the processes associated with design and construction of RCC and CTRB.[(1)]

The RCC mixture contained a nominal maximum aggregate size of ¾ inches and was designed to meet a minimum 28-day compressive strength of 5,000 psi. The typical structure for both sections is presented in Figure 5 and Figure 6.

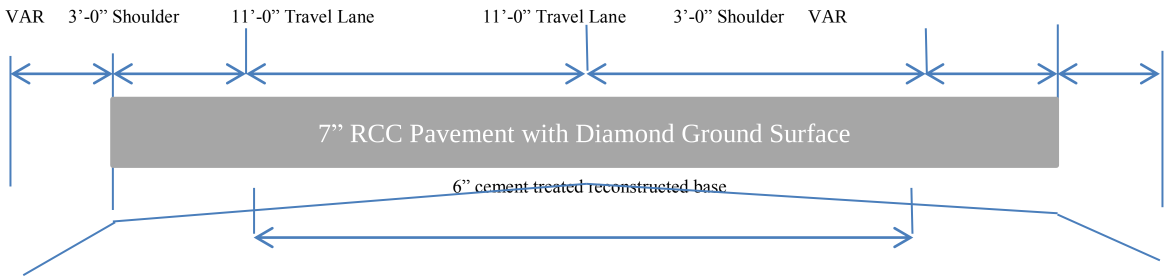

Figure 5. Diagram. Section 1 typical pavement from log mile 2.02 to log mile 2.88 of State Highway 213.

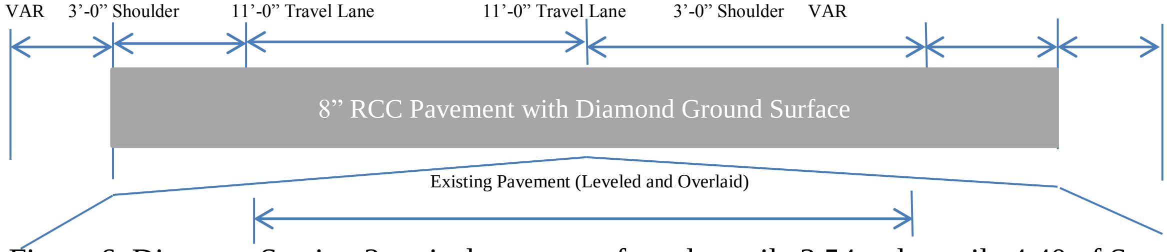

Figure 6. Diagram. Section 2 typical pavement from log mile 3.54 to log mile 4.40 of State Highway 213.

Construction of CTRB

CTRB is a technique similar to full-depth reclamation (FDR). CTRB involves pulverizing and mixing equipment to utilize the existing pavement structure in forming the base layer for the new pavement structure.

The base was reconstructed in several phases. The CTRB for the Section 1 westbound lane and Section 2 eastbound lane were completed in two consecutive days, November 1 and 2, 2012. The CTRB product allowed the existing materials to be utilized to form a structurally desirable base for the RCC pavement layer, and only materials that were required to be hauled in were cement and water. The contractor did not use aggregate haul trucks during the reconstruction process.

To begin, the existing AC pavement and base were milled using a traditional milling machine with a 2-meter (6.56 feet) milling head that required two passes to completely mill each lane. The in-place base reconstruction involved pulverization of the existing asphalt and base materials to a depth of 6 inches, such that the following ASHTD specifications were met for the processed material (see Table 2).[(1)]

Table 2. Percent passing requirements for CTRB.

Sieve Size	Percent Passing
2-inch	98-100
1.5-inch	95
#4	25-55

The ASHTD specification required a minimum in-place density of 96 percent and a thickness tolerance of ±1 inch. The maximum dry density and optimum moisture content of the CTRB were identified using the modified Proctor method (AASHTO T180). The cement content was determined for a target compressive strength in the range of 300 to 500 psi. On this project, a laboratory maximum dry density of 126.9 pcf, an optimum moisture content of 7.6 percent, and a cement content of 4 percent were achieved for CTRB.[(1)]

While the contract specified a milling depth of 6 inches, an 8-inch depth was used as a target to ensure all AC surface and base material were included without disturbing the underlying soil (see Figure 7).

Each lane width was pulverized using two passes of a milling machine, following which the cement and water were worked into the mixture in 1,500-foot lengths.[(1)] After the second pass with the milling machine, the surface was leveled with a motor grader followed by addition of water to increase moisture content (see

Figure 8).

