Virginia Demonstration Project:

Pavement Rehabilitation Using Roller Compacted Concrete Pavement along a Section of Staffordboro Boulevard, Stafford, Virginia

Final Report
March 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, and 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 Virginia Department of Transportation (VDOT) was awarded a grant to demonstrate the use of roller compacted concrete pavement (RCCP) to rehabilitate existing asphalt concrete (AC) pavements. The project selected for the demonstration is located along a section of Staffordboro Boulevard (SR11/SR 53/SR 211) that has heavy commuter traffic. The project also included construction of a new RCCP in an adjacent commuter parking lot. All RCCP along Staffordboro Boulevard was overlaid with 2 inches of hot mix AC surface layer.

This report documents the application of the RCCP technology for pavement rehabilitation along the section of Staffordboro Boulevard. Because of the technology focus for this project, no economic analysis was required to be performed. The bid price for the 8-inch-thick RCC pavement, without the 2-inch-thick AC surfacing, along Staffordboro Boulevard was $41 per square yard.

Using the RCCP technology on this project allowed VDOT to evaluate RCCP technology for rehabilitation of distressed AC pavements without requiring extended lane closures and without impacting the daily commute of the road users along a heavily trafficked suburban roadway. VDOT gained valuable experience with design, mixture proportioning, and construction of new RCCP with an AC surface. VDOT evaluated the RCCP application in Stafford to determine the feasibility of applying the technology to the rehabilitation of similarly trafficked urban/suburban roadways without significantly affecting commuter traffic flow. VDOT is expected to move forward with the implementation of RCCP technology for such applications. The rapid pavement rehabilitation strategy used in Stafford is considered successful and can be considered applicable for similar projects in Virginia and other States.

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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
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)

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ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
ACPA	American Concrete Pavement Association
dB(A)	A-weighted decibels
DOT	Department of Transportation
FHWA	Federal Highway Administration
HfL	Highways for LIFE
HMA	Hot mix asphalt
HOV	High-occupancy vehicle
IRI	International Roughness Index
mph	Miles per hour
OBSI	Onboard sound intensity
OSHA	Occupational Safety and Health Administration
RCC	Roller compacted concrete
RCCP	Roller compacted concrete pavement
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
VDOT	Virginia Department of Transportation

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)—was authorized to provide incentives to a maximum of 15 demonstration projects a year. The funding amount authorized was up to 20 percent of the demonstration project cost, but not more than $5 million per project. Also, the Federal share for an HfL project could 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 the demonstration 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 or another mutually agreeable highway section. 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 2006 through 2013. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, then 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 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:

1. Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
2. 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 the applicant State has never or rarely used, even if it is standard practice in other States.
3. 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.
4. 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.
5. Demonstrate the willingness of the applicant State 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. The goals were 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 were encouraged to use all applicable goals on a project, as listed below:

1. **Safety**
    a. Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
    b. 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.
    c. Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.

2. **Construction Congestion**
    a. Faster construction—Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
    b. Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
    c. Queue length during construction—A moving queue length of less than 0.5 mile 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).

3. **Quality**
    a. Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile.
    b. Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.

4. 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 Virginia Department of Transportation (VDOTs) HfL demonstration project, which involved the use of roller-compacted concrete pavement (RCCP) to rehabilitate a section of Staffordboro Boulevard in Stafford, Virginia. The report presents project details relevant to the HfL program. The lessons learned are also discussed.

The report is organized as follows:

1. Project Overview and Lessons Learned.
2. Project Details.
3. Data Acquisition and Analysis.
4. Technology Transfer.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

The purpose of this HfL demonstration project was to assess the feasibility of rehabilitating an existing asphalt concrete (AC) roadway using RCCP without impacting the daily commuter traffic on the roadway. The overall project objective was to improve the condition of the access roadways to the Staffordboro Boulevard commuter parking facility. The parking facility was expanded under this project, which had been mandated as part of the governor's Priority Transportation Projects. The expanded parking lot will:

1. Reduce congestion and improve safety on adjacent sections of I-95 by creating 1,000 additional parking spaces at the existing commuter bus parking facility.
2. Improve access roadways to the parking facility.
3. Facilitate high-occupancy vehicle (HOV) ridership through an informal carpool program.

Additional bus ridership is anticipated due to improved parking lot drop off locations and improvements to abutting street access.

VDOT selected roller-compacted concrete (RCC) to rebuild Staffordboro Boulevard in conjunction with the construction of the parking facility to enable the roadway to withstand the heavy truck loadings that were expected during the construction of this project. Staffordboro Boulevard is also expected to carry heavy bus traffic after the parking facility is complete. This roadway could not be closed for construction as it is the only access road to the parking facility. Closing the road during the weekdays would have had a direct impact on the traffic on I-95. Use of conventional concrete for the roadway would have required road closure for many days. The RCC option could be constructed using only nighttime or weekend construction without disturbing the weekday rush hour commuter traffic. The RCCP was also considered to have a low initial cost. Additionally, the RCCP could be designed to withstand the high amount of heavily loaded construction truck traffic and future in-service bus traffic.

The project location is shown in figure 1. The project is located in Stafford County, under the jurisdiction of the VDOT Fredericksburg District. It includes the roadways leading to the Staffordboro Boulevard "park and ride" commuter parking lot, which is the initial point of HOV lanes along I-95 in Virginia.

Figure 2 shows an overview of the existing parking facility and the proposed addition to the parking facility next to Staffordboro Boulevard, and figure 3 shows a view of the section of Staffordboro Boulevard just prior to construction. The existing pavement along Staffordboro Boulevard was an asphalt pavement with a granular base.

