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Use of Roller-Compacted Concrete Pavement in Stafford, Virginia

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Final Report VCTIR 15-R19

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www.VTRC.net

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VCTIR 15-R19	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Use of Roller-Compacted Concrete Pavement in Stafford, Virginia		5. Report Date: May 2015 6. Performing Organization Code:
7. Author(s): M. Shabbir Hossain, Ph.D., P.E., and Celik Ozyildirim, Ph.D., P.E.		8. Performing Organization Report No.: VCTIR 15-R19
9. Performing Organization and Address: Virginia Center for Transportation Innovation and Research 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 105219
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:
15. Supplementary Notes:		

16. Abstract:

Roller-compacted concrete (RCC) is a relatively stiffer hydraulic cement concrete mixture than regular concrete when fresh. Similar to regular concrete, RCC is a mixture of aggregate, cementitious materials, and water, but it is placed using asphalt pavers and compacted by vibratory rollers, and it hardens into concrete. RCC contains a low amount of water, exhibits no slump, and requires asphalt paving equipment for placement rather than expensive slip-form paving equipment. It does not contain reinforcement, tie-bars, or dowels. RCC can be placed and opened to traffic in a short period of time. All of these factors combined make it a relatively low-cost material for roadways compared to asphalt or conventional concrete pavements. However, RCC may lack the smoothness required for high-speed roadways and can undergo raveling and/or cracking; an asphalt overlay may remedy the smoothness and raveling issues. Although cracks might occur in the RCC and potentially reflect through the asphalt layer, such cracks should stay tight because of the low shrinkage of RCC. A composite pavement with RCC and an asphalt overlay has the potential to be a cost-effective long-lasting pavement system.

The purpose of this study was to document the construction procedures and provide lessons learned for a RCC project recently completed by the Virginia Department of Transportation that covered about 134,000 ft2, equivalent to 2 lane-miles, at the Park & Ride lot in Stafford County, Virginia. About one-third of the RCC was used to rehabilitate the existing Staffordboro Boulevard (Route 684). The mixture used had 15% fly ash to provide improved durability and sustainability. Batches of the RCC mixture fluctuated in moisture content, and delays in placement sometimes occurred that also resulted in wet and dry mixtures. The compaction, surface smoothness, and road profile were affected by the fluctuations in moisture content. RCC cylinders prepared using a vibratory hammer usually exceeded compressive strengths of 1,600 psi and 4,000 psi at 12 hours and 28 days, respectively. Only a few early cracks were observed in the pavement. Opening to traffic at an early age for a section, i.e., within 5 to 6 hours of placement, did not result in any visual damage to the pavement; most sections were opened in less than 48 hours. RCC overlaid with 2 in of asphalt is performing well after two winters and 18 months of traffic for one section and after one winter and 8 months of traffic for the rest.

Based on the observations in this study, for successful construction of RCC, proper compaction and mixing equipment are essential. Achieving the proper level of compaction in the field is key to attaining quality RCC. To avoid early cracks, joints need to be cut deeper than one-fourth depth of the pavement and continuous curing is essential. A continuous paving operation is needed to avoid unplanned and poor-performing cold joints. The Virginia Department of Transportation should consider RCC in future field trials, particularly for applications where fast construction of rigid (concrete) or composite pavement is needed.

17 Key Words: Roller compacted concrete, RCC, composite pavement		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 61	22. Price:

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FINAL REPORT

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Center for Transportation Innovation and Research
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

May 2015
VCTIR 15-R19

DISCLAIMER

ABSTRACT

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INTRODUCTION

Roller-compacted concrete (RCC) is a relatively stiff mixture of aggregate, cementitious materials, and water that is placed using asphalt pavers and compacted by vibratory rollers; it then hardens into concrete (American Concrete Institute [ACI], 1995). RCC contains a low amount of water; exhibits no slump; requires asphalt paving equipment rather than expensive slip-form paving equipment for placement; and can be placed and opened to traffic in a short period of time. It does not contain reinforcement, tie-bars, or dowels. All of these factors combine to produce a relatively low-cost roadway compared to asphalt or conventional concrete pavements (Nanni et al., 1996). However, such a roadway may lack the smoothness required for high-speed roadways and can undergo raveling and/or cracking (Piggott, 1999). An asphalt overlay could remedy the smoothness and raveling issues; however, cracks might reflect through the asphalt layer. Nevertheless, a composite pavement of RCC and asphalt overlay might be a cost-effective long-lasting pavement system. With recent advancements in grinding technology, a feasible alternative to an asphalt overlay is diamond grinding of the RCC surface to achieve smoothness. RCC has been identified by the Federal Highway Administration (FHWA) in its "Long Term Plan for Concrete Pavement Research and Technology: The Strategic Road Map" as one of the potential research topics that could result in cost-effective, high-quality pavements for high-speed roadway construction.

Since the early 1970s, RCC has been used in more than 100 paving projects in North America (Piggott, 1999). These projects span a range of pavement applications, such as intermodal container terminals, log and lumber storage yards, warehouse floors, intersections, and small roads. RCC was used in these instances mainly to deal with heavy loads moving at slow speeds. However, there is considerable potential for the use of RCC pavements in streets and highways with higher traffic speeds.

Evaluation of test data has shown that the structural behavior of RCC is similar to that of conventional hydraulic cement concrete (HCC). Compressive strengths can range from 5,800 to 8,700 psi (Pigeon and Marchand, 1996), and splitting tensile strength can be more than 600 psi (ACI, 1995). Because of the difficulty of making beams and sawing beam specimens, there is limited information on flexural strengths (ACI, 1995). The flexural strength ranges from 500 to 1,000 psi (Harrington et al., 2010). Very little evidence of structural failure has been observed in RCC pavements, attributable in part to the high strength they achieve with age.

The freezing and thawing durability of stiff concrete or RCC has always been a concern. It has been difficult to entrain air in stiff concretes. However, RCC pavements in British Columbia were reported to have satisfactory freeze-thaw resistance without any air entrainment even though they were exposed to a severe environment (Gagne, 1999).

There are pavement surface characteristics for which RCC has not demonstrated satisfactory performance. These characteristics are surface condition (rough textured and raveling), skid resistance (attributable to difficulty in texturing), and surface smoothness. It is because of these concerns that an asphalt overlay is recommended. Thus, RCC will provide the primary structural support for the roadway, and the asphalt overlay will provide a proper riding surface. As mentioned earlier, diamond grinding may also be used if necessary. For slow-moving vehicles, a high degree of smoothness may not be required.

As with any other concrete, RCC may also have shrinkage cracks; however, the spacing of the cracks is highly variable, with a range of 20 to 60 ft (Harrington et al., 2010). Saw cutting at 20- to 30-ft spacing was successfully tried on a few projects to eliminate random cracking (Harrington et al., 2010). In a few projects (Piggott, 1999) with RCC, the closely spaced, naturally occurring cracks did not show any faulting and held tightly as hairline cracks. These cracks would reflect through the surface asphalt only as hairline cracks if the overlay were intentionally delayed for several weeks or months. There are concerns of load transfer at the transverse joints. Sealant may be used in the joints to reduce edge chipping or raveling.

RCC is generally mixed in continuous mixing pugmills that provide high volumes and are able to mix stiff mixtures efficiently. The material is transported to the construction location in dump trucks that discharge into the paver, and layers up to 10 in thick are placed. However, many designers restrict the lift heights to 8 in to ensure proper compaction in the lower part of the lift (Canadian Portland Cement Association, 1997). Proper compaction is essential since it provides the density, strength, and surface smoothness and texture. The pavers provide the initial compaction, which is followed by the rollers to achieve the specified compaction level as measured by nuclear density gauges (NGs). Good curing practices are important. Water spray or an asphalt emulsion spray is commonly used to seal the surface to avoid loss of water needed for the hydration process and to prevent early shrinkage cracks (Canadian Portland Cement Association, 1997). The joints are generally cut as soon as the saws can provide a clean cut without raveling (Harrington et al., 2010).

An RCC project recently completed by the Virginia Department of Transportation (VDOT) covers about 134,000 ft^2, equivalent to 2 lane-miles, at the Park & Ride facility in Stafford County, Virginia. About one-third of the RCC was used to rehabilitate the existing Staffordboro Boulevard (Route 684). VDOT received incentive funding from FHWA for the implementation of RCC in the Fredericksburg District under FHWA’s Highways for LIFE program.

PURPOSE AND SCOPE

The purpose of this study was to construct a section of pavement with RCC using locally available materials. The objectives were to document the construction steps and challenges, including RCC mixture development and production. Two lane-miles of roadway were constructed using 6- to 8-in-thick RCC in Stafford, Virginia, and was overlaid with a 2-in layer of asphalt for ride quality. The performance was monitored visually throughout the construction period.

METHODS

Overview

To achieve the study objectives, the following tasks were conducted:

1. Select a site to implement RCC technology, and construct a section for future evaluation.

2. Conduct a trial installation of RCC before actual construction.

3. Document the construction of and lessons learned with RCC.

4. Assess the initial performance of RCC for a period of up to 1 year.

Site Selection

The project is located in Stafford County, Virginia, under the jurisdiction of VDOT's Fredericksburg District. It comprises the roadways leading to the Staffordboro Park & Ride lot, which is the initial point of high-occupancy vehicle / toll lanes in Virginia leading to Washington, D.C. RCC was used to rehabilitate Staffordboro Boulevard (State Route 684) near the Garrisonville Road (State Route 610) / I-95 interchange and other connector roadways leading to and within the Park & Ride lot. Staffordboro Boulevard also leads to a major shopping center, Stafford Market Place.

RCC was used to rebuild existing Route 684 (Staffordboro Boulevard) prior to the construction of the Park & Ride facility to enable it to withstand heavy truck loadings during the construction of this project. Staffordboro Boulevard is also expected to carry heavy commercial trucks along with bus traffic when the facility is complete. This road could not be closed for construction, as it is the only access road to this Park & Ride facility that has direct connection to I-95. RCC could be constructed at reasonable cost using only nighttime or weekend construction. The RCC pavement was designed to withstand high volumes of heavily loaded trucks and buses.

RCC Pavement Design

Pavement Design

The AASHTO (American Association of State Highway and Transportation Officials) *Guide for Design of Pavement Structures* (AASHTO, 1993) was used by the Fredericksburg

District to design the pavement for rehabilitation and new construction. The RCC was designed in a manner similar to that of regular HCC pavement without any reinforcement or dowel bars. The RCC design thickness was 8 in for Staffordboro Boulevard and 6 in for the rest of the access roads inside the Park & Ride lot. All RCC was overlaid with 2 in of dense-graded hot-mix asphalt (HMA) for a smoother ride.

Mixture Design

The RCC was designed by the producer to achieve a 28-day compressive strength of 4,000 psi as required by the specification. A blend of three aggregates was used to meet the specified gradation for RCC. The mix design consisted of 15% fly ash for durability. The compaction moisture content was determined from moisture-density relationships in accordance with AASHTO T 180, Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop (AASHTO, 2010), otherwise known as the modified Proctor method, and the water–cementitious material ratio (w/cm) was based on this moisture content.

Documentation of Construction and Lessons Learned

Researchers were present on-site during the construction of the RCC and collected information regarding base preparation, plant production, paver operation, compaction, joint cutting, curing, and formation of fresh and cold joints. Researchers also collected RCC samples and prepared cylinders for strength testing. Achieved density information was also gathered from the field inspectors. Numerous site visits and discussions with field personnel led to the lessons learned.

Construction Quality Control and Quality Assurance

Construction quality control and quality assurance (QC/QA) was an integral part of the RCC construction and involved measurement of concrete compressive strength, mixture moisture content, and mat density and thickness. QC/QA activities were executed and monitored by Fredericksburg District personnel, but some of the data were shared for the purpose of documentation in this study.

The moisture content of the concrete mixtures was measured at both the plant (by the producer) and project site (by VDOT district staff) using a hot plate in accordance with ASTM D4959, Standard Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating (American Society for Testing and Materials [ASTM], 2013) to aid in moisture control during production.

Samples of the fresh concrete mixture were collected from the paver for at least two trucks per day of production. Three to five cylinders (6 by12 in) were prepared per truck load using a vibrating hammer, as shown in Figure 1, in accordance with ASTM C1435-08, Standard Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer

(ASTM, 2013). In most cases, additional cylinders and a few beams (6 by 6 by 21 in) were prepared using the same vibrating hammer for this implementation study. Cylinders were compacted in four equal lifts, whereas beams used only two layers; enough pressure was exerted by the operator to achieve good compaction.