Figure 7. Photo. Milling machine on second pass of reclamation process.

Figure 8. Photo. Target depth of reclamation process after initial milling.

The cement and water were then continuously distributed onto the pulverized material to achieve the target cement and optimum moisture contents, following which they were mixed and compacted in place (see Figure 9). A grader (see Figure 10) and sheepsfoot roller were used for initial compaction, and two additional passes of a steel-wheel vibratory roller were used for intermediate compaction.

Figure 9. Photo. Application of cement to milled surface.

Figure 10. Photo. Using motor grader to level milled surface.

The actual mixing of the cement with the reclaimed pavement/base material was then accomplished using a Trex RS-600 Reclamation/Stabilization machine. As shown in Figure 11 and Figure 12, the machine used a 96-inch mixing head, placed behind a water truck, to feed water directly to the front end of the milling head.

Figure 11. Photo. Water truck coupled to reclamation/stabilization unit.

Figure 12. Photo. Side view of water truck coupled to reclamation unit.

After the mixing was completed, the surface was regraded and recompacted using a footed roller (see Figure 13).

Figure 13. Photo. Cement stabilized material during compaction process.

A single pass of the steel-wheel roller in static mode was used to perform finish rolling. The densities achieved were marginal (ranging from 95 to 97 percent) for the westbound lane. The densities in the eastbound lane were increased using the vibratory passes that were applied more quickly after the mixing process. The density measurements, conducted using the nuclear density gauge at various distances from the centerline of the roadway, indicated that the densities varied across the width of the lane. The highest densities were measured at about 7 feet from the centerline, and lower densities were measured near the centerline. The lane edge was found to be denser than the area near the centerline. Additional roller passes were used in low density areas identified during the quality control/quality assurance testing.(1)

On November 1, 2012, the westbound traffic was closed for the construction of the CTRB. A pilot car was deployed to guide traffic from one end to another. Since at least a portion of one of the two available lanes was closed for traffic, the pilot car was helpful in limiting the vehicle speeds to approximately 35 mph on the newly compacted CTRB. The CTRB surface was graded again to eliminate raveling and provide a smooth surface to facilitate the placement of the RCC.(1)

Construction of RCC

RCC Production

An RCC mix production facility was set up near the aggregate quarry located at the east end of Section 2. The RCC mix was transported to the job site using dump trucks.

RCC Mix Design

The contractor supplied the mix design for RCC. The details of the mix design are presented in Table 3. The compressive strengths obtained on the tested cylinders are presented in Table 4.

Table 3. Contractor-supplied mix design.

Materials	Weight
Type 1 cement	451.2 lb/yd^3
Class C fly ash	112.8 lb/yd^3
Fine aggregate (sand)	1,132.4 lb/yd^3
Manufactured screenings	210.3
Coarse aggregate #57	1,892.9 lb/yd^3
Water	28.4 gallon
Water/cement ratio	0.42
Air entraining additive	0.270

Table 4. Compressive strengths of cylinders tested during mix design.

Age Tested (days)	Compressive Strength (psi)
3	3,240
5	4,410
7	5,350

Test Strip Construction

A test strip was placed at the Point Remove Inn on October 10, 2012, to evaluate the consistency of the plant production process. The density (behind the paver) and core compressive strength measurements indicated lower than desired values. Following the first test strip, a new European Caterpillar high-density paver was acquired. A second test strip was later placed at the same location to facilitate the paving crew's experience with the new paver.[(1)]

RCC, Section 1

The RCC was placed on Section 1 between November 5 and November 16, 2012. The paving operation consisted of placing the concrete mix on the stabilized base using a transfer vehicle and a traditional asphalt paver (see Figure 14 and Figure 15).

Figure 16 shows the RCC construction behind the paver.

The westbound lane of Section 1 was paved first, and its paving was limited to less than 1,000 linear feet per day for the first 3 days. Paving was not performed at night.

Figure 14. Photo. RCC mix emptied into transfer vehicle.

Figure 15. Photo. Placement of RCC using traditional AC paver.

Figure 16. Photo. RCC construction behind paver.