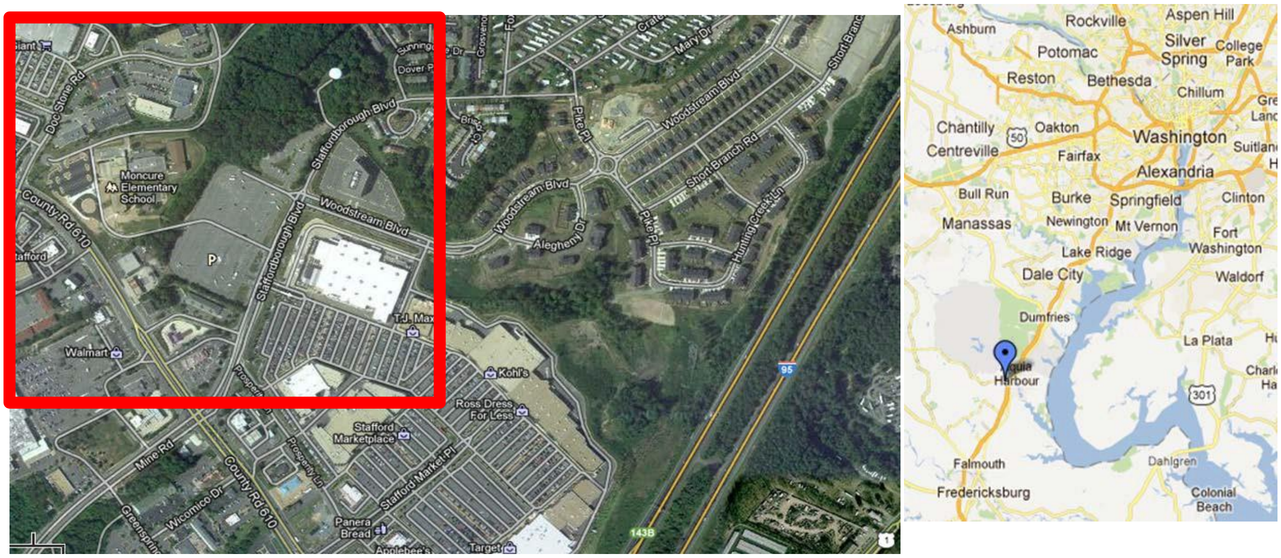

Figure 1. Photo and map. Location of the demonstration project, adjacent to I-95.

Figure 2. Photo. The park and ride facility, existing (lower circle) and planned (upper circle).

Figure 3. Photos. Views of Staffordboro Boulevard just prior to construction.

The decision to use RCCP to rehabilitate Staffordboro Boulevard was based on meeting the following objectives:

1. It would minimize the effect of the work zone on the highway users by employing an accelerated construction method and by reducing the construction hours to nighttime and weekends only. The overall impact to the traveling public would be reduced.
2. During construction, the traffic would be reduced to one lane at night and weekends. Full capacity (two lanes) would be maintained during weekdays.
3. The project would significantly reduce the highway user cost in terms of the cumulative increase in trip time for all highway users impacted by the construction.
4. Maintenance costs would be reduced because of the decreased likelihood of early distressed pavement on this lower speed roadway and parking area, where maintenance is a difficult endeavor because the parking lot is utilized at or beyond its capacity.
5. The addition of three destination specific pickup locations and a dedicated bus pickup location within the parking area would help reduce traffic impacts to an already highly congested commuter roadway (I-95).

The successful implementation of the innovative features of this project is expected to lead to further utilization of this technique for rapid rehabilitation of similar projects in high-volume, urban traffic areas. RCC can be constructed rapidly, as it uses asphalt paving equipment. It will provide the same benefit of longevity as conventional concrete pavement except for the surface characteristics. Asphalt overlay or diamond grinding could be used to achieve surface smoothness similar to conventional asphalt or concrete pavement. Furthermore, RCC does not use dowel bars or reinforcement or form work and also uses less cementitious material especially for early opening to traffic, so it is usually less expensive than conventional asphalt or concrete pavement.

HfL Performance Goals

The successful implementation of an HfL project is 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 where appropriate, to demonstrate that the featured innovations can be deployed while simultaneously meeting the HfL performance goals in these areas.

For the Staffordboro Boulevard project, the HfL performance goals were met as follows:

1. **Safety**
2. Work Zone Safety – No incidents occurred during the construction period, including the lane closure periods. This met the HfL goal of achieving a work zone crash rate equal to or less than the preconstruction rate.
3. Worker Safety during Construction – No worker injuries occurred during construction, which exceeded the HfL goal of less than a 4.0 rating on the OSHA 300 form.
4. Facility Safety after Construction – The facility safety after construction is yet to be determined.

5. **Construction Congestion**

    a. Faster Construction – Because all construction took place at night and during weekends and the roadway was returned to service the next morning, there was no impact to weekday commuter traffic movements or trip times within the construction area. In addition, during the construction period, one lane of traffic was maintained in both directions. Therefore, no traffic impact study was conducted.
    b. Trip Time – Overall, there was little impact on trip time through the length of the project because construction generally took place during off-peak traffic periods.
    c. Queue Length – There was no traffic backup during the daytime, as most of the RCCP and AC surface construction took place at night or on weekends along the Stafford Boulevard portion of the project. The parking lot RCCP and AC surface was constructed in new alignment and was not opened to traffic. During the few times that construction along Stafford Boulevard took place during the daytime, traffic was diverted through the parking lot without significantly increasing the trip time and resulted in no noticeable queue formation.

6. **Quality**
    a. Smoothness – Due to the low speed along the rehabilitated section of Stafford Boulevard, no smoothness goal was established for this project. The project specification required that normally specified smoothness goals be met after the AC surface was constructed.
    b. Noise – No noise measurements were taken along the project because of the designated speed limit of only 30 miles per hour (mph) for the completed project. Due to the slow speed along this length of the project, the pavement-tire noise is not expected to be an issue.
    c. Durability – Several innovations included in this project are expected to improve the durability and performance of the roadway.
        i. The no-slump RCC concrete is expected to be very durable because of the dense concrete matrix resulting from roller compaction.
        ii. The RCCP is surfaced with an AC layer, which will protect the RCC from the adverse effects of wintertime freeze-thaw related damage.