Cylinders were cured in the laboratory and tested for compressive and tensile strengths in accordance with ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM, 2013), and ASTM C496 / 496M, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM, 2013), respectively. Beams were used to measure flexural strength in accordance with ASTM C78, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (ASTM, 2013). Strength measurements were conducted at various ages after moist curing in the laboratory.

RCC mat density was measured behind the paver and after roller compaction using an NG in a direct transmission mode. The probe rod for the NG was inserted into the mat to a depth 2 in shorter than the thickness of the layer.

The compacted RCC thicknesses were verified by taking 4-in cores after at least 5 days of field curing. These same cores were also used to measure permeability and compressive strengths in the laboratory after more than 28 days. They were kept wrapped in the laboratory to prevent moisture loss after collection from the field.

Figure 1. Vibrating Hammer to Prepare RCC Cylinders

Measurement of Initial Performance

The initial performance of the RCC was measured for a period of up to 1 year with the following measures:

1. visual distress observations
2. falling weight deflectometer (FWD) measurements.

The performance of the RCC on northbound Staffordboro Boulevard was determined after 1 year of traffic, but the rest of the sections were only a few months old when tested.

Visual observation included development of cracks in RCC and their reflection through 2 in of an asphalt layer. The condition of joints and exposed RCC surfaces were also noted. Some FWD measurements were taken on top of exposed RCC, and others were over asphalt overlay. Subgrade resilient modulus and effective RCC modulus were back-calculated from the FWD measurements. The load-transfer efficiency of joints and cracks was also measured where possible using the FWD.

RESULTS AND DISCUSSION

Site Description

The first placement of RCC for VDOT was in Stafford County, Virginia, for the rehabilitation of a section of Staffordboro Boulevard along with the access roads to the Staffordboro Park & Ride lot for Washington, D.C., travelers. This project is a part of the expansion of the Park & Ride lot, which is supposed to alleviate congestion on I-95 by facilitating carpooling and access to transit buses. Figure 2 shows the schematic of the RCC placement location, which is within 1 mile of I-95.

A total of 134,000 ft^2, equivalent to approximately 2.0 lane-miles, was paved with RCC. About one-half of it was used to rehabilitate the existing Staffordboro Boulevard (State Route 684) with 8 in of RCC. This section of road has curb and gutter, which helped the construction process by providing a rigid vertical surface against which to pave and compact. The remaining portion comprised the access roads inside the old and the newly expanded sections of the Park & Ride lot. The RCC inside the Park & Ride lot was only 6 in thick. The existing roadway sections were milled 8 to 10 in and filled with RCC. All RCC was overlaid with 2 in of dense-graded HMA surface course (12.5-in maximum size) for a smoother ride. The traffic count on Staffordboro Boulevard was expected to go up to 12,800 vehicles per day with 18% buses when opened for commuters to Washington, D.C., in late 2014.

Figure 2. RCC Project Location in Stafford, Virginia

RCC Material and Production

A mixture was designed to achieve a compressive strength of 4,000 psi in 28 days. Three aggregates, No. 68, No. 10 screenings, and concrete sand, were blended together to meet the required dense gradation in accordance with the VDOT project specification, as shown in Figure 3. It is a regular practice for VDOT to add supplementary cementitious material, such as Class F fly ash, to improve the durability of concrete. Therefore, 15% fly ash was added to improve workability, provide fines for compactability, and improve the durability of RCC. A water-reducing admixture was added at 3 oz/cwt of cement. The mixture proportions are presented in Table 1.

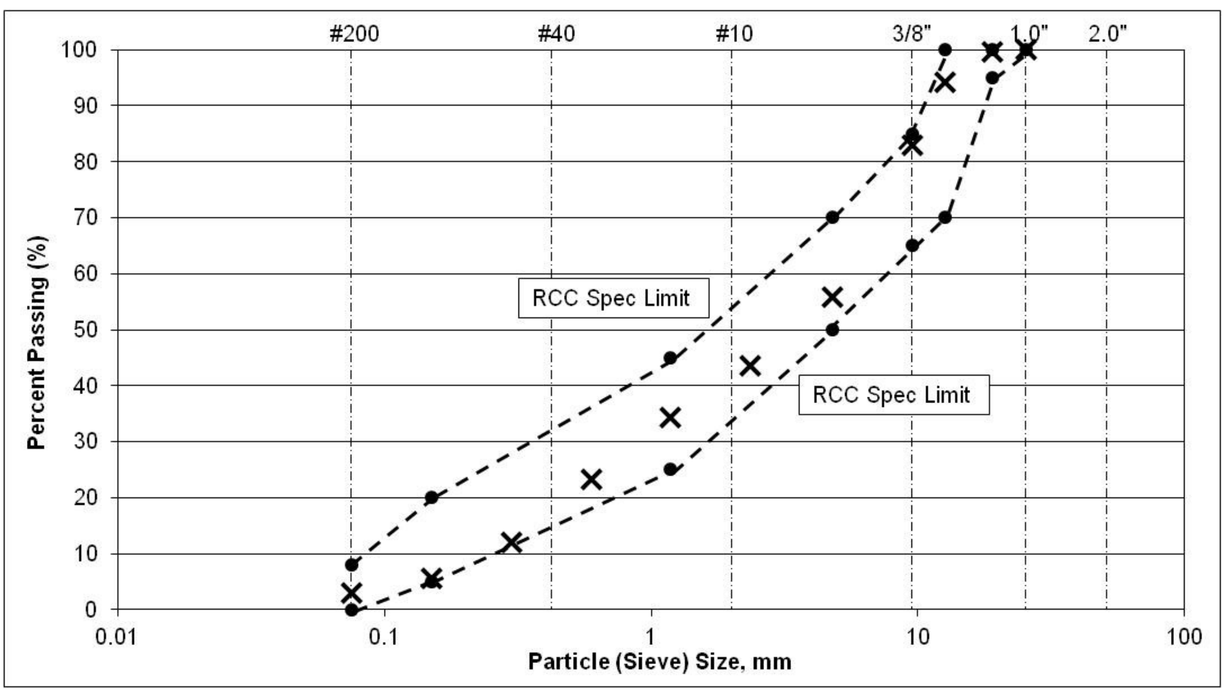

Figure 3. RCC Mixture Gradation. Dashed lines = specification limits; x = actual gradation used.

Table 1. Mix Design Proportions

Material	Amount (lb/yd^3)
Type II hydraulic cement	479
Fly ash (15%)	85
Coarse aggregate (No. 68)	1,600
No. 10 aggregate	630
Sand	1,119
Water	233
Water–cementitious material ratio	0.41

Figure 4. RCC Production Plant With Pugmill Attachment

It was important for the plant to maintain a consistent moisture content for better compaction control in the field. Therefore, a RCC sample was collected from the belt for every load, and moisture content was determined using a hot plate at the plant by the producer. Mixing water was adjusted accordingly. This plant needed a wash cycle between batches, which also impacted the moisture control process.

Trial Installations

Two trial sections of 8-in-thick RCC were constructed on the road inside the Park & Ride lot. The first section was 100 ft long and two lanes (24 ft) wide. Figure 5 shows the very first construction of RCC by VDOT. During these early operations, the densities achieved behind the paver were 83% to 88%, and the paver screed left deep marks in the pavement. Many passes of rollers in both the vibratory and static mode did not achieve 98% density, and they were not able to smooth out the marks; the maximum achieved density was 96%. There was a wide variation of mixture moisture, from 5.0% to 7.7%. Despite this variation in moisture, the cylinders prepared using the vibratory hammer achieved the required 4,000 psi strength in 28 days; strength development with time is shown in Figure 6. However, cores taken from the first trial section achieved only about 3,000 psi, and separation of the top 2 in of concrete is evident in the cores shown in Figure 5. Such delamination was attributed to an over-compactive effort, or excessive rolling.

A second trial was performed after some adjustment to the paver, and the RCC marginally achieved the specified density behind the paver and after roller compaction. The core strengths from the second trial were more than 3,500 psi in 28 days. A consistent moisture content was maintained during this trial, and the paver was adjusted to achieve the desired density.

Figure 5. First Trial Installation of RCC

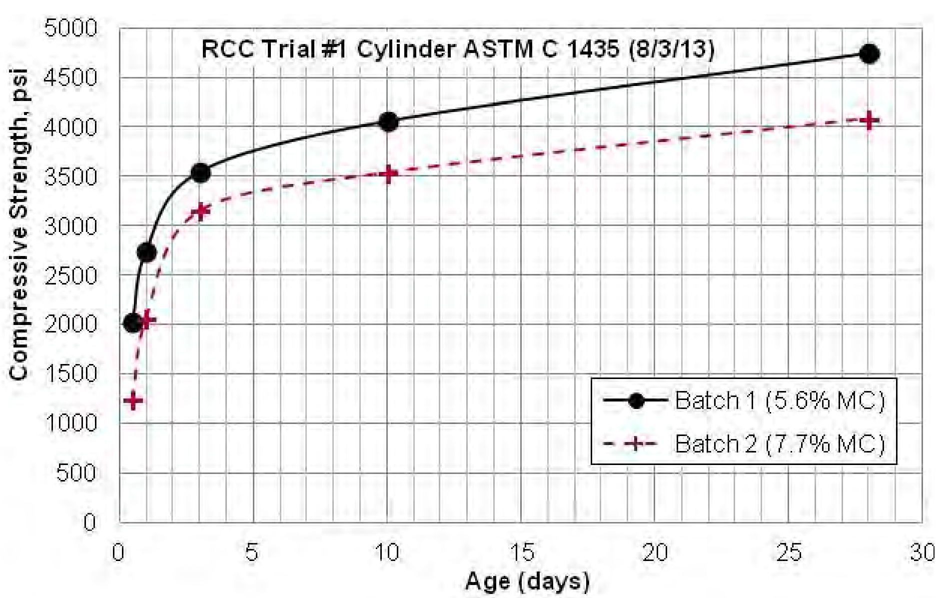

Figure 6. Strength Development of RCC Cylinders Made With Vibratory Hammer. MC = moisture content.

Removal of Existing Pavement and Base Preparation

Staffordboro Boulevard (VA 684) was rehabilitated with 8 in of RCC overlaid by 2 in of asphalt. Therefore, 10 in of existing pavement was removed to facilitate the new construction without any grade change. Similarly, 8 in of existing pavement was removed in other areas inside the Park & Ride lot where 6 in of RCC was desired. Subgrade was exposed in most places, and a few inches of base was left in other areas. A significant amount of moisture intrusion was observed after pavement removal, and the subgrade soil was found to be fat clay, which made it impossible to construct RCC without a stabilized base course. A small section (300 to 500 ft) on the south end of the right turn lane of northbound Staffordboro Boulevard was paved without base stabilization, and significant settlement of the paver and/or haul truck was observed, as shown in Figure 7. Therefore, 12 in of subgrade was removed for more than 60% of the area and stabilized with 6 in of open-graded aggregate (No. 57) over a biaxial geogrid followed by 6 in of compacted dense-graded base aggregate (VDOT 21B) on top of the No. 57 aggregate. Figure 8 shows the base preparation and stabilization.

Figure 7. Settlement of Unstabilized Base During Paving

Figure 8. Base Stabilization Using Dense-Graded and Open-Graded Aggregates Over Geogrid

Paving Operation

RCC was paved with a high-density paver during two construction seasons. During the second season, multiple lanes were constructed in a day's work and fresh joints were formed as shown in Figure 9. Pavement about 12- to 17-ft wide was constructed with a single pass of the paver. In a three-lane construction, the middle lane was paved with cold joints; in the next day's operation, about 6 in of the pavement was sawed to create a vertical face. In order to form a fresh joint, two lanes were paved within 60 min of each other and about 6 to 12 in of the first lane was rolled together with the second lane.

Densities behind the paver and after roller compaction were measured using an NG in direct transmission mode. A density of 90% to 94% was achieved behind the paver in most cases, except when the mixtures were too dry or too wet. Even though the specification suggested a vibratory roller, two or three passes of a static roller were sufficient to achieve 98% density in this study. In a few cases, dry mixtures had to be removed because they did not achieve the required density. On the other hand it was difficult to achieve adequate thickness in mixtures that were too wet, and the paver screed left deep marks in the pavement as shown in Figure 10. Consistent moisture content was necessary for proper operation of the paver.

Although a wet mixture helped in hydration and was easier to compact, the surface became cracked and too soft to support the paver or roller. In areas where the paver could not reach, such as the corners and curvatures, manual spreading and compacting with handheld vibratory equipment were performed. Those sections are also performing satisfactorily.