On the first day of paving, the contractor used a roller with a vibratory steel wheel on the front and a rubber tire on the back. The densities achieved with compaction ranged from 90 to 95 percent, which were less than the specified minimum in-placed density of 98 percent. Moreover, the rubber tire marks resulted in excessively rough pavement surfaces (see Figure 17). To improve in-place density levels, the contractor replaced the original roller with a larger steel-wheel vibratory roller. The vibratory roller followed closely behind the paver to ensure proper compaction and strength requirements. The larger roller provided better compaction, with densities ranging from 97 to 99 percent and a smoother initial surface (and Figure 18). On November 15, 2012, the contractor tried using the steel-wheel breakdown roller and rubber-tire finish roller but ended up going back to the large steel-wheel roller.

The rolling pattern involved two passes of the vibratory roller followed by one pass in static mode. Following the compaction, a curing compound was sprayed onto the mat, and joints were sawed at 15-foot spacings using an early-entry saw.[1]

Figure 17. Photo. Initial light roller. Note rubber tire marks resulting in excessive roughness.

Figure 18. Photo. Larger steel wheel roller (replacing initial light roller) resulting in better compaction and smoother surface.

RCC, Section 2

The section east of Hattieville was constructed between November 26 and December 5, 2012. Section 2 of the project involved the placement of 8-inch RCC over an existing AC surface. Prior to RCC placement, a thin AC leveling course was applied to fill the existing ruts and to provide a smooth paving platform. The thickness of the overlay was approximately 1.5 inches, the minimum required to fill the existing ruts. The paving operation was, for all practical purposes, maintained to be the same as that for the reconstructed base. Figure 19 shows the placement of the RCC mix over the existing AC surface.

Figure 19. Photo. RCC surface immediately behind paver (courtesy University of Arkansas).

Strength Testing and Reconstruction of Section 1

One of the advantages of using RCC is the early opening of the newly constructed pavement to traffic. The RCC pavement mat needed to gain adequate strength to handle concrete delivery trucks. A good rule of thumb for early opening to traffic is 2,500 to 3,000 psi compressive strength.[(3)] The ASHTD Special Provisions for RCC specified that the RCC mat may be opened to light traffic after 24 hours, provided a compressive strength of at least 1,800 psi has been achieved. The Special Provisions also required a compressive strength of at least 2,500 psi to allow unrestricted traffic on the pavement. For acceptance, the ASHTD Special Provisions specified a minimum 28-day compressive strength of 5,000 psi, while the rejection limit was set at 3,499 psi or lower. A pay deduction of 10 percent was applied for inadequate 28-day compressive strengths between 4,999 and 4,000 psi, while a deduction of 20 percent was applied for strengths between 3,500 and 3,999 psi.

The contractor cut cores for both early strength (24-hour) and 28-day strength measurements. The early strengths of the concrete were then determined based on the compressive strength testing of the cores. Additionally, 12 cylinders were cast for acceptance testing at 2 locations within each lane of each section. Compressive strengths of RCC cylinders were measured using AASHTO T22 testing at 24 hours and 3, 7, 14, 28 and 90 days. Tables 05 and 06 present a summary of compressive strengths and densities of cylinders/cores, respectively.

Table 5. Compressive strengths of RCC cylinders/cores.[1]

Location	Average Compressive Strength (psi)						
-	**1 day (Cyl.)**	**3 day (Cyl.)**	**7 day (Cyl.)**	**14 day (Cyl.)**	**28 day (Cyl.)**	**28 day (Cores)**	**90 day (Cyl.)**
S1 – Westbound	1,418	2,982	3,395	3,505	3,661	2,813	4,545
S1 – Eastbound	457	1,837	2,553	2,897	3,328	2,175	4,139
S2 – Westbound	2,077	3,873	4,279	4,726	4,943	3,337	5,284
S2 – Eastbound	4,102	5,307	6,504	6,016	6,289	3,938	6,993
S1 – Reconst.	2,096	4,340	4,837	5,174	5,722	4,531	6,212

Table 6. Densities of RCC cylinders/cores.[1]

Location	Density (pcf)	
-	**Cyl.**	**Cores**
S1 – Westbound	148.8	144.8
S1 – Eastbound	150.6	138.6
S2 – Westbound	148.2	143.0
S2 – Eastbound	151.3	142.5
S1 – Reconst.	149.8	141.1

For the eastbound lane of Section 1, the compressive testing of cores indicated very low strengths of approximately 500 psi, while the concrete cylinders appeared very green. As indicated in

Table 5, the compressive strengths of cylinders were less than desirable at all ages, with averages ranging from 457 psi at 24 hours through 4,139 psi at 90 days. The cores obtained from the westbound lane of Section 1 indicated improved but inadequate compressive strengths. The average 28-day compressive strength of 3,661 psi, which was much lower than the ASHTD specifications, resulted in a 20 percent pay deduction for inadequate strength. It is believed that the cooler-than-anticipated temperatures resulted in issues related to development of the required strength. Nighttime temperatures were in the 30s during the paving of the west section.