7. **User Satisfaction**
8. Notification of construction and the changes in the traffic pattern during construction were effectively conveyed to the public by news release(s) to the local media from VDOT's Public Affairs Office, and variable message sign boards were placed along the highway in advance of construction warning travelers that nighttime construction and a single lane closure was imminent. Also, the affected businesses in the area were notified in a timely manner of impending traffic pattern changes during any given week.
9. During construction, the effect of the work zone and traffic pattern changes on travelers was minimal, as commuter traffic flow through the work zone during the daytime was rarely stopped.

ECONOMIC ANALYSIS

Because of the technology focus for this project, no economic analysis was required to be performed. The bid price for the 8-inch-thick RCC pavement, without 2-inch-thick AC surfacing, along Stafford Boulevard was $41 per square yard. The bid price for the 6-inch-thick RCC pavement, without 2-inch-thick AC surfacing, placed in the parking lot was $32 per square yard. The RCCP bid price was most likely affected by the small volume of RCC used and with construction spread out over several months.

LESSONS LEARNED

Overall, the RCCP project was a success. The pavement was reconstructed with minimal negative impact to the heavy commuter traffic that uses the roadway. The following are some of the lessons learned:

1. It is important to ensure that the base for the RCCP is well compacted. If the base is not compacted or gets wet due to a rain event, there is a good potential for the base to rut under construction traffic delivering RCC to the paver.
2. Project delays occurred several times due to equipment malfunction. The AC paver used for the RCC placement needed to be calibrated to ensure that the density of the RCC behind the paver was at 90 percent of the maximum density.
3. The project staging could have been organized better to allow completion of the project within a shorter period of time. However, the scheduling for the RCCP was dependent on the contractor's overall work schedule for the project that included the construction of the adjacent parking lot and other activities that were in progress as a result of the parking lot construction.
4. Construction of a test section off-site prior to RCC placement at the project site allows all parties to understand the various requirements of the project and the owner's expectations regarding the outcomes.
5. As in any new application of pavement construction technology, it is important that an expert be on-site for the first few days to help resolve any technical issues that may develop with the RCC mixture and RCC placement.

CONCLUSIONS

VDOT gained valuable experience with design, mixture proportioning, and construction of new RCCP with an AC surface. VDOT evaluated the RCCP application in Stafford to determine the feasibility of applying the technology to the rehabilitation of similarly trafficked urban/suburban roadways without significantly affecting commuter traffic flow. VDOT is expected to move forward with the implementation of RCCP technology for such applications. The rapid pavement rehabilitation strategy used in Stafford is considered successful and can be considered applicable for similar projects in Virginia and other States.

PROJECT DETAILS

RCCP TECHNOLOGY OVERVIEW

RCC is a no-slump concrete that is placed using AC paving machines and compacted by vibratory rollers. RCCP is a lower cost alternative to conventional jointed concrete pavements and generally provides structural performance that is equivalent to that of conventional jointed concrete pavements for equal design features. However, RCCP does not incorporate all the features of conventional jointed concrete pavement. The key features that cannot be considered in RCCP include the following:

1. Use of dowel bars and tie-bars at joints.
2. Use of an air-entraining admixture to develop an entrained air void system in the concrete.
3. Hand finishing of the final surface.
4. Texturing of the surface (e.g., tining).
5. Highway-type pavement smoothness requirements.
6. Highway-type surface friction properties.

Most of the larger RCCP projects in the U.S. have been constructed since the early 1980s. Most of the early applications were for off-highway facilities, such as log sorting yards, forest haul roads, and port facilities. The RCCP construction technology has improved considerably over the last 30 years, and new well-designed and well-constructed RCC projects can be expected to provide the desired long-term performance for a range of applications, including roadway applications. For highway applications, the RCCP surface is typically diamond ground to provide surface smoothness and surface friction properties comparable to conventional concrete pavements. Alternatively, thin hot mix asphalt (HMA) surfacing of about 2 inches may be considered to provide the desired surface smoothness and friction properties.

RCC is placed in a single lift when the compacted thickness of the RCC is about 8 inches or less. For compacted thickness greater than about 8 inches, RCC is typically placed in two or more lifts that are bonded, so as to behave monolithically. The cementitious materials used in the RCC mixture (about 12 to 15 percent by total weight of the concrete) are of the same order as that used for conventional paving concrete. RCC requires the use of dense graded aggregates that contain a higher percentage of fine aggregate than for conventional paving concrete. The fine aggregate facilitates dense compaction and produces a tight surface under rolling.

RCC is required to meet the same requirements for cement type/quality, aggregate type/quality, and other concrete-making materials as for conventional paving concrete. RCC mixes can be proportioned to achieve strength levels comparable to conventional paving concrete, typically, compressive strength of 4,000 to 5,000 psi at 28 days, corresponding to flexural strength of 650 to 750 psi. Because of the dry nature of the RCC mix and the method of production (pugmill mixing), air cannot be entrained effectively in RCC mixtures. However, the hardened RCC has a dense matrix and very low permeability. As a result, RCCP has been used successfully in a range of environmental conditions without impacting pavement durability or serviceability. Many well-designed and well-constructed RCCPs in the northern U.S. are performing well with respect to freeze-thaw durability.