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Figure 9. Paver Operation of 12- to 17-ft-Wide Placement; Preparation for Fresh and Cold Joints

Figure 10. Settlement of RCC Attributable to Wet Mixture

NG testing indicated satisfactory density; however, field cores in some cases indicated lack of consolidation in the bottom portion of the layer. This may be attributable to variations in the moisture content of the RCC mixture, areas of lower stiffness of the base material, or the inadvertent spilling of loose RCC mixture ahead of the paver, all of which affect the compaction effort. Use of rigid base, such as cement-treated aggregate, would help the compaction of the RCC layer.

A continuous operation was needed to prevent formation of cold joints and inadequate compaction because of drying and setting of concrete. In a few places, early cracks occurred in the pavement. A continuous paving operation is necessary to achieve a smooth and crack-free pavement. The use of a batch plant necessitated a well-coordinated effort among plant production, number of haul trucks, and staging for a continuous paving operation. In a few sections, the paving operation was a "stop-and-go" operation because of concrete plant production interruptions and lack of an adequate number of haul trucks. This created dips and cracks in the areas such as shown in Figure 11. The specification requires compaction to be completed within 60 min of mixing. If the paver had to stop for a longer period of time, the resulting cold joint would have to be formed by a vertical saw cut before paving could resume. A material transfer vehicle is preferred to be used for a continuous paving operation. The use of a continuous production pugmill instead of a batch plant pugmill would also have helped support continuous paving.

The experience showed that uneven thicknesses and non-uniform vertical cuts between two lanes when paved as a cold longitudinal joint may result in raveling of the joints as shown in Figure 12. Spreading loose material to compensate for thickness also led to raveling of the surface since bonding of this material did not occur through roller compaction.

There were instances of RCC hydrating and setting in the paver, as shown in Figure 13. The paver should be cleaned at some interval so that RCC material does not build up and harden.

Figure 11. Cracks and Dips Attributable to Stop-and-Go Paving Operations

Figure 12. Uneven Longitudinal Joints and Raveling

Figure 13. Hardened RCC in Paver

Curing and Joint Cuts

The contractor had decided to use water curing because of the need to open the pavement to traffic in 48 hours. It was thought that curing compound might create a slick surface when open to traffic at an early age. Water spraying started as early as 3 to 4 hours after compaction in hot weather conditions and continued for 7 days as the surface became dry. In hot weather, the water on the surface evaporated fast, and keeping the surface wet continuously was a problem. Toward the end of the project, plastic sheets (3-mil polyethylene) were also used to retain moisture; the sheets were placed over the completed RCC and maintained for 3 to 4 days. Control joints were cut every 15 ft as soon as was practical without raveling the edges. Initially, a regular saw was used and cutting was done in 5 to 6 hours to avoid raveling. But in the second season, an early entry saw was used to cut the joints in 2 to 3 hours or earlier. Water curing and saw cutting are shown in Figure 14. Although one-fourth of the depth was required to be saw cut, only 1 to 1.5 in cutting was done in some places instead of the required 2 in for an 8-in-thick section. This might have initiated some random mid-slab cracks instead of cracking through the control joints. It was important to align saw cuts for the adjacent sections in the transverse direction to avoid unintended crack propagation.

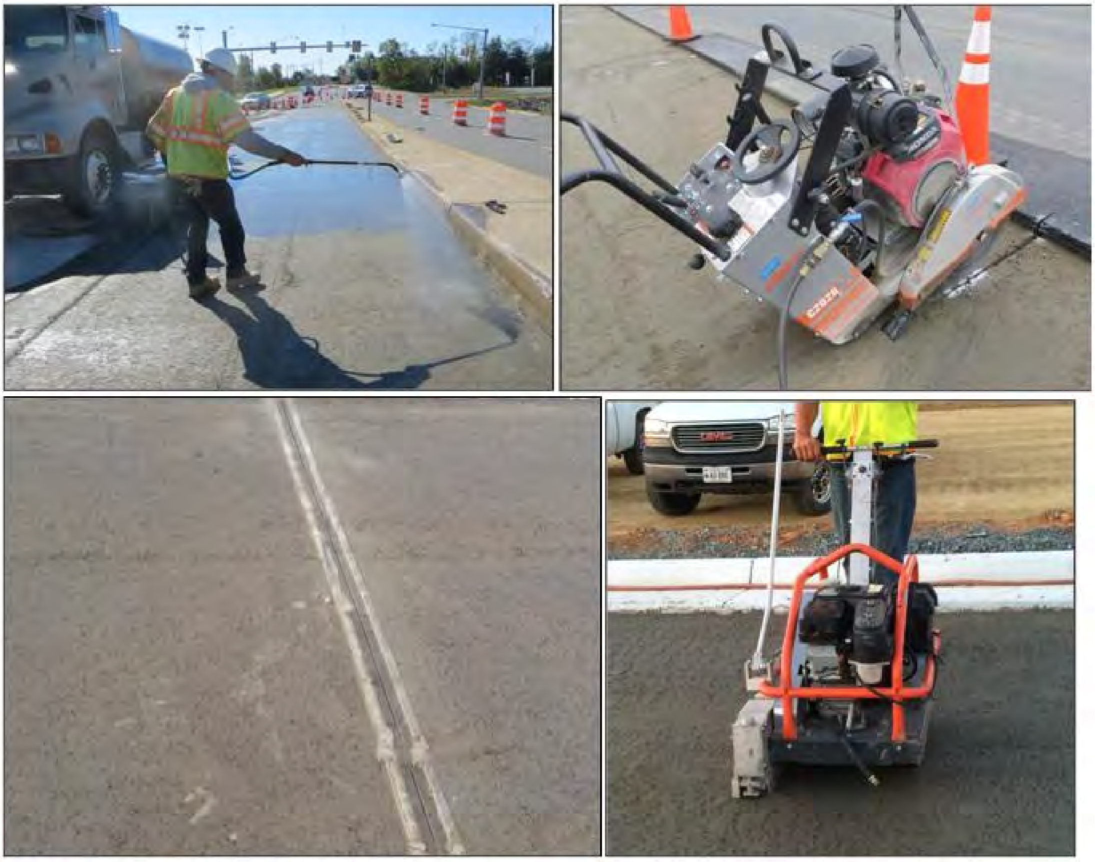

Figure 14. Water Curing and Saw Cutting of Joints

Opening to Traffic

All sections of Staffordboro Boulevard were open to traffic in 48 hours or less. Construction usually started on Saturday mornings, and the sections were open to traffic early on Monday mornings. Cylinders made using the vibratory hammer were tested at 24 hours, and all of them had a compressive strength of more than 2,000 psi.

One section of the southbound lanes was opened to traffic in 5 to 6 hours. This section was composed of 300 ft of all three lanes at the south end. It was constructed from 7:00 P.M. to 11:30 P.M. on a weekday and opened to traffic the next morning at 5:00 A.M. for commuter traffic composed of mostly passenger vehicles/vans. The cylinders made with a vibratory hammer from this section achieved a strength of only 1,600 psi in 12 hours. That section of pavement is performing similar to other sections without any visible distresses.

Asphalt Overlay

All sections of RCC were overlaid with 2 in of HMA within a few months of RCC placement to achieve a smooth riding surface. A 12.5-in dense-graded asphalt mixture was used throughout the project. The northbound lanes of Staffordboro Boulevard were overlaid in November 2013 and have been open to traffic since then.

Quality Control/Quality Assurance

As mentioned earlier, the RCC producer monitored the moisture content during production and made adjustments accordingly to keep the moisture consistent at about 0.5% to 1% above optimum moisture content according to the modified Proctor test. The contractor also monitored the moisture using an NG as the RCC was paved. Although the NG monitoring did not give the actual moisture content because of the presence of cement, the contractor was able to monitor for consistent moisture content among different truckloads.

Densities were tested behind the paver and after final compaction with an NG. For the most part, density behind the paver was between 90% and 94%. The density met the requirement for an average density of 98% with no value below 96% per day's work with a few passes of the roller. Testing was conducted on a minimum of five locations per day of paving operation.

At least six cylinders were made per day and tested for 3- and 28-day compressive strengths as required by the specification. As mentioned earlier, additional cylinders and beams were made from a few trucks. Cylinders were tested for compressive strength at 12 hours, 1 day, 3 days, 14 days, 21 days, and 28 days after placement. Some were tested for splitting tensile strength. A few beams were also tested for flexural strength. Table 2 summarizes the results. Achieved compressive strengths exceeded 1,600 psi, 2,500 psi, and 4,000 psi in 12 hours, 1 day, and 28 days, respectively. The elastic modulus of RCC cylinders was more than 4 million pounds per square inch and comparable to that of conventional concrete. Average splitting tensile and beam flexural strengths were 526 psi and 744 psi, respectively. A few 4-in field cores were taken to verify the in-place thickness of each day's production; a few places did not meet the thickness tolerance of ±½ in. These same cores were used to measure in-place achieved compressive strength, and average values are also included in Table 2. Core strengths were generally lower than the cylinder strengths but had high variability, which is attributed to compaction issues such as inconsistent mixture moisture, unusual delay between mixing and compaction, and lack of base support. However, core strengths exceeding 3,500 psi at 28 days were achieved in more than 70% of the tested cores. Because of the presence of fly ash, the RCC is expected to achieve higher strength over time. Sixteen cores were cured in lime water for accelerated strength development and tested at an average of 5,800 psi compressive strength at 2 months.

Table 2. Average Compressive, Splitting Tensile, and Beam Flexure Strengths

Measured Property	Age	No. of Samples	Standard Deviation	Average (psi)	Coefficient of Variation (%)
Cylinder compressive strength, psi	12 hours	12	266	1,639	16
	1 day	18	401	2,646	15
	3 days	19	631	3,391	19
	7 days	14	429	4,121	10
	28 days	38	881	5,071	17
Cylinder modulus of elasticity, psi	28 days	17	0.3×10^6	4.17×10^6	7
Cylinder splitting tensile strength, psi	28 days	16	64	526	12
Beam flexure strength, psi	28 days	6	46	744	6
4-in field core compressive strength, psi	28 days	14	1,013	4,065	25
4-in field core (lime cured) compressive strength, psi	>2 months	16	1,296	5,823	22

Construction Phases and Cost

The contractor was required to demonstrate proper equipment operation and mixture placement through a trial installation before actual construction could start. This project necessitated two trial sections. The second trial indicated that the contractor's RCC construction methods would be successful. The northbound lanes of Staffordboro Boulevard were paved, one lane at a time (per day), in August 2013. RCC was placed over 750-ft sections of two lanes and 575 ft of a right-turn lane. The paving operation started again in June 2014 with the construction of access roads. In addition to all the access roads inside the Park & Ride lot, the rest of Staffordboro Boulevard was completed during this second construction season: three southbound lanes of 800 ft each, and 300 ft of single lanes in both directions just north of the previous RCC. Although the total length of RCC placement was only 2 lane-miles, the actual construction took place on 13 different days spread over more than a 1-year period. If one assumes one lane-width (12 ft) paving at a time and 8-hour workdays, the production rate would be 800 ft per day; that rate is about one-third of the rate at which the paver actually moved, which was 5 ft/min or 2,400 ft per 8-hour day. The many stop-and-go operations during the paving contributed to this slow production.

The paving rate also depends on the plant production rate, the availability of a continuous supply of RCC, and an adequate number of hauling trucks. An RCC production rate of 6 to 8 ft/min was reported in the literature (Adaska et al., 2014). Traffic control constraints on Staffordboro Boulevard limited construction to weekends only. The concrete plant also could not supply RCC during normal business hours because of its regularly scheduled concrete production and the additional time (2 to 3 hours) needed to switch between the two types of production. RCC production required the addition of a pugmill with a high-voltage generator. So most construction took place during weekends and at night, even though the road sections inside the Park & Ride lot did not have traffic control constraints. The bid prices for 8-in and 6-in RCC were \$41.60 and \$32.20 per square yard, respectively. The constraint of constructing small quantities at a time because of the geometry might have contributed to these prices. For comparison, the average cost of 6 to 8 in of RCC was reported as \$33/ yd^2 by Pittman and Anderton (2012) of the U.S. Army Corps of Engineers.

Pavement Condition and Performance

The RCC is performing satisfactorily as judged by visual appearance, as shown in Figure 15. Pavement conditions were visually observed a few days after construction for each section. Despite the cutting of joints at 15-ft intervals, a few random transverse cracks were observed within a couple of days in some of the sections, with or without having been exposed to any traffic. Most were related to the stop-and-go paving operation or improper jointing or inadequate joint depth.