The poor strength levels prompted the contractor to remove and replace the majority of Section 1. The replacement of Section 1 was done between December 8 and December 13, 2012. For Section 2 and the replacement of Section 1, the contractor modified the concrete mix by removing fly ash to allow for higher early strength gains. As indicated in

Table 5, the compressive strengths of samples obtained from Section 2 and Section 1 replacement areas greatly improved to provide adequate strengths. The entire RCC paving process was completed in just over 1 month.

Safety Edge

The concept of the safety edge was developed to minimize the severity of incidents when vehicles drift off the roadway. The safety edge was formed by a steel attachment on the screed, which assisted in providing confinement at the outer edge and provided an additional safety feature for the roadway.[1] The centerline edge was not confined during paving, so the longitudinal joints of both sections were transversely sawed at a spacing of 15 feet to control random cracking. Approximately 4 inches of the pavement was sawed and removed at the centerline to provide a vertical surface (prior to placement of the opposing lane) against which the lane compacted. The traditional vertical pavement edge is replaced by a beveled edge, making it easier for a vehicle to re-enter the roadway by minimizing the overcorrection often associated with these incidents. It has been shown that the optimal angle for this slope is 30 degrees (see Figure 20).

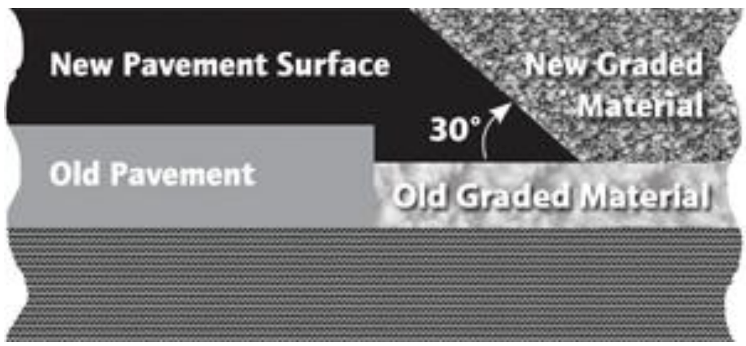

Figure 20. Diagram. Basic safety edge construction detail (courtesy FHWA).

Both sections on this project incorporated a formed safety edge on the RCC pavement. A simple modification was made to the paver by adding an adjustable section of angle iron immediately behind the paver (see Figure 21). The compaction efforts tended to make the initial angle steeper, which required adjustments to achieve the desired angle.


Figure 21. Photo. Adjustable jig used to create safety edge behind paver.

Figure 22 and Figure 23 present the completed safety edge after the granular shoulder material was pulled up to it.


Figure 22. Photo. Close-up of completed safety edge.

Figure 23. Photo. Completed safety edge after project completion.

Surface Diamond Grinding

The contract required the surface of the RCC mix to be diamond ground. Prior to the reconstruction process, the IRI measured between 200 and 300 inches per mile. After construction, the IRI was reduced to an average of 69.5 inches per mile, using the surface diamond grinding. Figure 24 and Figure 25 present the traditional diamond grinding process. While the HfL target IRI of 48 inches per mile could not be achieved, the surface smoothness was considered acceptable given the rural nature of the facility and the significant improvement from the pre-construction numbers.

Figure 24. Photo. Traditional diamond grinding operation (courtesy University of Arkansas).

Figure 25. Photo. Diamond ground surface at core sample locations (courtesy University of Arkansas).

DATA ACQUISITION AND ANALYSIS

As appropriate, safety, construction congestion, and quality data were collected before and after the project construction to determine if this project met the HfL performance goals. The primary objective of this data acquisition and analysis was to quantify the project performance, to provide an objective basis to determine the feasibility of the project innovations, and to demonstrate that the innovations can be used to do the following:

1. Achieve a safer work environment for the traveling public and workers.
2. Reduce construction time and minimize traffic interruptions.
3. Produce a high-quality project and gain user satisfaction.

This section discusses how well the ASHTD project met the specific HfL performance goals related to these areas.