For a given cementitious content, the most economical design of the RCC mixture is achieved when the mixture is compacted close to its maximum compactable density. The RCC construction specifications typically require RCC to be compacted to an average density of 98 percent of the wet density (based on maximum dry density and optimum moisture content). The RCC-making materials are metered and continuously charged into the pugmill at one end, and the well-mixed mixture exits at the other end. The mixing time in the pugmill typically ranges from 20 to 50 seconds. The exiting mixture is typically continuously collected in a gob-hopper, from which it is transferred onto dump trucks. However, on this project, there was no gob hopper use and the belt immediately discharged into the truck. The RCC mixture delivered to the paver and exiting the paver must be dry enough to be able to support a vibratory roller without significant settlement and be wet enough to allow the paste and aggregates to be redistributed under vibratory roller compaction to achieve high density.

Typically, RCC is placed using heavy-duty asphalt paving machines. Roller compaction is the most important step in the construction of the RCCP, as the in-place density is a key attribute of the RCC and will impact the durability and strength properties of the RCC. The RCC material that extrudes out of the asphalt paver is at about 85 to 95 percent of the maximum wet density (based on maximum dry density), depending on the density test procedure used. Heavy-duty pavers with dual tamping bars can compact the RCC mix in the 90 to 95 percent range. The roller compaction further densifies the RCC to achieve a final compacted dry density exceeding 98 percent of the maximum dry or wet density.

The constructed RCC must be allowed to cure to ensure that adequate moisture is available for cement hydration. In the early days of RCC construction, moist curing was typically used over a period of 3 to 7 days. The current practice is to use curing compounds to seal the surface, sometimes with 1 day of moist curing. On this project, curing compound was not used because an asphalt overlay was planned and there were concerns that the curing compound may result in a poor bond between the asphalt overlay and the RCC surface. For highway applications, the RCC surface may be jointed. This may then be followed by surface grinding or placement of HMA surfacing. The RCCP can be opened to light traffic within 12 hours of placement or soon after the HMA surfacing is placed.

PROJECT BACKGROUND

The project serves a 22-acre park and ride facility in Stafford County. The RCCP along Staffordboro Boulevard and within the new/extended parking lot covers an area of about 200,000 square feet. Commuters to Washington, D.C., are among the typical users of this facility, with about 12,800 vehicles (including 18 percent trucks/buses) using the facility on a daily basis. During construction of the parking lot, many heavily loaded construction trucks traveled on this section of Staffordboro Boulevard. Figure 4 shows the limits of the RCCP. The original limits are shown in pink, and additional lengths of RCC are shown in blue.

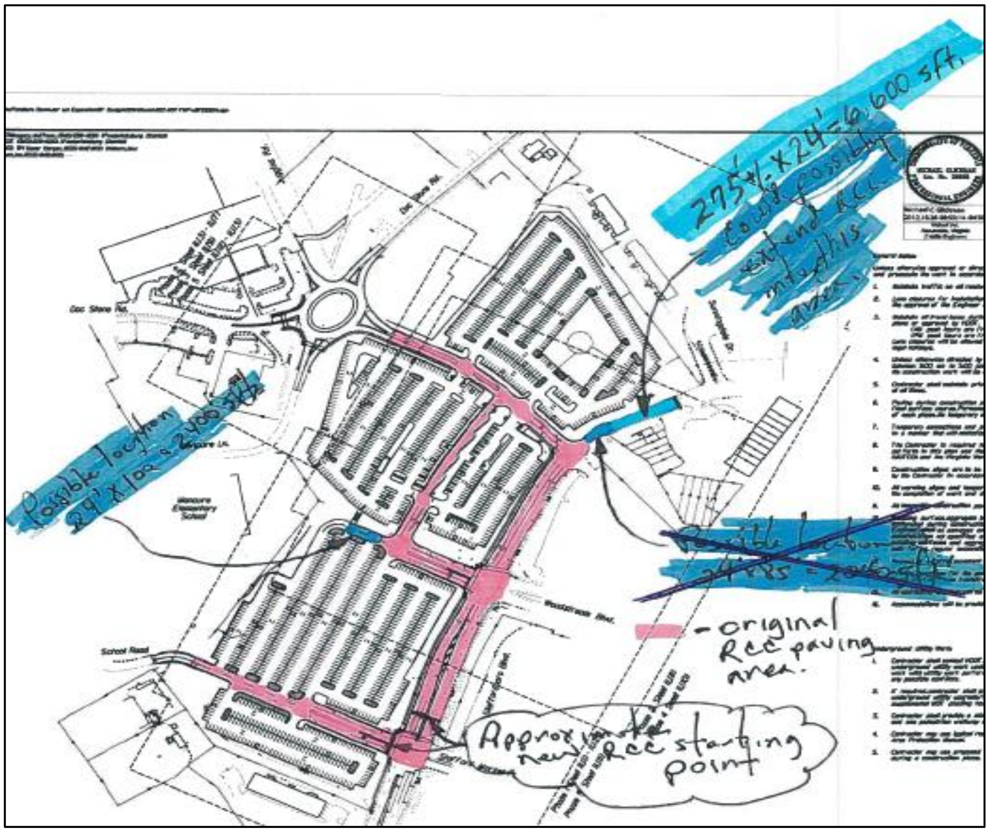

Figure 4. Map. RCC pavement limits.

PROJECT DETAILS

The RCCP portion of this project was added to an existing VDOT contract for upgrading the existing commuter parking lot adjacent to Staffordboro Boulevard. The project pavement details are as follows:

1. Project length: 2 lane miles.
2. Design speed: 25 mph.
3. Area of RCCP: 6,200 square yards.
4. RCC thickness:
    a. Staffordboro Boulevard: 8.0 inches.
    b. Parking lot lanes: 6 inches.
5. Base: Existing granular base, compacted and graded.
6. Transverse joint spacing: 15 feet.
7. AC surfacing thickness: 2 inches.
8. Existing pavement: AC over granular base.