The oldest section of RCC is on the northbound lanes of Staffordboro Boulevard. There was one crack on one of these northbound lanes, as shown in Figure 16, and it did not reflect through the 2 in of asphalt overlay after 1 year of traffic, which included the haul trucks used to fill the adjacent construction site. The RCC surface stayed exposed for about 1 month before it was overlaid in November 2013. The southbound Staffordboro Boulevard had three cracks develop within a few days of paving. The probable reason for one (Figure 16) of the cracks, which was near the cut joint, was the shallowness of the cut. Some of the measured cut depths were 1 to 1.5 in for this 8-in-thick pavement. Deeper cuts might have prevented the cracks. Though not specifically documented for any of these locations, some of these cracked areas may also have suffered from long stops of the paver or mixtures that were more than 60 min old before placement. Many of the control joints on both lanes of Staffordboro Boulevard had reflected through the overlay, but the cracks were still tight with no sign of spalling or raveling except for a few (four) where cracks were as wide as ¼ to ½ in. A part (750 ft) of the northbound lane had 18 months of traffic over two winters, but the rest of the section had 8 months of traffic over one winter.

Figure 15. Completed RCC on Staffordboro Boulevard

Figure 16. Transverse Cracks on Staffordboro Boulevard (*left:* northbound; *right:* southbound)

Four cracks developed on a section of road (Alignment D) inside the Park & Ride lot where 6-in-thick RCC was placed. These cracks were mostly related to the stop-and-go operation of the paver as shown in Figure 11. Some raveling and cracks were observed near poorly formed construction joints, both longitudinal and transverse, as shown in Figures 11 and 12.

Some of the transverse construction joints also suffered from dips and cracks near the header as shown in Figure 17. The jointing in Figure 17(a) was done in at least 12 hours, whereas the two sections shown in Figure 17(b) were constructed in 2 to 3 hours. In both cases, the cracks showed up in a few days along the border despite the adjacent joint cutting.

The main contributing factor for transverse cracks was the stop-and-go operation, during which delays between loads were observed. Construction joints, both cold and fresh, were formed throughout the project. Cold joints were formed by cutting a vertical face through hardened RCC. Fresh joints needed to be formed before the receiving surface hardened or set.

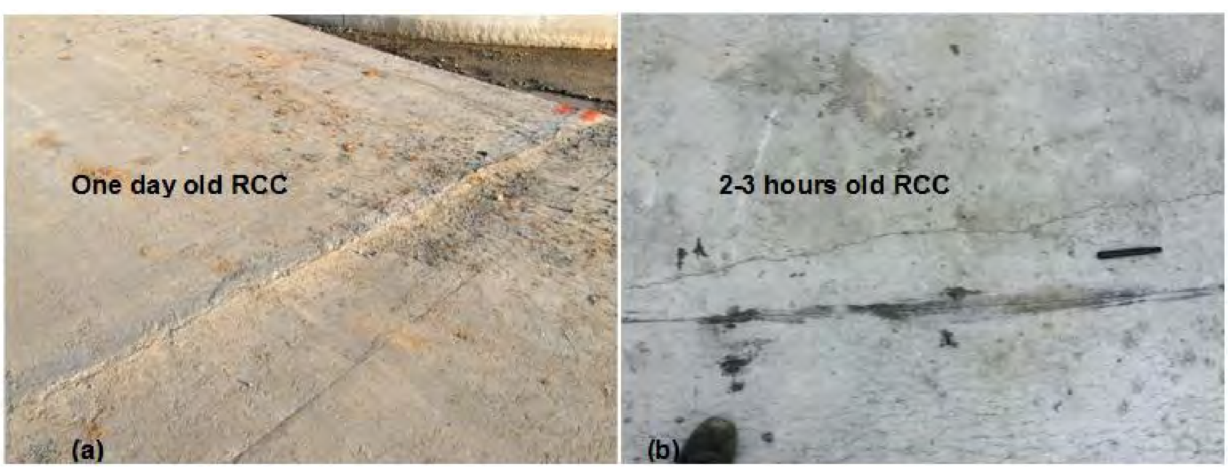

Figure 17. Crack Near Transverse Construction Joint

Placement is easier when the surfaces are nearly vertical. If not carefully performed, placement along construction joints may result in voids and discontinuities, as shown in Figure 18. Longitudinal cracks were also caused by delays between the placements of successive lanes. Despite a couple of hours of delay, they were constructed as fresh joints. Other factors leading to the cracks might be inadequate cut depth for control joints and lack of appropriate curing. During the hot summer days, it was challenging to keep the surface moist for 7 days using water spray.

An FWD was used to measure the in situ condition of the RCC pavement. The tested sections were from 2 months to 1 year of age at the time of testing. Four load levels (6 kips, 9 kips, 12 kips, and 16 kips) were used with four drops per load. The deflection profiles and back-calculated effective modulus of the RCC for northbound Staffordboro Boulevard are shown in Figure 19. The testing on Staffordboro Boulevard was conducted on 2-in asphalt overlays. The remaining sections had exposed RCC surfaces during the test. The deflection and effective modulus for RCC under the 9-kip load varied between 6 to 10 mils and 5 million to 10 million psi, respectively. Although there was a lot of variability in these values, the averages were typical for concrete pavement. The load transfer efficiencies across the cracks and a few control joints were also measured, and most were above 80%, which indicated good aggregate interlock. Another interesting observation was that the effective modulus for RCC was low in the vicinity of cracks.

Figure 18. Core Through Stop-and-Go Section

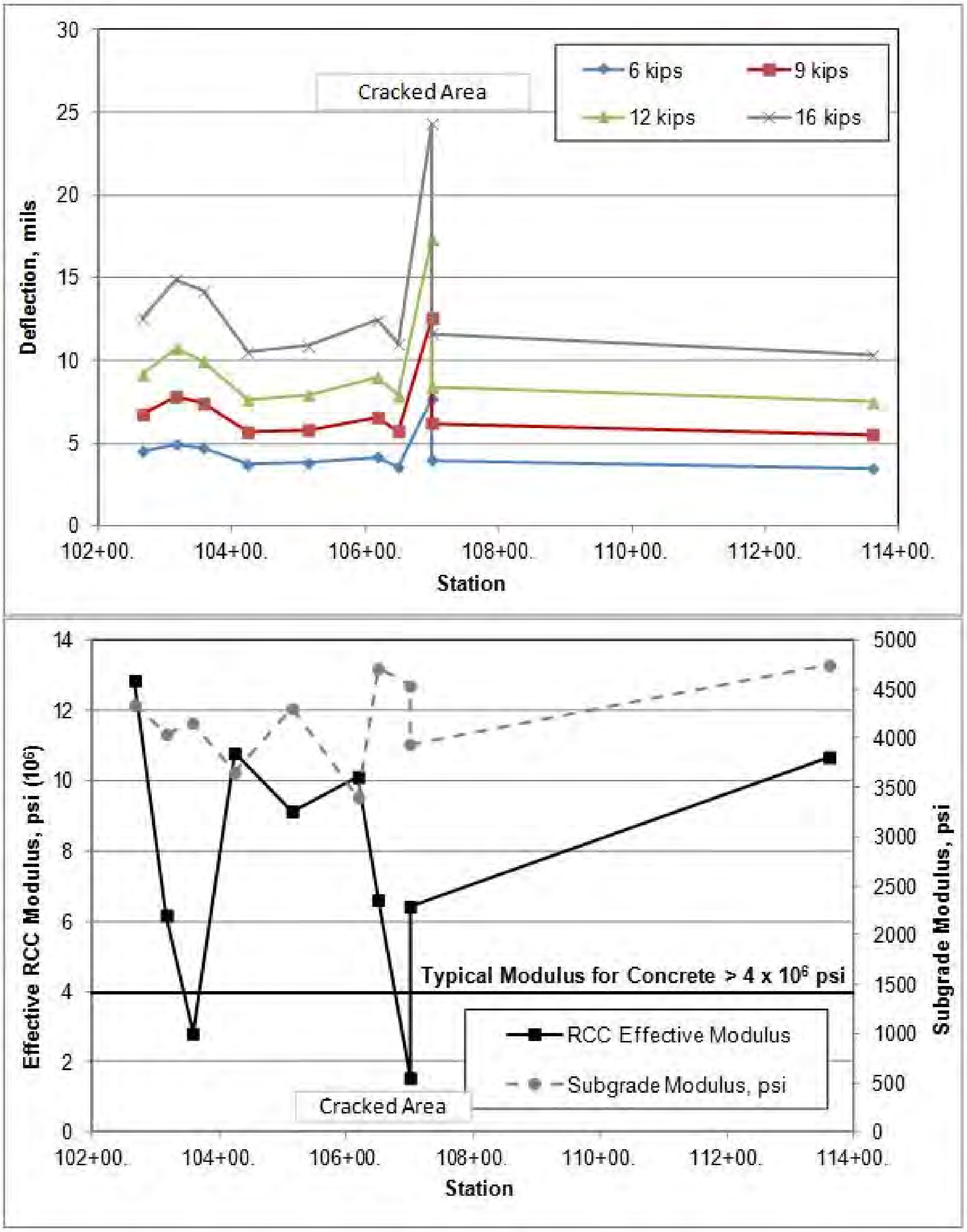

Figure 19. FWD Results for Northbound Staffordboro Boulevard

SUMMARY OF FINDINGS

- RCC was successfully constructed to rehabilitate Staffordboro Boulevard and new sections of roadways inside the Park & Ride lot. Many valuable lessons were learned during this construction.

- At the batch plant loading, each truck received two batches of RCC within about 10 min. A wash cycle was needed between batches, which took time and also made moisture control difficult. Delivery time to the site was 20 min. In addition, delays during the transfer of material to the paver made it difficult to meet the requirement of finishing compaction within 60 min of mixing. A continuous operation pugmill would have alleviated some of these problems and helped in continuous paving operation in the field.

- Compressive strengths exceeding 1,600 psi at 12 hours; 2,500 psi in 24 hours; and 4,000 psi at 28 days were achieved.

- Fly ash was added to the RCC to improve workability, increase fine material for compactability, and improve durability.

- Target and achieved (mixture) moisture contents were about 0.5% to 1% higher than the optimum moisture content to facilitate compaction.

- Dry mixtures were difficult to compact but had a somewhat good surface finish. Delays between mixing and compaction caused drying of the mixture.

- Density was easier to achieve with wet mixtures, but it was difficult to retain surface smoothness, profile, and thickness. The surface looked cracked and rough. The weight of the paver caused settlement and reduced the pavement thickness.

- Too many passes with the roller in an attempt to achieve compaction damaged the top layer (about 2 in deep) of RCC and separated it, thereby creating a delamination.

- Loose RCC spread over the layer just behind the paver to fill the dips or compensate for thickness never bonded to the layer and created raveling.

- Improper jointing practices and excessive delays between the successive lanes of paving caused joint raveling.

- In hot weather, the water on the surface evaporated fast. It was challenging to keep the surface wet continuously. In some sections, a plastic sheet was used successfully to aid curing.

- Placements of RCC in small quantities at a time could be expensive because of equipment rentals and inefficiencies. The costs in this project were $32 to $42 per square yard for 6 to 8 in of RCC. Construction took more than 1 year of weekend-only work to finish because of traffic and construction constraints.

- The paver speed was 5 ft/min; however, because of plant production, delivery, transfer to paver, and multiple stop-and-go operations, only 800 ft was paved in an 8-hour day.

- In most areas, RCC was opened to traffic in 24 to 48 hours. But earlier opening to traffic is also possible. A section was opened within 5 to 6 hours and did not exhibit any visual distress after 4 to 5 months.

- The overlaid RCC is performing well after up to 1 year of traffic and service.

CONCLUSIONS

- Construction of RCC can be completed successfully.

- A trial section is essential to demonstrate successful execution of RCC placement and to address any deficiencies before actual construction can start.

- A high-density asphalt paver is necessary to achieve 90% density behind the paver. It was not possible to get 98% density with the roller unless 90% density was achieved behind the paver. Adequate compaction is crucial for strength development.

- For proper compaction throughout the layer, stiff base and consistent uniform moisture contents and avoidance of spilled loose material on the surface are needed.

- Consistent moisture content is essential to achieve uniform thickness.

- A continuous pavement operation is needed to avoid unplanned and poor-performing cold joints; a stop-and-go operation creates dips and cracks.

- Jointing practices, whether for fresh or cold joints, must be followed as detailed in the specification. Alignment of transfer joints between adjacent lanes is important to avoid crack propagation.

- Fresh joints should be formed before setting of concrete, and a vertical face should be prepared for cold joint compaction. Early entry saws can be used successfully.

- The crack control joints should be cut at least one-fourth of the RCC thickness; otherwise, unintended cracks between the joints may develop.