SAFETY

The HfL performance goals for safety include satisfying the following criteria:

- Meeting worker and motorist safety goals during construction
- Reduction in fatalities and injuries after construction

ASHTD adopted several measures to ensure safety on this project:

- Accelerated placement of RCC and rapid curing.
- Use of pilot car for guiding traffic through the work zone during construction.
- Use of safety edge to prevent motorist incidents due to pavement drop-off.

While the entire reconstruction process could have been constructed (and disrupted) one lane at a time, the decision to complete all of the CTRB allowed for a shorter timeframe in which the 7-inch elevation differential at the centerline would be present, reducing potential safety risks.

Table 7 presents the crash history at the project location for 2009 through 2011. Crash data for 2012 and 2013 were not available for inclusion in this report. The crash rate for the project location was calculated to be 52.4 (per 100 million vehicle miles traveled) a rate nearly half the statewide average of 93.7. No incidents occurred during construction, which meets the HfL goal of achieving a work zone crash rate equal to or less than the preconstruction rate.

Similarly, no worker injuries were reported on this project. The performance goal of achieving an incident rate for worker injuries of less than 4.0 (based on OSHA Form 300) was thus met for this project.

Table 7. Pre-construction crash rates (source: ASHTD).

Route	Reference	Length (mi)	No. of crashes			Crash Rate (crashes/ 100 million VMT)	
-	-	-	Fatal	Injury	PDO	3-Year Rate	3-Year Rate (Statewide)
Ark 213	Log Mile 1.95 to Log mile 4.47	2.52	0	1	0	52.4	93.7

The SafetyEdge installed on this project is expected to improve the safety of this facility. In addition, the RCC was diamond ground to provide a durable and smoother surface that would further enhance user safety. The net effect that these safety improvements will have on the HfL goal of 20 percent reduction in fatalities and injuries in 3-year crash rates after construction is yet to be determined.

CONSTRUCTION CONGESTION

One of the HfL performance goals was to achieve a 50 percent reduction in the time highway users are impacted during construction compared to traditional practices. As discussed earlier, the traditional alternative on a project of this nature would have been a thin AC overlay, a treatment that would need to be repeated approximately every 5 years. The construction time for a traditional overlay was estimated to be 3 days per treatment. Although the total construction time for this RCC project was 30 days, the RCC pavement is expected to require little or no work in the future. While the HfL goal of a 50 percent reduction was not achieved on this project, future disruption of travel for additional treatments is expected to offset some of the difference between the as-built and traditional scenarios. Furthermore, the experience gained by ASHTD on this first RCC project is expected to prove helpful in reducing the construction time and associated costs for future RCC projects in Arkansas.

Travel Time

The HfL travel time performance goal specifies less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling. The floating car methodology was adopted to collect travel time data before and during the project construction. The data collection involved conducting a series of travel time runs through the project segment. The preconstruction travel time data under normal (before) travel conditions were collected on October 31, 2012, and the during construction travel time data, in presence of an alternating one-lane pilot car operation, were collected on November 5, 2012. The travel time data were collected over a 1.72-mile segment in the eastbound direction and over a 1.67-mile segment in the westbound direction. Under normal traffic conditions, since the traffic was approaching the eastern Hattieville city limit, the eastbound travel was observed to be slightly longer than the westbound travel. The travel speeds in the eastbound direction averaged about 45 mph, and the travel speeds in the westbound direction were slightly higher, at 52 mph.

During the single-lane closures, a series of travel times were collected in the eastbound direction. On an average, the single-lane operation led to an average travel time delay of 7.34 minutes, which included the wait time at the flag stop and the reduced travel speeds through the work zone. The travel time data for the eastbound direction before and during construction are presented in Table 8.

Table 8. Travel time in the eastbound direction before and during construction.

	Preconstruction	**During Construction**
	Eastbound	
Travel time measurements (min)	2.28 2.33 2.21 2.46 2.25 2.28	9.31 10.76 8.59 9.92
Average time (min)	2.30	9.65
Time Difference (min)	7.34	
Time Difference (%)	76.13	
Length (miles)	1.72	
Direction	From Road Work Ahead 1,500 Feet Sign to East City Limit of Hattieville	

The average travel time measured during construction for the eastbound direction was 76.13 percent more than the corresponding travel time measured before construction. This increase in travel time can be attributed to the use of pilot car operations and associated idle time for traffic in the work zone. The use of a pilot car was helpful in limiting vehicle speeds to approximately 35 mph in the work zone.