HIGHLIGHTS OF THE RCC CONSTRUCTION SPECIFICATION

VDOT developed customized RCC project specifications and plans for this project. The specification, designated as Order No. B20 for Contract No. C00097552C01 and dated October 15, 2012, incorporates the following key provisions.

RCC Aggregate Gradation

The aggregate for the RCC was specified to be well graded conforming to the gradation shown in table 1.

Table 1. Specified RCC aggregate gradation.

Sieve Size	% Passing by Weight
1 in.	100
¾ in.	95-100
½ in.	70-100
3/8 in.	65-85
No. 4	50-70
No. 16	25-45
No. 100	5-20
No. 200	0-8

RCC Pugmill

RCC was specified to be produced using a twin-shaft pugmill located within 30 minutes of hauling distance from the RCC placement site. The pugmill capacity was required to be at least 200 tons per hour.

RCC Paver and Compaction Equipment

RCC was specified to be placed using a high-density or conventional asphalt type paver capable of placing RCC to a minimum of 90 percent of the wet density in accordance with American Association of State Highway and Transportation Officials (AASHTO) test procedure T-180, Method D. A self-propelled smooth steel drum vibratory roller having a minimum weight of 10 tons was specified for the primary compaction. A steel drum roller operating in a static mode was specified for the final compaction.

Preparation of the Base/Subgrade

The subgrade and base were required to be compacted to 95 percent of the maximum dry density, in accordance with the AASHTO T-180 procedure.

Transverse Control (Contraction) Joints

Transverse contraction joints were required at a spacing of 20 feet. On this project the joint spacing ended up being 15 feet. Joints were required to be sawed to a depth of one-quarter of the compacted RCC thickness.

Test Section

The contractor was required to demonstrate acceptable RCC production and placement at a test section at least 30 days before the start of the production RCC paving. The test section was required to be at least 50 feet in length and two lanes wide. The equipment and processes to be used at the test section were required to be the same as those to be used for production paving. During the test section construction, the contractor was required to establish the optimum rolling pattern to obtain the desired density level in the RCC. Strength testing for RCC was to be performed using samples fabricated using as-delivered RCC and using cores obtained from the test section. The RCC mixture was required to be designed to achieve compressive strength of 4,000 psi at 28 days. For field testing, compressive strength of 3,500 psi at 28 days was considered acceptable.

Construction Staging and Traffic-Related Requirements

The planned construction phasing for the RCC placement was based on completing a portion of the RCC placement during the second half of 2013. The remaining RCC placement was to be completed in early 2014. The RCC test sections were constructed during August 2013, and production paving was started on September 21, 2013. The last segment of RCCP was placed on September 18, 2014.

During production paving, one lane of traffic was maintained in the direction of RCC placement. Typically, preparatory work involving existing asphalt pavement removal and base preparation was conducted during the night preceding the RCC placement. RCC placement on Staffordboro Boulevard was generally carried out on a Saturday. As a result, there was very little disturbance to weekday commuter traffic, and no significant traffic backup was reported. During some construction days, traffic was diverted through the parking lot.

Test Sections

A test section (24 feet by 100 feet) was constructed in the existing park and ride parking lot on August 8, 2013. The test section incorporated RCC production using a pugmill, base preparation, and RCC placement and compaction. VDOT did not consider the test section acceptable for a number of reasons, including poor surface, poor compacted density for the RCC, and poor RCC thickness control. On August 23, 2013, a second test section (12 feet by about 100 feet) was placed adjacent to the initial test section. Figure 5 shows views of both test sections. VDOT found the second acceptable, and the contractor was authorized to proceed with production RCC paving.

a) RCC placement at the test section

b) Completed RCC test sections

Figure 5. Photos. Views of the RCC test sections.

RCC Production

As indicated previously, VDOT had specified use of a twin-shaft pugmill for RCC production. The RCC paving subcontractor had acquired a pugmill that was integrated with an existing ready mix concrete plant in Stafford, Virginia, about 5 miles from the project site. The Stephens Systems pugmill was rated at 200 cubic yards per hour. Figure 6 shows views of the pugmill used. The pugmill mixer had a capacity of about 5 cubic yards. Each haul truck hauled about 9 cubic yards of RCC, requiring two batches from the mixer. It took about 10 minutes to load a truck.

The RCC mixture design is shown in table 2. The combined aggregate gradation used for the as-designed RCC mixture is shown in table 3.

Figure 6. Photos. RCC pugmill integrated with an existing ready mix concrete plant.

Table 2. RCC mixture proportions as designed.

Material	Amount
Cement	479 lb/cy
Flyash	85 lb/cy
Sand	1,119 lb/cy
Fine Aggregate	630 lb/cy
No. 68 Stone	1,600 lb/cy
Water	233 lb/cy
Water Reducer (WRDA 35 by W. R. Grace)	3.0 oz/cwt
Retarder (Daratard 17 by W. R. Grace)	3.0 oz/cwt

Table 3. Combined RCC aggregate gradation used.

Sieve Size	% Passing by Weight
1 in.	100
¾ in.	100
½ in.	91
3/8 in.	73
No. 4	53
No. 16	32
No. 100	7
No. 200	5

The average test data for the RCC mixture using the Modified Proctor Test (ASTM D1557) were as follows:

1. Maximum wet density: 151.1 pcf.
2. Optimum moisture content: 5.8%

RCC PLACEMENT AND AC SURFACING

The RCC placement work involved the following steps:

1. Night before RCC placement (typically).
    a. Removal of the existing asphalt pavement and base material to result in a depth of 10.5 inches, to account for 8.5 inches of compacted RCC and 2 inches of AC surfacing layer.
    b. Base preparation. The base was compacted and graded to meet the specification requirements related to density and smoothness.
2. Day of RCC placement.
    a. RCC mixture production and hauling of the RCC mixture by haul trucks to the project site.
    b. RCC mixture placement and compaction.
    c. Quality assurance and quality control testing.
        i. As-compacted density and moisture using a nuclear gage in the field and using a hot plate at the plant and also at the job site.

        ii. Preparation of strength testing samples.