RECOMMENDATIONS

1. *VDOT's Materials Division and the related district sections should consider RCC in future field trials, particularly for applications where fast construction of rigid (concrete) or composite pavement is needed; examples of such areas would be those that carry heavily loaded, slow-moving vehicles such as at intersections and access roads to truck or bus parking areas.* A trial installation is recommended at the beginning of each project for such construction.

2. *VDOT's Materials Division and the Virginia Center for Transportation Innovation and Research (VCTIR) should consider the following modifications to the RCC special provision in future implementations:*

   — *Continuous paving operation should be ensured.*
   — *A material transfer vehicle (MTV) may be used.*

3. *The materials and maintenance personnel in VDOT's Fredericksburg District and VCTIR should monitor the long-term performance of the sections constructed in this project.*

4. *VCTIR should continue to provide technical assistance to VDOT districts for future implementations of RCC until its use becomes a regular practice.*

BENEFITS AND IMPLEMENTATION

RCC could provide the benefit of rigid pavement and could be constructed and opened to traffic in less than 24 hours, as opposed to regular HCC pavement, which needs 5 to 7 days. One section of RCC was opened to traffic in 5 to 6 hours on this project and is performing satisfactorily after 4 months of traffic. Since RCC construction uses the same equipment as asphalt paving, it should be cost-competitive. Although the installed cost for this project was \$32 to \$42 per yd^2 for 6- to 8-in RCC, the constraint of constructing small quantities at a time because of the geometry and the team's lack of experience with the technology might have contributed to higher prices than might be expected under regular production. The average cost reported elsewhere (Pittman and Anderton, 2012) is about \$33/yd^2. The asphalt material costs as bid for this project were \$66.00, \$76.00, and \$80.50 per ton for base, intermediate, and surface mixtures, respectively. Assuming a unit weight for asphalt material of 110 lb per square yard per inch thickness, the cost for asphalt would range from \$22 to \$35 per square yard for thicknesses of 6 to 8 in depending upon the mixture. In addition to cost-competitiveness and early opening to traffic, RCC can provide a rut-free pavement structure for heavily loaded vehicles.

This project was an implementation project and was completed successfully, so future use of RCC should be explored in other locations within Virginia.

ACKNOWLEDGMENTS

The authors acknowledge the sponsorship of FHWA's Highways for LIFE program for the construction of this RCC trial. The authors also thank VDOT's Fredericksburg District personnel Randall McKinney, Alex Teklu, Stephen Wilson, Alexander Appea, Robert Dittmann, Michael Whanger, Sameer Shetty, and Kimberly McKinney for their help and contribution in implementing RCC, facilitating site visits by the researchers, and collecting data during construction. The members of the technical review panel for the study, Alex Teklu, Chung Wu, Michael Fitch, and David Kaulfers, are acknowledged for their contributions. The authors also acknowledge VCTIR technicians Lewis Lloyd, Daniel Haileselassie, and Mike Burton and summer interns for their laboratory and field work. Thanks to Linda Evans and Mary Bennett of VCTIR for their support in reviewing and preparing the report.

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APPENDIX A

VDOT Special Provision for Roller Compacted Concrete (RCC) Pavement
Dated 10/15/2012

ROUGH DRAFT
VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
ROLLER COMPACTED CONCRETE (RCC) PAVEMENT

10/15/2012

1. General Provisions

1.1. Description

This work shall consist of constructing Roller Compacted Concrete (RCC) pavement on a prepared subgrade or subbase course in accordance with the requirements of these specifications and within the specified tolerances for lines, grades, thickness, and cross sections shown on the plans or as established by the Engineer.

1.2. Related Standards

AASHTO T 180	Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
AASHTO T 22	Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 31	Practice for Making and Curing Concrete Test Specimens in the Field
ASTM C 39	Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 42	Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C 171	Specification for Sheet Materials for Curing Concrete
ASTM C 496	Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C 1435	Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer

1.3. Submittals

The Contractor shall submit the following to the Engineer at least 35 days before start of any production of RCC pavement:

(a) **Proposed RCC Mix Design**: Contractor shall submit the proposed mix design from a qualified laboratory or any suggested change to the approved mix design to the Engineer for approval. This mix design shall include details on aggregate gradation, cementitious materials, admixtures (if used), compressive strengths, required moisture and density to be achieved. This shall also include the quantities of individual materials per cubic yard for the mix design.

(b) **Paving Schedule**: Contractor shall submit a construction schedule for all RCC related operations describing direction of paving operations, paving widths, planned longitudinal and transverse cold joints, curing methods and patterns and description of all equipment including layout of plant location showing mixing plant, cement and aggregate storage, and water supply.

2. **Materials**

All materials to be used for RCC pavement construction shall meet the requirements of the following specifications:

Materials	**VDOT Specification**
Coarse Aggregate	203
Fine Aggregate	202
Hydraulic Cement, Type 1	214
Portland Pozzolan cement	215
Hydraulic Cement Concrete Admixtures	215
Fly Ash and Slag	241 and 214
Concrete Curing Materials	220
Joint Fillers and Sealers	212
Water	216
Curing Compound	220

Unless otherwise specified, quality of aggregate shall conform to ASTM C 33. The aggregate shall be well-graded. Aggregates may be obtained from a single source or may be a blend of coarse and fine aggregate to conform to the following gradation:

Sieve Size	**% Passing by weight**
1 in (25 mm)	100
3/4 in (19 mm)	95-100
1/2 in (12.5 mm)	70-100
3/8 in (9.5 mm)	65-85
No. 4 (4.75 mm)	50-70
No. 16 (1.18 mm)	25-45
No. 100 (150 μm)	5-20
No. 200 (75 μm)	0-8

Contractor must produce evidence that the selected proportions have the potential for strength development at 28 days as required in subsection “Approval of Mix Design Proportions”.

3. **Equipment**

RCC pavement shall be constructed with such equipment and tools that will produce a complete pavement meeting the requirements for mixing, transporting, placing, compacting, finishing, and curing as provided in this specification. Equipment and tools necessary for handling materials and performing the work shall be subject to the approval of the Engineer.

3.1. **Mixing Plant**

3.1.1. **Pugmill**

RCC shall be mixed in a ***Pugmill Plant*** located within 30 minutes of hauling distance from the RCC placement site. With the approval of the Engineer and prior demonstration, a set retarding admixture may be used to extend the haul distance. The plant shall be capable of producing a mixture in the proportions defined by the approved mix design and within the specified tolerances. The capacity of the plant shall be sufficient to produce a uniform mixture at a rate compatible with the placement equipment. If the plant is unable to produce material at a rate adequate to prevent unnecessary cold joints and frequent paver stoppages, production may be halted until such time that a plant (or multiple plants) of appropriate capacity is used. Following are the requirements of the pugmill plant:

(a) **Pugmill** shall be a central plant with a twin shaft pugmill mixer, capable of batch or continuous mixing, equipped with synchronized metering devices and feeders to maintain the correct proportions of aggregate, cement, mineral admixture and water. Capacity of the plant shall be more than 200 tons per hour.

(b) **Aggregate Storage** may be in a stockpile from which it is fed directly to a conveyor feeding mixer, if previously blended aggregate is furnished. If aggregate is furnished in two or more size/ type groups, separate stockpiles must be used/ provided for each. Aggregate shall be stockpiled on a concrete platform or in a manner that will avoid contamination.

(c) **Aggregate Bins** shall have a capability of controlling feed rate by a variable speed belt or an operable gate calibrated to accurately deliver any specified quantity of material. If two or more aggregate size/ type are used, the feed rate from each bin shall be readily adjustable to change aggregate proportions, when required. Feed rate controls must maintain the established proportions of aggregate from each stockpile bin when the combined aggregate delivery is increased or decreased.

(d) **Plant Scales** for any weigh box or hopper will be either of beam or spring-less-dial type, and be sensitive to 0.5 percent of the maximum load required. Beam-type scales shall have a separate beam for each aggregate size, with a single telltale actuated for each beam, and a tare beam for balancing hopper. Belt scales shall be of an approved design. Standard test weights accurate to plus or minus 0.1 percent shall be provided for checking plant scales.

(e) **Cement, Fly Ash or Slag Storage** shall be in separate and independent storage silos. Each silo must be clearly identified for Portland cement or mineral admixture to avoid confusion during silo loadings. If the Contractor chooses to use pre-blended cementitious material, he must employ blending equipment acceptable to the Engineer and demonstrate, with a testing plan, the ability to successfully produce a uniform blended material meeting the mix design requirements. Testing of the pre-blended cementitious material shall be done on a daily basis to assure both uniformity and proper quantities.

(f) **Cement, Fly Ash or Slag Feed Unit** shall be capable of satisfactorily dispensing Portland cement and mineral admixture, volumetrically or by weight, to assure a uniform and accurate quantity of cementitious material entering in the mixer.
(g) **Water Control Unit** shall be equipped with an accurate metering device to measure, by weight or volume, required amount of water for the approved mix. The water flow shall be controlled by a meter, valve or other approved regulating device to maintain optimum moisture content (determined during mix design) at all time in the RCC mixture.

3.1.2. **Other mixing equipment**

Other mixing equipment shall be permissible if approved by the engineer. RCC shall be mixed within 30 minutes of hauling distance from the RCC placement site. The mixing plant shall be of a design that can produce a consistent RCC mixture at the proportions defined in the approved mix design. The mixing plant may be a Central-Mix Drum or Horizontal Mixer, or a batch or continuous twin shaft Pugmill Mixer. Portable mixers that can be utilized with a dry batch plant to produce RCC can be considered. Truck mixers will not be acceptable. The mixing plant shall have a minimum manufacture's rated capacity of 200 tons per hour.

3.2. **Paver**

RCC shall be placed with a high-density or conventional asphalt type paver subject to approval by the Engineer. The paver shall be capable of placing RCC to a minimum of 90% of the maximum wet density in accordance with AASHTO T 180, Method D or equivalent test method. The paver shall be of suitable weight and stability to spread and finish the RCC material, without segregation, to the required thickness, smoothness, surface texture, cross-section and grade.

3.3. **Compactors**

(a) A self-propelled smooth steel drum vibratory rollers having minimum weight of 10 tons (9.07 Mg) shall be used for primary compaction. For final compaction or for removing roller marks, a steel drum roller operating in static mode shall be utilized.
(b) Walk-behind vibratory rollers or plate tampers may be used for compacting areas inaccessible to large rollers.

3.4. **Haul Trucks**

Sufficient number of trucks shall be provided to ensure adequate and continuous supply of RCC mixture to the paver at the site. Trucks used for hauling RCC mixtures shall have tight, clean and smooth beds. Trucks hauling RCC mixtures from the plant to the paver shall be equipped with a waterproof cover large enough to extend over the sides and ends of the bed. These waterproof covers shall be securely fastened before the vehicle begins moving to protect the mixture from inclement weather such as rain or excessive evaporation losses.

3.5. **Water Trucks**

At least one water truck or other similar equipment shall be on-site and available for use throughout the paving and curing process. The water truck shall be equipped with a spreader pipe containing fog nozzles capable of evenly applying a fine mist of water to the surface of the RCC without damaging the final surface.

3.6. **Inspection and Calibration of Equipment**

Before start-up, the Contractor's equipment shall be carefully inspected. Should any of the equipment fail to operate properly, no work shall proceed until the deficiencies are corrected. The Engineer shall have access at all times to any plant, equipment or machinery to be used on this project in order to check calibration, scales, controls or operating adjustments.

4. **Construction Requirements**

4.1. **Preparation of Subgrade/ Subbase**

Subgrade/subbase shall be prepared as required by the Plans and Specifications before placing the RCC. Such preparation shall ensure the foundation immediately under the RCC pavement and the areas supporting the paving equipment will not contribute to deficient pavement thickness or excessive yield losses.

The subgrade shall be uniformly compacted to a minimum of 95% of the maximum dry density in accordance with AASHTO T 180. The Contractor shall check for any soft or yielding subgrade areas by proof rolling with a loaded dump truck or pneumatic-tire roller over the entire area to be paved. All soft or yielding subgrade areas shall be corrected and made stable before RCC construction begins. If a subbase is shown on the Plans, it shall also be uniformly compacted to a minimum of 95% of the maximum dry density in accordance with AASHTO T 180.

4.2. **Test/ Trial Section**

Contractor shall demonstrate an acceptable RCC production and placement on a trial section. RCC placement at the site will not commence until the following criteria are satisfied. The site will be selected by the Engineer.