The roadway in the westbound direction was approximately 250 feet shorter than that in the eastbound direction. Correspondingly, the average preconstruction travel time in the westbound direction was approximately 22 seconds less than that in the eastbound direction. No travel time data were collected for the westbound direction during construction. Overall, the HfL performance goal less than 10 percent increase in trip time during construction compared to the average preconstruction speed was not met on this project.

Queue Length

During the construction process, two 1.5-mile segments of flagger and pilot-car-controlled alternating one-lane operations were established on the roadway. This approach helped to eliminate lane closures for the project.

It is estimated that the temporary traffic control approach resulted in traffic queues of no more than 12 vehicles at a time. This meets the HfL performance goal of less than 0.5 miles queue length in a rural work zone.

QUALITY

Sound and Smoothness

Due to the rural nature of this project, noise was not a major concern. ASHTD provided the smoothness data for pre- and post-construction scenarios. The pre-construction IRI for both eastbound and westbound sections averaged 149 inches per mile. The project contract included an incentive clause that required grinding to a smoothness of a 7-inch-per-mile profile index. This grinding was expected to achieve the HfL goal of 48 inches per mile. The diamond grinding was thus performed to ensure a smooth surface for the traveling public. The initial grinding was not able to achieve the desired smoothness level, partly because of the high measured IRI values for the new RCC surface (200 to 300 inches per mile). The average post grinding IRI was measured to be 69.5 inches per mile.

While this reduction in IRI did not meet the HfL goal for smoothness, the contractor elected to take a pay reduction rather than remobilize to perform additional grinding. Given the rural nature and relatively low traffic volume on the project location, and the considerable IRI improvement from the pre-construction levels, ASHTD believes that the pavement surface will provide adequate smoothness to the traveling public.

Quality Assurance Testing

Based on ASHTD’s quality assurance test results, a total pay deduction of $121,241.65 was made from the contractor’s final pay. The total deduction included $40,893.22 for smoothness and $80,348.43 for strength and thickness.

USER SATISFACTION

The HfL requirement for user satisfaction includes a performance goal of 4-plus on a Likert scale ranging from 1 to 7. ASHTD conducted a survey using a slightly different format in which the local residents were asked to take a written survey related to the following:

1. The condition of the facility after construction compared to before construction
2. Delay or disruptions through the work zone during construction.

The respondents were asked to rate these conditions based on a 5-point adjectival scale ranging from “much worse” to “greatly improved.”

Nine responses were obtained. Eighty-seven percent of the respondents believed that the project resulted in a high-quality roadway surface (improved or greatly improved). Additionally, 62 percent of the respondents believed the delay or disruption was minimized by the construction techniques used (agree or strongly agree). The favorable responses indicate that the local traveling public was satisfied with this project and the improved facility.

ECONOMIC ANALYSIS

A key aspect of HfL demonstration projects is quantifying, as much as possible, the value of the innovations deployed. This entails comparing the benefits and costs associated with the innovative project delivery approach adopted on an HfL project with those from a more traditional delivery approach on a project of similar size and scope. The latter type of project is referred to as a baseline case and is an important component of the economic analysis.

The key innovation on the State Highway 213 project was RCC, while the baseline case is a traditional AC overlay. The economic analysis compares the benefits and costs of RCC with those of a traditional AC overlay. ASHTD supplied the cost figures for both the as-built project and the baseline case.

CONSTRUCTION TIME

The construction of RCC on this project lasted for 30 days, while the placement of a thin AC overlay would take approximately 3 days. However, the longer construction time associated with RCC placement would be partially offset by a decreased need for future maintenance activities.

For the as-built scenario, the first chip seal treatment will be applied on the RCC pavement surface in 5 years, followed by subsequent chip seal treatments every 7 years, until a thin AC overlay is placed at year 30 in a 30-year analysis period. Each chip seal application would disrupt the traffic for a single day.

For the baseline case, the placement of thin AC overlays would have to be repeated approximately every 5 years. In a 30-year analysis period, the RCC construction would result in a net increase of 10 days of traffic disruption in comparison with the baseline case, as the future maintenance with chip seal applications would save only 11 days of disruption.

While the HfL goal of a 50 percent reduction was not achieved, the traffic impacts would not be significant considering the average traffic volume on this roadway. Moreover, since the ASHTD has implemented RCC pavement for the first time, more savings in construction time are expected with subsequent use of this technology.