3. Several days after RCC placement (typically).
    a. Placement of AC surfacing.

Base Preparation

After removal of the existing AC pavement, the base was graded and compacted. On the first day of the production RCC paving, issues developed with RCC placement as a result of poor base compaction. Because of a rain event after the base had been prepared, the exposed base and the underlying subbase along a portion of the prepared roadway got wet. During the RCC placement, the base and the subgrade along the wet portion of the roadway with poor drainage yielded under the weight of the hauling trucks, creating deep ruts in the base. In addition, it was difficult to compact the RCC mixture to the target density because of the yielding base. After the problem was corrected over this short section of the roadway, RCC placement proceeded as planned. No similar soft base/subgrade issues were encountered on subsequent RCC placement days. The base compaction operation and the prepared base condition are shown in figure 7.

RCC Placement

The RCC mixture was placed using a Titan asphalt paver with a tamping bar. The Titan paver, shown in figure 8, is a heavy-duty paver capable of densifying the RCC mixture to 90 to 95 percent of the optimum density. The haul time from the pugmill location to the project site averaged about 20 minutes. However, on many occassions, the haul time got extended because of traffic congestion along roadways adjacent to the project and the RCC paving was in a stop-and-go mode.

The RCC placement typically started at about 8 a.m. and was completed by mid-afternoon. The RCC placement operation is shown in figure 9. A summary of RCC production/placement by day is given in Table 4. It should be noted that the RCC placement schedule was determined by the schedules of other activities being carried out as part of the overall parking lot improvement project. As a result, the RCC placement had to be scheduled over a period of almost 1 year, from September 2013 to September 2014. Normally, the amount of RCC required for this project could have been placed within a period of not more than 2 weeks.

Table 4. Summary of RCC production/placement by day.

Date RCC Placed	RCC Thickness, in.	RCC Volume, cy	RCC Placement Location	Date AC Surfacing Placed
08/03/13	8.0	63	RCC Test Pad 1	11/22/2013
08/24/13	8.0	36	RCC Test Pad 2	11/22/2013
09/21/13	8.0	171	Staffordboro NB - Right turn lane – Sta. 101+59 to 107+36.5	11/22/2013
10/19/13	8.0	243	Staffordboro NB - Center lane – Sta. 103+07 to 111+24	11/22/2013
10/26/13	8.0	239	Staffordboro NB - Left lane - Sta. 103+07 to 110+98	11/22/2013
06/06/14	6.0	99	Alignment D, Sta. 505+05 - 507+10	10/18/2014
06/07/14	6.0	252	Alignment D, Sta. 505+05 - 507+10,	10/18/2014
06/07/14	6.0		Align A, Sta. 209+58 - 212+15	10/27/2014
06/17/14	6.0 & 8.0	261	Alignment D and Rt. 684, widening (6" & 8")	7/22/2014
06/28/14	8.0	257	Rt. 684 SBL, Sta. 106+60 to 111+25 Lt C/L	7/22/2014
07/01/14	8.0	216	Rt. 684 SBL Sta. 103+06 - 106+60	7/22/2014
07/12/14	8.0	234	Rt. 684 SBL	7/22/2014
08/16/14	6.0	135	Align A Sta. 207+40 - 211+15	10/27/2014
08/16/14	6.0	27	Align A Sta. 207+40 - 211+15 - NEW MIX DESIGN	10/27/2014
08/27/14	6.0	194	Align C Sta. 401+03 - 404+73 thru lane Lt, 402+33 - 404+73 Rt turn lane	10/27/2014
09/18/14	6.0	153	Align B, (Bus lane)	10/30/2014
09/18/14	6.0	81	Align B, (Bus lane)	10/30/2014
09/20/14	6.0	225	School access road	10/30/2014
	Total	**2,885**		

Figure 7. Photos. Base compaction and finished base just before RCC placement. Note that geogrid was used to stabilize the subgrade prior to placement of the base.

Figure 8. Photo. Asphalt paver used.

RCC Compaction

Two rollers were used for the compaction behing the paver (see figure 10). The primary roller was a Sakai SW dual wheel steel roller used in the static mode. Based on the experience from the test section construction, the contractor decided to operate the primary roller in the static mode only. Typically, it required about three passes to achieve RCC density of 98 percent of the optimum density. The primary roller was followed by the Hamm HD 14 (Wirtgen) roller, also operated in a static mode, to smooth out the RCC surface.

The RCC compaction was monitored behing the paver and after the compaction was completed. The RCC compaction operation is shown in figure 11. Typically, five density tests were performed after final compaction for every 500 feet of paving. The densities, except for the first day of paving, typically met the specification requirements of 98 percent of optimum density. In addition, RCC strength specimens were prepared and transported to the testing laboratory. The RCC strength met the requirement of 4,000 psi at 28 days. The RCC testing operations are shown in figure 12.