(a) At least 30 days before the start of paving operations, the Contractor shall construct a test section using the trial mix design. This test pavement will allow the Engineer to evaluate the strength of the RCC material, methods of construction, curing process and surface conditions of the completed test pavement. The test section shall be at least 50 feet (15 meters) long and a minimum of two paver widths wide. It shall be located in a non-critical area or as indicated on the Plans. The test pavement will be constructed over an extended period to demonstrate the construction of cold joints in both a longitudinal and transverse direction, as well as fresh joint construction.

(b) The equipment, materials and techniques used to construct the test section shall be that which will be used to construct the main RCC pavement.

(c) Contractor shall demonstrate the capability of the paver in placing RCC to a minimum of 90% of the maximum wet density in accordance with AASHTO T 180, Method D or equivalent test method during this trial construction.

(d) During construction of the test section the Contractor will establish an optimum rolling pattern and procedure for obtaining a density of not less than 98% of the maximum wet density in accordance with AASHTO T 180 or equivalent test method. In addition, the Contractor must also demonstrate the ability to achieve a smooth, hard, uniform surface free of excessive tears, ridges, spalls, segregation, and loose material.

(e) Strength Testing
Field Cast Specimens: Specimens shall be prepared in accordance with AASHTO T 180 and ASTM C 1435, transported to the laboratory and cured in accordance with ASTM C 31, and tested for splitting tensile strength (ASTM C 496) and compressive strength (ASTM C 39) at 1, 3, 7, and 28 days of age.

Cores: The test section shall be cured at least 5 days prior to extracting cores for testing. The cores shall be obtained in accordance with ASTM C 42. The cores will be tested for splitting tensile strength (ASTM C 496) and compressive strength (ASTM C 39) at 7, and 28 days of age. All coring, and testing of the test section shall be conducted by the Department.

4.3. **Mixing Process**

(a) Same mix design and materials shall be used for the entire project. If the source of cement, fly ash, slag, or aggregates is changed, construction should be suspended and a new mix design should be submitted to the Engineer for approval.

(b) Except for minor variations in moisture content, the same mixture proportions shall be used for the entire project, unless otherwise stated in the project documents.

(c) **Mixture Ingredient Tolerances**: The mixing plant must receive the quantities of individual ingredients to within the following tolerances:

Materials	Variation in Percentages by Weight
Cementitious Materials	± 2
Water	± 3
Aggregate	± 4

(d) **Mixing time** shall be such as to ensure complete and uniform mixing of all ingredients.

(e) All material shall be discharged before recharging. The mixing chamber and mixer blade surfaces shall be kept free of hardened RCC or other buildups. Mixer blades shall be checked routinely for wear and replaced if wear is sufficient to cause inadequate mixing. In continuous operations this is not applicable.

(f) Prior to commencement of RCC production, the Contractor shall carry out a complete and comprehensive calibration of the plant in accordance with the manufacturer's recommended practice. All scales, containers and other items necessary to complete the calibration shall be provided by the Contractor. After completion of the initial calibration, the plant shall be recalibrated as directed by the Engineer.

(g) The Contractor shall supply daily plant records of production and quantities of materials used each day to the Engineer. These records may be used as a check on plant calibration.

4.4. **Transportation**

The transportation of the RCC pavement material from the plant to the areas to be paved shall be in dump trucks fitted and equipped, when necessary, with retractable protective covers for protection from rain or excessive evaporation. The trucks shall be dumped clean with no buildup or hanging of RCC material. For paver placed RCC, the dump trucks shall deposit the RCC material directly into the hopper of the paver or into a secondary material distribution system which deposits the material into the paver hopper. Dump truck delivery must be scheduled so that RCC material is spread and compacted within the specified time limits.

4.5. **Placement of RCC**

(a) **Condition of the Subgrade/Subbase:** Prior to RCC placement, the surface of the subgrade/subbase shall be clean and free of foreign material, ponded water and frost prior to the placement of the RCC pavement mixture. The subgrade/subbase must be uniformly moist at the time of RCC placement. If sprinkling of water is required to remoisten certain areas, the method of sprinkling shall not be such that it forms mud or pools of free-standing water. Prior to placement of RCC, the subgrade/subbase shall be checked for proper density and soft or yielding areas and these areas shall be corrected as specified in Section 4.1.

(b) **Paver Requirements**: RCC shall be placed with an approved paver as specified in Section 3.2 and shall meet the following requirements:

i. The quantity of RCC material in the paver shall not be allowed to approach empty between loads. The material shall be maintained above the auger shaft at all times during paving.

ii. The paver shall operate in a manner that will prevent segregation and produce a smooth continuous surface without tearing, pulling or shoving. The spread of the RCC shall be limited to a length that can be compacted and finished within the appropriate time limit under the prevailing air temperature, wind, and climatic conditions.

iii. The paver shall proceed in a steady, continuous operation with minimal starts and stops. Paver speed during placement operations shall not exceed the speed necessary to ensure that minimum density requirements as specified in Section 3.2 are met and surface distress is minimized.

iv. The surface of the RCC pavement once it leaves the paver shall be smooth, uniform and continuous without excessive tears, ridges or aggregate segregation.

(c) **Thickness**: Thickness of compacted RCC pavement shall be as indicated on the Plans. If RCC pavements are to be constructed in a thickness greater than 10 inches (250 mm), the use of two lifts shall be utilized. No lift shall be less than 4 inches (100 mm).

(d) **Adjacent Lane Placement**: Adjacent paving lanes shall be placed within 60 minutes to avoid cold joints; 60 minutes may be increased or decreased depending on the use of admixtures or the ambient weather conditions of temperature, wind, and humidity. If cold joints are expected, they shall be handled in accordance with subsection 4.8(b).

(e) **Multiple Lift Placements**: For multiple lift placements, the total pavement thickness shall be as shown on the Plans, and the Contractor shall submit his method of placement and lift thickness as part of a paving plan subject to approval by the Engineer. In multiple lift construction, the second lift must be placed within 60 minutes of the completion of the first lift to avoid cold joints; 60 minutes may be increased or decreased depending on the use of admixtures or the ambient weather conditions of temperature, wind and humidity. The use of multiple pavers in tandem formation is advantageous to reduce the opportunity for cold joints to develop. If cold joints are expected, they shall be handled in accordance with subsection 4.8(b).

(f) **Hand Spreading**: Broadcasting or fanning the RCC material across areas being compacted will not be permitted. Such additions of material may only be done immediately behind the paver and before any compaction has taken place. Any segregated coarse aggregate shall be removed from the surface before rolling.

(g) **Segregation**: If severe segregation occurs in the RCC during paving operations the spreading shall be ceased until the cause is determined and corrected to the satisfaction of the Engineer; removed and replaced at no additional cost to the Department. Severe segregation is defined as a mixture or surface area which lacks homogeneity and cohesiveness where visible separation of ingredients is evident.

(h) **RCC placeme**nt shall be done in a pattern so that the curing water from the previous placements will not pose a runoff problem on the fresh RCC surface or on the subbase layer.

(i) **Paving Inaccessible Areas**: Areas inaccessible to either paver or roller may be placed by hand and compacted with walk-behind vibratory rollers or plate tampers (equipment specified in Section 3.3(b). Compaction of these areas must satisfy minimum density requirements as specified in Section 8.3. An alternate and preferred method for paving inaccessible areas is to use cast-in-place, air-entrained concrete with a minimum compressive strength of 4000 psi (27 MPa) or as specified by the Engineer. In areas that may be subjected to high load transfer, the Engineer may require the cast-in-place concrete to be doweled into the RCC.

4.6. Weather Conditions

(a) **Cold Weather Precautions**: RCC material shall not be placed on any surface containing frost or frozen material or when the air temperature is below 40°F (4°C). When the air temperature is expected to fall below 40°F (4°C), the Contractor must present to the Engineer a detailed proposal for protecting the RCC pavement. This proposal must be accepted by the Engineer before paving operations may be resumed. A sufficient supply of protective material such as insulating blankets, plastic sheeting, straw, burlap or other suitable material shall be provided by the Contractor at his expense. The methods and materials used shall be such that a minimum temperature of 40°F (4°C) at the pavement surface will be maintained for a minimum of five days. Approval of the Contractor‘s proposal for frost protection shall not relieve the Contractor of the responsibility for the quality and strength of the RCC placed during cold weather. Any RCC that freezes shall be removed and replaced at the Contractors expense.

(b) **Hot Weather Precautions**: During periods of hot weather or windy conditions, special precautions shall be taken to minimize moisture loss due to evaporation. Under conditions of excessive surface evaporation due to a combination of air temperature, relative humidity, concrete temperature and wind conditions, the Contractor must present to the Engineer a detailed proposal for minimizing moisture loss and protecting the RCC. Precautions may include cooling of aggregate stockpiles by use of a water spray, protective covers on dump trucks, temporary wind breaks to reduce wind effect, cooling of concrete mix water, and decreasing the allowable time between mixing and final compaction.

(c) **Rain Limitations**: No placement of RCC pavement shall be done while it is raining hard enough to be detrimental to the finished product. Placement may continue at the approval of the Engineer during light rain or mists that does not wash-out or damage RCC. Dump truck covers must be used during these periods. The Engineer will be the sole judge as to when placement must be stopped due to rain.

4.7. **Compaction**

(a) **Compaction** shall begin immediately behind the placement process and shall be completed within 60 minutes of the start of plant mixing. The time may be increased or decreased at the discretion of the Engineer depending on use of admixtures or ambient weather conditions of temperature, wind and humidity. Sufficient number of rollers shall be supplied to satisfy this criteria.

(b) **Rolling**: The Contractor shall determine the sequence and number of passes by vibratory and non-vibratory rolling to obtain the minimum specified density, compressive strength, and surface finish without excessive segregation to the satisfaction of the engineer at the initial placement of RCC on the project and whenever a new mix design is used.

(c) **Rollers** shall only be operated in the vibratory mode while moving/ compacting; operation of rollers in the vibratory mode while stopped or reversing direction is not allowed.

(d) **Pneumatic-tire rollers** may be used during compaction to knead and seal the surface.

(e) **Final compaction** shall remove all roller marks; a smooth steel drum roller in static mode shall be used.

(f) **Speed of the rollers s**hall be slow enough at all times to avoid displacement of the RCC pavement. Displacement of the surface resulting from reversing or turning action of the roller shall be corrected immediately.

(g) **Rolling Longitudinal and Transverse Joints**: The roller shall not operate within 12 in. (300 mm) of the edge of a freshly placed lane until the adjacent lane is placed. Then both edges of the two lanes shall be rolled together within the allowable time. If a cold joint is planned, the complete lane shall be rolled and cold joint procedures, as specified in subsection 4.8(b) shall be followed.

(h) **Longitudinal joints** shall be given additional rolling with a vibratory roller as necessary to produce the specified density for the full depth of the lift and a tight smooth transition across the joint. Any uneven marks left during the vibrating rolling shall be smoothed out by non-vibrating steel wheel roller. The surface shall be rolled until a relatively smooth, flat surface, reasonably free of tearing and cracking is obtained.

(i) **Areas inaccessible** to large roller shall be compacted with walk-behind vibratory rollers or plate tampers (as specified in Section 3.3(b) and 4.5(j)).

4.8. **Joints**

Joints shall be constructed such as to assure continuous bond between new and previously placed RCC. Fresh joints do not require any special treatment but cold joints would need careful preparation.

(a) **Fresh Joints:** A joint shall be considered a fresh joint when an adjacent RCC is placed within 60 minutes of placing the previous, with the time adjusted depending on use of retarders or ambient conditions.

i. **Vertical** joints are between two vertical faces such as adjacent lanes

ii. **Horizontal** joints are considered for multi-layer construction when a subsequent RCC lift is placed over the previous lift. The surface shall be cleaned of all loose material and moisten prior to placement of the subsequent lift.

(b) **Cold Joints**: Any planned or unplanned construction joints that do not qualify as fresh joints shall be considered cold joints. In joining fresh concrete to set concrete, the work already in place shall have its surface roughened and thoroughly cleaned of any loose or foreign material in horizontal and vertical faces. Both the horizontal and vertical surfaces shall be washed and scrubbed with wire brooms when necessary to remove substances that will interfere with bonding. Concrete of the preceding placement shall be thoroughly wetted prior to placement of the next unit of fresh concrete.

i. **Longitudinal and Transverse Cold Joints**: Formed joints that do not meet the minimum density requirements of Section 8.3 and all unformed joints shall be cut vertically for the full depth. The vertical cut shall be at least 6 in (150 mm) from the exposed edge. Cold joints cut within two hours of placement may be cut with an approved wheel cutter, motor grader or other approved method provided that no significant edge raveling occurs. Cold joints cut after two hours of placement shall be saw cut 1/4 to 1/3 depth of the RCC pavement with the rest removed by hand or mechanical equipment. Any modification or substitution of the saw cutting procedure must be demonstrated to and accepted by the Engineer. All excess material from the joint cutting shall be removed.

ii. **Note**: Vertical joints that are constructed utilizing a drop extension or edging shoe are exempt from the above requirement when placed up to 15 degrees from vertical.