CONSTRUCTION COSTS

Table 9 presents a summary of comparison of capital costs for both the as-built and baseline options. The table shows the cost breakdown that includes ASHTD's costs for design, engineering, and construction inspection, and the actual bid costs for construction, traffic control, and mobilization. The bid costs for construction include RCC placement, CTRB construction, diamond grinding, SafetyEdge, shoulder preparation and pavement marking, etc. The RCC unit bid prices were $25.50 and $28.00 per square yard for 7-inch and 8-inch pavements, respectively. The breakdown of traffic control costs for the as-built RCC option is summarized in Table 10. Note that there was a contractor pay deduction of $121,241.65 that included $40,893.22 for smoothness and $80,348.43 for RCC strength and thickness.

Table 9. Capital cost summary.

Cost Category	AC Overlay – Baseline	RCC -As Built
Design & Engineering	$47,988	$9,050
Const. Inspection	$5,000	$60,447
Mobilization	$15,000	$77,250
Construction	$319,920	$1,467,062
Traffic Control	$10,000	$203,457
Total Cost	**$397,908**	**$1,817,266**
Difference	**$1,419,358**	

Table 10. Traffic control costs for the as-built scenario.

Cost Category	RCC -As Built
Maintenance of Traffic	$80,000
Pilot Car	$111,135
Signs	$2,604
Construction Pavement Markings	$9,718
Total	**$203,457**

Life Cycle Cost Analysis—Construction Costs

Construction using either traditional portland cement concrete pavement or RCC would result in pavements of approximately equal thickness and strength. Both would provide long-term service with maintenance treatments being considered equal for either alternative. The cost of the RCC surface was approximately $1.81 million. The cost of the complete reconstruction of this location was estimated to be about $3 million per mile, or approximately $5.2 million. Assuming the same future maintenance costs for both, the RCC treatment competes very well.

However, the DOT indicated that it was highly unlikely that a complete reconstruction would have been undertaken at this location, given the relatively low traffic volume. They indicated that the more likely alternative would have been a series of thin AC overlays applied at an estimated interval of 5 years.

Given this assumption, a life cycle cost analysis was performed to capture the cost impact of the differences in performance between a RCC pavement and an AC overlay. The ASHTD estimates that the RCC surface would require a chip seal at 5 years, with a series of chip seals applied on a 7-year cycle. A thin overlay would be applied in year 30. Given the traditional method, a thin AC overlay would be applied every 5 years throughout the service life. With an average cost for chip sealing of $13,000 per lane mile, an analysis of the two alternatives can be performed.

The estimated life cycle costs were discounted to present values using a long-term 30-year discount rate of 3.0. The period chosen for this analysis was 30 years. No salvage values were applied for either case.

Tables 11 and 12 present the life cycle costs of construction for both RCC and AC overlay alternatives, respectively. The difference in the net present value between the two alternatives is $230,461, indicating that the RCC option was not a cost-effective option.

Table 11. Life cycle construction costs for RCC alternative.

Treatment	Capital Cost	Application Year	Net Present Value
RCC Overlay	$1,817,266	0	$1,817,266
Chip Seal	$44,720	5	$38,576
Chip Seal	$44,720	12	$31,366
Chip Seal	$44,720	19	$25,503
Chip Seal	$44,720	26	$20,736
Thin Overlay	$397,908	30	$163,933
Total Construction Cost			$2,097,380

Table 12. Life cycle construction costs for AC overlay alternative.

Treatment	Capital Cost	Application Year	Net Present Value
Thin Overlay	$397,908	0	$397,908
Thin Overlay	$397,908	5	$343,239
Thin Overlay	$397,908	10	$296,082
Thin Overlay	$397,908	15	$255,401
Thin Overlay	$397,908	20	$220,312
Thin Overlay	$397,908	25	$190,044
Thin Overlay	$397,908	30	$163,933
Total Construction Cost			$1,866,919

USER COST

Generally, three categories of user costs are used in an economic/life cycle cost analysis: vehicle operating costs, delay costs, and safety-related costs. The only user costs associated with the construction technique employed on this project were related to the reduced operating speeds and construction time.

One of the major advantages of the use of RCC pavement is the ability to allow traffic to access the pavement much sooner than when using traditional paving methods. Consequently, the road user costs can be dramatically lower through application of this method.