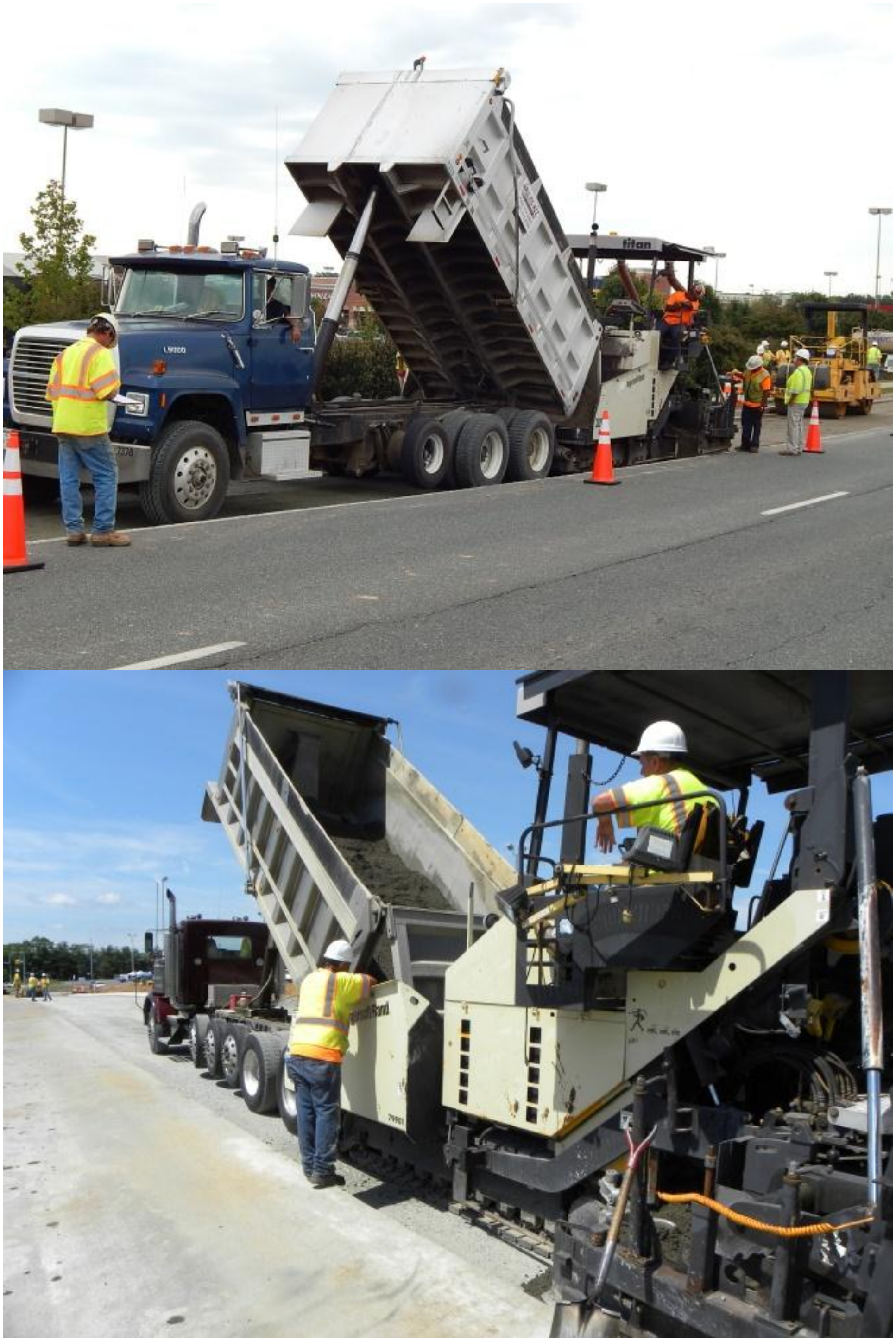

Figure 9. Photos. RCC placement.