(c) **RCC Pavement Joints at Structures**: The joints between RCC pavement and concrete structures shall be treated as cold vertical joints.

(d) **Control Joints (Optional)**: Control joints may be constructed in the RCC pavement to induce cracking at pre-selected locations. Joint locations shall be shown on the Plans or as directed by the Engineer. Early entry saws should be utilized as soon as possible behind the rolling operation and set to manufacturer's recommendations. Conventionally cut control joint width shall be 1/8 inch (3 mm) and saw cut to 1/4 depth of the compacted RCC pavement. Joints shall be saw cut as soon as those operations will not result in significant raveling or other damage to the RCC pavement. Joints shall be formed at 25 and 20 ft apart for thicknesses of 8 and 6 inches, respectively.

4.9. **Finishing**

(a) **Surface Smoothness**: The finished surface of the RCC pavement, when tested with a 10 foot (3 meter) straight edge or crown surface template, shall not vary from the straight edge or template by more than 1/4 inch (6 mm) at any one point and shall be within 5/8 inch of the specified finished grade. When the surface smoothness is outside the specified surface tolerance the Contractor shall grind the surface to within the tolerance by use of self-propelled diamond grinders. Milling of the final surface is not acceptable, unless it is for the removal of the pavement.

(b) **Thickness**: The thickness of the RCC pavement shall not deviate from that shown on the plans or as directed by the Engineer by more than minus 1/2 inch (12.5 mm). Pavement of insufficient thickness shall be removed and replaced the full depth with conventional concrete (either high early strength or regular strength depending on the job requirements) at no cost to the Department. Skin patches shall not be accepted.

(c) When surface irregularities are outside the tolerances cited above, the contractor shall grind the surface to meet the tolerance at no additional cost to the Owner.

4.10. **Curing**

Immediately after final rolling and compaction testing, a curing method as mentioned below shall be applied to the surface of the RCC pavement. The Engineer will make the final decision on the selection of the curing method.

(a) **Water Cure**: Water cure shall be applied by water trucks equipped with misting spray nozzles, soaking hoses, sprinkler system or other means that will assure a uniform moist condition to the RCC. Application of this moisture must be done in a manner that will not wash out or damage the surface of the finished RCC pavement.
(b) **Curing Compound**: The specified membrane curing compound shall be applied in accordance with VDOT specifications (VDOT Spec. section 316.04(j)). This application must ensure a uniform void-free membrane across the entire RCC pavement. If the application rate is found to be excessive or insufficient, the Contractor, with approval of the Engineer, can decrease or increase the application rate to a level which achieves a void-free surface without ponding.
(c) **Sheet Materials**: Curing paper, plastic and other sheet materials for curing RCC shall conform to ASTM C 171. The coverings shall be held securely in place and weighted to maintain a close contact with the RCC surface throughout the entire curing period. The edges of adjoining sheets shall be overlapped and held in place with sand bags, planking, pressure adhesive tape, or other Engineer-approved method.
(d) **Tack Coat**: If RCC is planned to be overlaid with asphalt, a tack coat shall be sprayed before the asphalt overlay in accordance with VDOT special provision for nontracking tack coat dated October 5, 2010c or a later version.

5. **Joint Sealing**

All joints shall be cleaned and sealed with hot poured elastic joint sealer in accordance to applicable sections of VDOT Standard Specifications if required by the Plans or directed by the Engineer.

6. **Opening to Traffic**

The Contractor shall protect the RCC from vehicular traffic during the curing period. Completed portions of the RCC pavement may be opened to traffic after 12 hours of curing if a compressive strength of at least 2000 psi (14 MPa) is achieved. Strength can be determined by the maturity method or core strengths or control cylinders.

If required by the Plans or directed by the Engineer, joints shall be sealed before permitting vehicles or equipment on the pavement.

7. Maintenance

The Contractor shall maintain the RCC pavement in good condition until all work is completed and accepted. Such maintenance shall be performed by the Contractor at his own expense.

8. Quality Control and Quality Assurance Requirements

8.1. Approval of Mix Design Proportions

The Department will review concrete mix designs and will verify compressive strength development.

(a) **Materials and Proportions**: The Department will approve material combinations and mix designs using approved materials and complying with gradation requirements in Section 2, “Materials”.

(b) **Compressive Strength**: The mix design shall demonstrate a compressive strength of 4000 psi (28 MPa) at 28 days. Six cylinders according to ASTM C 1435 shall be prepared and tested according to AASHTO T 22 to determine the 3 and 28 day compressive strength for RCC.

8.2. Moisture Control

At the Engineer’s discretion, moisture content tests shall be run (either microwave or field stove) on the material in the truck before it is placed in the paver, and require that the moisture content be +/- 1% from optimum. If the material is mixed on-site, then the moisture content shall be checked coming off the belt at the pugmill. Suggested frequency of testing is the first 2 loads of the day and then whenever a weather change occurs or the consistency of the mixture changes.

8.3. Compressive Strength of Field Samples

For each day’s production, up to 1000 cubic yards of mix produced, Department will prepare two sets of 3 test specimens in accordance with ASTM C 1435. A set of specimens consists of three cylinders. Two cylinders from each set will be tested for compressive strength in accordance with ASTM C 39 at 3 and 28 days. If the measured compressive strength between two cylinders varies by more than 10 percent of the stronger cylinder, the third cylinder will be tested and the average of the three cylinders will be taken. Otherwise, average compressive strengths of the two cylinders tested at 28 days will be considered as the compressive strength of the lot.

(a) If the compressive strength measured at 3 days indicates that the 28-day compressive strength will be less than 3500 psi based on trial section results, production shall be stopped immediately. The potential causes of the low strengths shall be investigate and rectified to the satisfaction of the Engineer within 24 hours.

(b) The compressive strength target at 3 days may be adjusted by the engineer as production continues based on field experience.

(c) Lot not meeting the 28 days compressive strength requirement of minimum 3500 psi shall be subjected to penalty (1 percent reduction for each 100 psi up to 3,000 psi). Engineer may decide to core and test according to subsection 8.5 for leaving the section in place.

8.4. **Density Requirements**

In-place field density tests shall be performed at five randomly selected locations for every 500 ft-lane in accordance with VTM 10, direct transmission, as soon as possible, but no later than 30 minutes after completion of rolling. Only wet density shall be used for evaluation. The required density shall be not less than 98% of the maximum wet density obtained by AASHTO T 180 or equivalent test method based on a moving average of five consecutive tests with no test below 96%. The contractor shall not proceed unless density meets the requirements.

8.5. **Core Strength Acceptance**

Engineer may decide to keep the RCC pavement, not meeting compressive strength or density requirements outlined in subsection 8.3 and 8.4, based on core strengths which must exceed the 3,500 psi at 28 days. The Engineer may require a reduction in payment if removal and replacement is not required.

(a) Cores will be taken and tested by the Department but core holes will be filled by the Contractor.
(b) If tested area achieves the 28 day design compressive strength of 3500 psi from testing the cores, it will be paid for at full price.
(c) Areas that fail the strength test will be removed and replaced at no additional cost to the Department. Engineer may decide to keep the concrete at a reduced price (1 percent reduction for each 100 psi reduction of 28-day core strength up to 3,000 psi).

8.6. **Thickness**

Department shall take cores for thickness verification but the Contractor shall fill the core holes.

(a) The Engineer will designate pavement areas to be examined for depth measurement compliance with the Plan and Specifications. The thickness of the completed RCC is measured at staggered intervals not to exceed 500 feet in length for two-lane roads. Thickness of the core shall be measured to the nearest 1/8 inch at three different, evenly spaced locations and averaged.
(b) A small (approximately 1 inch diameter or greater) core shall be extracted to determine the pavement thickness.
(c) The Engineer will evaluate areas deficient by more than 1/2 in (13 mm) thick. If the Engineer requires removal, the pavement shall be removed and replaced in full cross sections according to Plan requirements at no additional cost to the department. The Engineer may require a reduction in payment if removal and replacement is not required.
(d) Core holes shall be repaired using a packaged quick set repair mortar such as SikaQuick 1000 or approved equivalent or a Class 4000 or better ready mix concrete. Repair materials shall be rodded and neatly striked off.

9. Measurement and Payment

9.1. Measurement

The work described in this document will be measured in square yards of completed and accepted RCC pavement of the specified thicknesses as determined by the specified lines, grades and cross sections shown on the Plans.

9.2. Payment

(a) **Paving**: The work described in this document will be paid for at the contract unit price per square yard, rounded to the nearest tenth of a square yard, of completed and accepted RCC pavement. There shall be separate pay items for each specified thickness. The price shall include mixing, hauling, placement, compaction, curing, inspection and testing assistance, and all other materials and incidental operations expenses. Any cores taken shall be filled by the Contractor and this expense shall be included in the unit price of concrete. Payment will not be made for wasted concrete, for concrete used for the convenience of the Contractor, or for concrete outside the neat lines shown on the drawing. Concrete will be measured in the completed and accepted pavements in accordance with the dimensions shown in the plan and cross section. Any areas of pavement with excess thickness will be counted as having the thickness shown on the plans.

(b) **Test Section**: If an acceptable test section is constructed, it will be paid for on a lump sum basis. Such payment shall constitute full reimbursement for all materials, labor, equipment, mobilization, demobilization, and all other incidentals necessary to construct the Test Section in accordance with Section 4.2.

APPENDIX B

VDOT Special Provision for Roller Compacted Concrete (RCC) Pavement
Updated on 09/09/2014

ROUGH DRAFT
VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
ROLLER COMPACTED CONCRETE (RCC) PAVEMENT

~~10/15/2012~~*11/30/2014*

10. **General Provisions**

10.1. **Description**

This work shall consist of constructing Roller Compacted Concrete (RCC) pavement on a prepared subgrade or subbase course in accordance with the requirements of these specifications and within the specified tolerances for lines, grades, thickness, and cross sections shown on the plans or as established by the Engineer.

10.2. **Related Standards**

AASHTO T 180	Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
AASHTO T 22	Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 31	Practice for Making and Curing Concrete Test Specimens in the Field
ASTM C 39	Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 42	Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C 171	Specification for Sheet Materials for Curing Concrete
ASTM C 496	Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C 1435	Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer

10.3. **Submittals**

The Contractor shall submit the following to the Engineer at least 35 days before start of any production of RCC pavement:

(c) **Proposed RCC Mix Design**: Contractor shall submit the proposed mix design from a qualified laboratory or any suggested change to the approved mix design to the Engineer for approval. This mix design shall include details on aggregate gradation, cementitious materials, admixtures (if used), compressive strengths, required moisture and density to be achieved. This shall also include the quantities of individual materials per cubic yard for the mix design.

(d) **Paving Schedule**: Contractor shall submit a construction schedule for all RCC related operations describing direction of paving operations, paving widths, planned longitudinal and transverse cold joints, curing methods and patterns and description of all equipment including layout of plant location showing mixing plant, cement and aggregate storage, and water supply. *Contractor shall also elaborate on his plan for meeting the 60 minutes requirement of maximum elapsed time between mixing and compaction considering pugmill production capacity, hauling time, number of trucks, paver speed and staging plan.*

11. **Materials**

All materials to be used for RCC pavement construction shall meet the requirements of the following specifications:

Materials	**VDOT Specification**
Coarse Aggregate	203
Fine Aggregate	202
Hydraulic Cement, Type 1	214
Portland Pozzolan cement	215
Hydraulic Cement Concrete Admixtures	215
Fly Ash and Slag	241 and ~~214~~*215*
Concrete Curing Materials	220
Joint Fillers and Sealers	212
Water	216
~~Curing Compound~~	~~220~~

Unless otherwise specified, quality of aggregate shall conform to ASTM C 33. The aggregate shall be well-graded. Aggregates may be obtained from a single source or may be a blend of coarse and fine aggregate to conform to the following gradation:

Sieve Size	**% Passing by weight**
1 in (25 mm)	100
3/4 in (19 mm)	95-100
1/2 in (12.5 mm)	70-100
3/8 in (9.5 mm)	65-85
No. 4 (4.75 mm)	50-70
No. 16 (1.18 mm)	25-45
No. 100 (150 µm)	5-20
No. 200 (75 µm)	0-8

Contractor must produce evidence that the selected proportions have the potential for strength development at 28 days as required in subsection "Approval of Mix Design Proportions".