Construction Delay Costs

Assuming that the one-lane operation had to be maintained for an entire 24-hour period before traffic could be allowed to operate on the closed lane, the total delay generated per day of one-lane operation could be computed simply as the product of the per-vehicle delay and the AADT on the facility, as shown in Figure 26.

$$Total\ Delay = Days\ of\ one\ lane\ operations \times \frac{7.3\ min\ delay}{veh} \times \frac{1100\ veh}{day} \times \frac{1\ hr}{60\ min}$$

Figure 26. Equation showing the calculation of total delay.

For the as-built case, the road was limited to one lane operation for a period of 30 days, resulting in 4,015 hours of delay time for users of the facility. The average cost to the public used for such calculations by the ASHTD is $21.89 per hour for passenger vehicles, $23.06 per hour for single unit commercial vehicles, and $29.65 per hour for combination commercial vehicles. An actual count during the construction year provided a commercial percentage of 8.7 (3.5 percent single and 5.2 percent combination) at this location.

The delay costs per day are computed as follows:

Daily delay costs = (91.3% * 1,100 veh * (7.3/60) hr * $21.89/hr) +
(8.7% * 1,100 veh * (7.3/60) hr * $21.89/hr)
= $3019.97/day

Safety Costs

Due to the low accident history and the approximately equal future exposure for maintenance treatments, it is assumed that there is no safety cost or savings associated with the construction. This does assume that a safety edge would be incorporated into the AC alternative and maintained throughout the analysis period.

Life Cycle Cost Analysis—User Costs

Tables 13 and 14 present the life cycle analysis of user costs for both RCC and AC overlay alternatives over a 30-year analysis period. A long-term 30-year discount rate of 3.0 was used. No traffic growth was considered in the life cycle analysis of user costs. Considering future maintenance activities, the difference in the net present value in user costs between the two alternatives is $59,670, indicating that the RCC option would incur more user costs.

Table 13. Life cycle user costs for RCC alternative.

Treatment	Application Year	Days of Delay	Undiscounted User Costs $3,019.97/day	Net Present Value
RCC Overlay	0	30	$90,599	$90,599
Chip Seal	5	1	$ 3,020	$2,605
Chip Seal	12	1	$ 3,020	$2,118
Chip Seal	19	1	$ 3,020	$1,722
Chip Seal	26	1	$ 3,020	$1,400
Thin Overlay	30	3	$ 9,060	$3,733
Total User Costs				$102,177

Table 14. Life cycle construction costs for AC overlay alternative.

Treatment	Application Year	Days of Delay	Undiscounted User Costs $3,019.97/day	Net Present Value
Thin Overlay	0	3	$9,060	$9,060
Thin Overlay	5	3	$9,060	$7,815
Thin Overlay	10	3	$9,060	$6,741
Thin Overlay	15	3	$9,060	$5,815
Thin Overlay	20	3	$9,060	$5,016
Thin Overlay	25	3	$9,060	$4,327
Thin Overlay	30	3	$9,060	$3,733
Total User Costs				$42,508

COST SUMMARY

Construction costs for the Arkansas RCC project totaled about $1.817 million vs. an initial capital cost of about $397,900 for a traditional AC overlay. This is a difference of more than $1.419 million. Over a 30-year period, the RCC pavement would incur an additional net present value cost of $230,461 in agency costs and $42,508 in user costs.

Overall, using the RCC alternative would result in additional cost of $272,969 over a 30-year period. However, it should be considered that the future development of natural gas wells or other development would result in higher traffic volume with heavy loads far above those for which typical asphalt overlays are designed. It should also be noted that, in some cases, the asphalt overlays have failed in as little as 6 months. The costs RCC alternative is almost identical to the baseline alternative if overlays for the baseline alternative were performed every 5 years for the first 15 years and every 3 years thereafter until analysis period of 30 years. It is also believed that much of the additional cost of the RCC alternative was due to the ASHTD's unfamiliarity with the RCC technology and the short nature of the project.

REFERENCES

1. Williams, Stacy G., "Construction of Roller Compacted Concrete Pavement in the Fayetteville Shale Play Area," *Transportation Research Board 93rd Annual Meeting*, Paper #14-2701, 2014.
2. Williams, Stacy G., and Anna M. McFarland, *Roller Compacted Concrete for Roadway Paving*, Report No. TRC-1005, Prepared by the University of Arkansas, Fayetteville, 2013.
3. Harrington, Dale, Fares Abdo, Wayne Adaska, and Chetan Hazaree, *Guide for Roller-Compacted Concrete Pavements*, National Concrete Pavement Technology Center, August 2010.