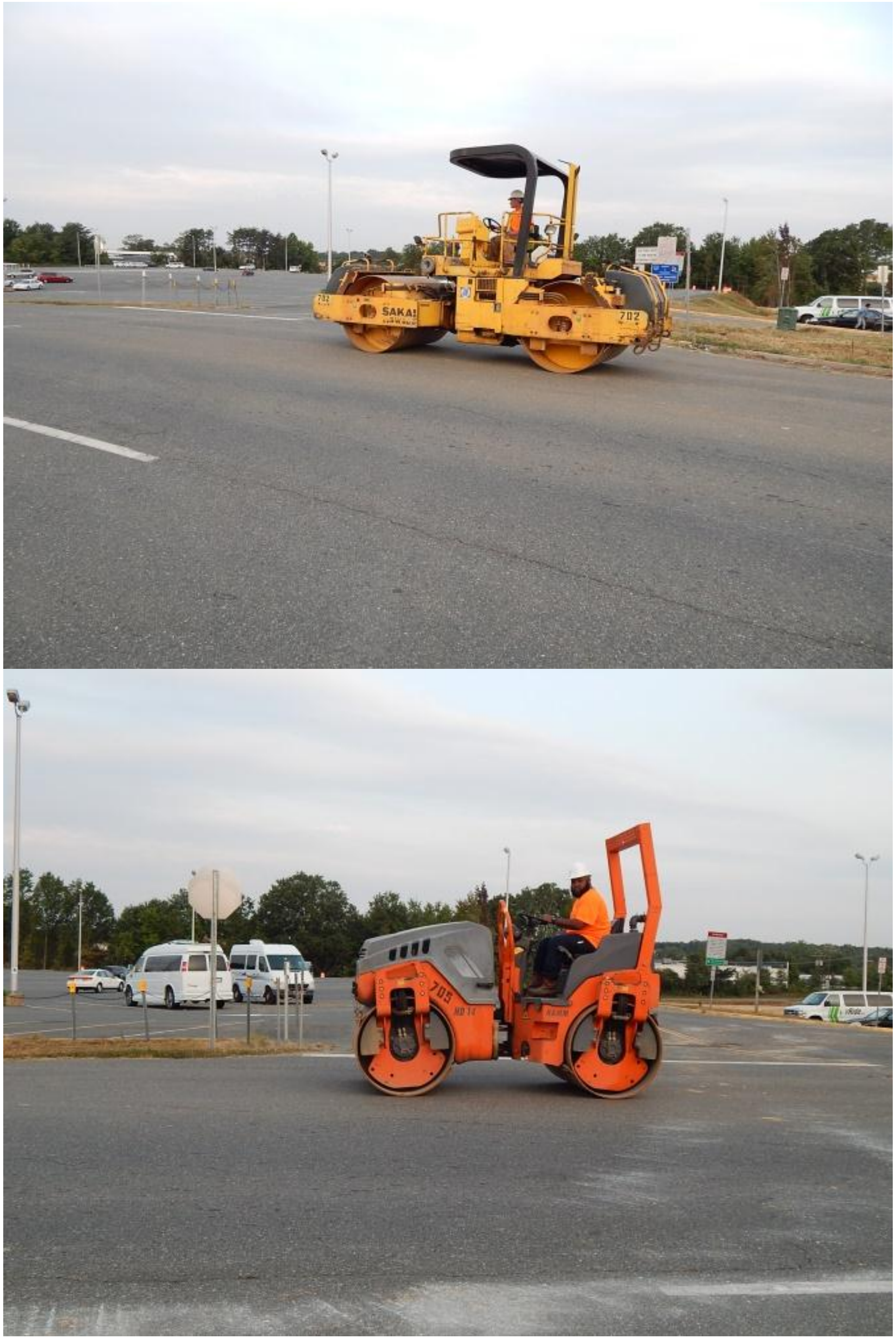

Figure 10. Photos. Asphalt roller used. Top - Primary Roller, Bottom - Finishing Roller.

Figure 11. Photos. RCC compaction behind the paver (with rollers operated in a static mode).

Top - Density testing using a nuclear gage, Bottom - Molding strength specimen
Figure 12. Photos. Field testing during RCC placement.

RCC Pavement Curing and Joint Sawing

The RCC pavement was cured with water, using a hand-held sprayer, immediately after the RCC compaction was completed and continued for a few hours (see figure 13). Water curing was continued typically for 7 days using a water truck spraying water at regular intervals under traffic.

Joints were cut in the RCCP after about 4 hours, as soon as the sawcut could be made without joint raveling. The joints were cut to a depth of one-quarter of the compacted RCC thickness. Figure 14 shows the joint sawing operations and the sawcut after the RCC was overlaid with the AC surfacing.

Figure 13. Photo. Water curing soon after compaction is completed.

AC Surfacing

The 2-inch-thick AC surfacing was placed a few days to a few weeks after the RCC placement was completed. The AC surfacing was placed using a standard surface hot mix AC mix and using conventional AC placement procedures. Section of Staffordboro Boulevard with AC surfacing are shown in figure 15. It should be noted that the RCC pavement placed during 2013 within the parking lot was left bare during the 2013/2014 winter season. As of early December 2014, many joints and a few cracks that did develop in the RCC had reflected through the AC surfacing indicating that these joints and cracks have cracked through the full depth of the RCC.

Figure 14. Photos. Joint sawing and AC surfacing over a sawcut in the RCC layer

Figure 15. Photos. Completed portions of Staffordboro Boulevard with AC surfacing, as of December 2014.

TRAFFIC FLOW THROUGH THE WORK ZONE

Traffic was maintained through the work zones in both directions. Typically, one lane of traffic was maintained in the direction of paving, and normal traffic flow was maintained in the opposite direction that had no work activity in progress. Views of the traffic through the work zone are shown in figure 16. On a few occasions, traffic along a portion of Staffordboro Boulevard was routed through the adjacent parking lot. No significant traffic backups were reported. As indicated previously, most of the RCC placement work was carried out during the weekends, and site preparation work was typically carried out the night before. The weekend commuter traffic to the parking lot was not impacted.

Figure 16. Photos. Traffic flow during RCC placement.

DATA ACQUISITION AND ANALYSIS

INTRODUCTION

Data on safety, traffic flow, quality, and user satisfaction were collected before, during, and after construction to determine compliance with the HfL performance goals where appropriate. The primary objectives of acquiring these types of data were to quantify the project performance, provide an objective basis on which to determine the feasibility of the project innovations, and 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.

The Staffordboro Boulevard project focused on the ability of the RCCP technology to achieve a low-cost and long-life rehabilitation of an existing asphalt pavement without affecting the suburban commuter traffic along a high traffic volume corridor. Therefore, many of the typical HfL goals were not considered directly applicable to this project. This section discusses how VDOT met the overall HfL performance goals related to this project, where applicable.

SAFETY

No worker injuries occurred during construction, which exceeded the goal of less than a 4.0 rating on the OSHA 300 form.

CONSTRUCTION CONGESTION

Because most of the construction work took place on weekends, construction congestion and queue length development were not studied for this project.

TRAFFIC STUDY

No traffic impact study was carried out. No impact to the public occurred as a result of the construction of this project. Traffic was maintained in both directions during the course of the project.

QUALITY

The VDOT specification for this project required RCC surface smoothness measurement using a 10-foot straight edge. The requirement was for the RCC surface to not vary by more than ¼ inch within the 10-foot straight edge. However, since the RCCP was to be surface with an AC surfacing, the RCC surface smoothness criterion was not enforced. Also, since the operating speed along the affected section of Staffordboro Boulevard was 25 mph, the typical HfL smoothness requirements were not enforced.

With a proposed speed limit of only 25 mph for the completed project, noise was not studied for this project.

USER SATISFACTION

A user satisfaction survey had not been completed as of early November 2014. The new parking lot facility was open to the general public on November 11, 2014.

TECHNOLOGY TRANSFER

To promote further interest and to encourage implementation of the RCCP technology used in this project, VDOT encouraged VDOT personnel from different districts to visit the site any time. As the RCC placement neared completion, VDOT organized a formal site visit by VDOT staff during the evening of September 18, 2014. During the site visit, VDOT personnel observed RCC production at the plant and the RCC placement in the last few segments in the parking lot.

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