12. **Equipment**

RCC pavement shall be constructed with such equipment and tools that will produce a complete pavement meeting the requirements for mixing, transporting, placing, compacting, finishing, and curing as provided in this specification. Equipment and tools necessary for handling materials and performing the work shall be subject to the approval of the Engineer.

12.1. **Mixing Plant**

12.1.1. **Pugmill**

RCC shall be mixed in a ***Pugmill Plant*** located within 30 minutes of hauling distance from the RCC placement site *during construction*. With the approval of the Engineer and prior demonstration, a set retarding admixture may be used to extend the haul distance. The plant shall be capable of producing a mixture in the proportions defined by the approved mix design and within the specified tolerances. The capacity of the plant shall be sufficient to produce a uniform mixture at a rate compatible with the placement equipment. If the plant is unable to produce material at a rate adequate to prevent unnecessary cold joints and frequent paver stoppages, production may be halted until such time that a plant (or multiple plants) of appropriate capacity is used. Following are the requirements of the pugmill plant:

(h) **Pugmill** shall be a central plant with a twin shaft pugmill mixer, capable of batch or continuous mixing, equipped with synchronized metering devices and feeders to maintain the correct proportions of aggregate, cement, mineral admixture and water. Capacity of the plant shall be more than 200 tons per hour.

(i) **Aggregate Storage** may be in a stockpile from which it is fed directly to a conveyor feeding mixer, if previously blended aggregate is furnished. If aggregate is furnished in two or more size/ type groups, separate stockpiles must be used/ provided for each. Aggregate shall be stockpiled on a concrete platform or in a manner that will avoid contamination.

(j) **Aggregate Bins** shall have a capability of controlling feed rate by a variable speed belt or an operable gate calibrated to accurately deliver any specified quantity of material. If two or more aggregate size/ type are used, the feed rate from each bin shall be readily adjustable to change aggregate proportions, when required. Feed rate controls must maintain the established proportions of aggregate from each stockpile bin when the combined aggregate delivery is increased or decreased.

(k) **Plant Scales** for any weigh box or hopper will be either of beam or spring-less-dial type, and be sensitive to 0.5 percent of the maximum load required. Beam-type scales shall have a separate beam for each aggregate size, with a single telltale actuated for each beam, and a tare beam for balancing hopper. Belt scales shall be of an approved design. Standard test weights accurate to plus or minus 0.1 percent shall be provided for checking plant scales.

(l) **Cement, Fly Ash or Slag Storage** shall be in separate and independent storage silos. Each silo must be clearly identified for Portland cement or mineral admixture to avoid confusion during silo loadings. If the Contractor chooses to use pre-blended cementitious material, he must employ blending equipment acceptable to the Engineer and demonstrate, with a testing plan, the ability to successfully produce a uniform blended material meeting the mix design requirements. Testing of the pre-blended cementitious material shall be done on a daily basis to assure both uniformity and proper quantities.

(m) **Cement, Fly Ash or Slag Feed Unit** shall be capable of satisfactorily dispensing Portland cement and mineral admixture, volumetrically or by weight, to assure a uniform and accurate quantity of cementitious material entering in the mixer.

(n) **Water Control Unit** shall be equipped with an accurate metering device to measure, by weight or volume, required amount of water for the approved mix. The water flow shall be controlled by a meter, valve or other approved regulating device to maintain optimum moisture content (determined during mix design *and verified through trial batches*) at all time in the RCC mixture.

12.1.2. **Other mixing equipment**

Other mixing equipment shall be permissible if approved by the engineer. RCC shall be mixed ~~within 30 minutes of hauling distance from~~ *in such a facility that it shall be delivered to* the RCC placement site *within 30 minutes of mixing*. The mixing plant shall be of a design that can produce a consistent RCC mixture at the proportions defined in the approved mix design. The mixing plant may be a Central-Mix Drum or Horizontal Mixer, or a batch or continuous twin shaft Pugmill Mixer. Portable mixers that can be utilized with a dry batch plant to produce RCC can be considered. Truck mixers will not be acceptable. The mixing plant shall have a minimum manufacture's rated capacity of 200 tons per hour.

12.2. **Paver**

RCC shall be placed with a high-density ~~or conventional~~ asphalt type paver *with vibratory screeds* subject to approval by the Engineer. The paver shall be capable of placing RCC to a minimum of 90% of the maximum wet density in accordance with AASHTO T 180, Method D or equivalent test method. The paver shall be of suitable weight and stability to spread and finish the RCC material, without segregation, to the required thickness, smoothness, surface texture, cross-section and grade.

12.3. **Compactors**

(c) A self-propelled smooth steel drum vibratory rollers having minimum weight of 10 tons (9.07 Mg) shall be used for primary compaction. For final compaction or for removing roller marks, a steel drum roller operating in static mode shall be utilized.

(d) Walk-behind vibratory rollers or plate tampers may be used for compacting areas inaccessible to large rollers.

12.4. **Haul Trucks**

Sufficient number of trucks shall be provided to ensure adequate and continuous supply of RCC mixture to the paver at the site. Trucks used for hauling RCC mixtures shall have tight, clean and smooth beds. *Trucks should have lips in the back (similar to asphalt haul trucks) or a material transfer vehicle (MTV) to prevent spillage of material during transfer into the paver.* Trucks hauling RCC mixtures from the plant to the paver shall be equipped with a waterproof cover large enough to extend over the sides and ends of the bed. These waterproof covers shall be securely fastened before the vehicle begins moving to protect the mixture from inclement weather such as rain or excessive evaporation losses.

12.5. **Water Trucks**

At least one water truck or other similar equipment shall be on-site and available for use throughout the paving and curing process. The water truck shall be equipped with a spreader pipe containing fog nozzles capable of evenly applying a fine mist of water to the surface of the RCC without damaging the final surface.

12.6. **Inspection and Calibration of Equipment**

Before start-up, the Contractor's equipment shall be carefully inspected. Should any of the equipment fail to operate properly, no work shall proceed until the deficiencies are corrected. The Engineer shall have access at all times to any plant, equipment or machinery to be used on this project in order to check calibration, scales, controls or operating adjustments.

13. **Construction Requirements**

13.1. **Preparation of Subgrade/ Subbase**

Subgrade/subbase shall be prepared as required by the Plans and Specifications before placing the RCC. Such preparation shall ensure the foundation immediately under the RCC pavement and the areas supporting the paving equipment will not contribute to deficient pavement thickness or excessive yield losses.

The subgrade shall be uniformly compacted to a minimum of 95% of the maximum dry density in accordance with AASHTO T 180. The Contractor shall check for any soft or yielding subgrade areas by proof rolling with a loaded dump truck or pneumatic-tire roller over the entire area to be paved. All soft or yielding subgrade areas shall be corrected and made stable before RCC construction begins. If a subbase is shown on the Plans, it shall also be uniformly compacted to a minimum of 95% of the maximum dry density in accordance with AASHTO T 180.

In the mill and fill construction, the base or subbase should be stable with proper drainage prior to the placement of RCC. If necessary, proper stabilization should be applied as approved by the Engineer.

13.2. **Test/ Trial Section**

Contractor shall demonstrate an acceptable RCC production and placement on a trial section. RCC placement at the site will not commence until the following criteria are satisfied. The site will be selected by the Engineer.

(f) At least 30 days before the start of paving operations, the Contractor shall construct a test section using the trial mix design. This test pavement will allow the Engineer to evaluate the strength of the RCC material, methods of construction *including compaction*, curing process and surface conditions of the completed test pavement. The test section shall be at least 50 feet (15 meters) long and a minimum of two paver widths wide. It shall be located in a non-critical area or as indicated on the Plans. The test ~~pavement~~ *section* will be constructed over an extended period to demonstrate the construction of cold joints in both a longitudinal and transverse direction, as well as fresh joint construction.

(g) The equipment, materials and techniques used to construct the test section shall be that which will be used to construct the main RCC pavement.

(h) Contractor shall demonstrate the capability of the paver in placing RCC to a minimum of 90% of the maximum wet density in accordance with AASHTO T 180, Method D or equivalent test method during this trial construction.

(i) During construction of the test section the Contractor will establish an optimum rolling pattern and procedure for obtaining a density of not less than 98% of the maximum wet density in accordance with AASHTO T 180 or equivalent test method. In addition, the Contractor must also demonstrate the ability to achieve a smooth, hard, uniform surface free of excessive tears, ridges, spalls, segregation, and loose material. *The contractor shall avoid excessive roller passes that causes separation of top layers.*

(j) Strength Testing

Field Cast Specimens: Specimens shall be prepared in accordance with AASHTO T 180 and ASTM C 1435, transported to the laboratory and cured in accordance with ASTM C 31, and tested for splitting tensile strength (ASTM C 496) and compressive strength (ASTM C 39) at 1, 3, 7, and 28 days of age.

Cores: The test section shall be cured at least 5 days prior to extracting cores for testing. The cores shall be obtained in accordance with ASTM C 42. The cores will be tested for splitting tensile strength (ASTM C 496) and compressive strength (ASTM C 39) at 7, and 28 days of age. All coring~~, and~~ *shall be contractor's responsibility, but* testing of the ~~test section~~ *cores* shall be conducted by the Department.

13.3. **Mixing Process**

(h) Same mix design and materials shall be used for the entire project. If the source of cement, fly ash, slag, or aggregates is changed, construction should be suspended and a new mix design should be submitted to the Engineer for approval.

(i) Except for minor variations in moisture content, the same mixture proportions shall be used for the entire project, unless otherwise stated in the project documents.

(j) **Mixture Ingredient Tolerances**: The mixing plant must receive the quantities of individual ingredients to within the following tolerances:

Materials	Variation in Percentages by Weight
Cementitious Materials	± 2
Water	± ~~3~~*1*
Aggregate	± ~~4~~*2*

(k) **Mixing time** shall be such as to ensure complete and uniform mixing of all ingredients.

(l) All material shall be discharged before recharging. The mixing chamber and mixer blade surfaces shall be kept free of hardened RCC or other buildups. Mixer blades shall be checked routinely for wear and replaced if wear is sufficient to cause inadequate mixing. In continuous operations this is not applicable.

(m) Prior to commencement of RCC production, the Contractor shall carry out a complete and comprehensive calibration of the plant in accordance with the manufacturer's recommended practice. All scales, containers and other items necessary to complete the calibration shall be provided by the Contractor. After completion of the initial calibration, the plant shall be recalibrated as directed by the Engineer.

(n) The Contractor shall supply daily plant records of production and quantities of materials used each day to the Engineer. These records may be used as a check on plant calibration.

13.4. **Transportation**

The transportation of the RCC pavement material from the plant to the areas to be paved shall be in dump trucks fitted and equipped, when necessary, with retractable protective covers for protection from rain or excessive evaporation. The trucks shall be dumped clean with no buildup or hanging of RCC material. For paver placed RCC, the dump trucks shall deposit the RCC material directly into ~~the hopper of the paver or into a secondary~~ *an auxiliary* material distribution system *(such as MTV)* which deposits the material into the paver hopper *or if approved by the Engineer into the hopper of the paver*. Dump truck delivery must be scheduled so that RCC material is spread and compacted within the specified time limits *not exceeding 60 minutes from the addition of mix water*.

13.5. **Placement of RCC**

(j) **Condition of the Subgrade/Subbase:** Prior to RCC placement, the surface of the subgrade/subbase shall be clean and free of foreign material, ponded water and frost prior to the placement of the RCC pavement mixture. The subgrade/subbase must be uniformly moist at the time of RCC placement. If sprinkling of water is required to remoisten certain areas, the method of sprinkling shall not be such that it forms mud or pools of free-standing water. Prior to placement of RCC, the subgrade/subbase shall be checked for proper density and soft or yielding areas and these areas shall be corrected as specified in Section 4.1.

(k) **Paver Requirements**: RCC shall be placed with an approved paver as specified in Section 3.2 and shall meet the following requirements:

i. The quantity of RCC material in the paver shall not be allowed to approach empty between loads. The material shall be maintained above the auger shaft at all times during paving.

ii. The paver shall operate in a manner that will prevent segregation and produce a smooth continuous surface without tearing, pulling or shoving. The spread of the RCC shall be limited to a length that can be compacted and finished within the appropriate time limit under the prevailing air temperature, wind, and climatic conditions.

iii. The paver shall proceed in a steady, continuous operation with minimal starts and stops *not exceeding 3 minutes*. Paver speed during placement operations shall not exceed the speed necessary to ensure that minimum density requirements as specified in Section 3.2 are met and surface distress is minimized.

iv. The surface of the RCC pavement once it leaves the paver shall be smooth, uniform and continuous without excessive tears, ridges or aggregate segregation.

(l) **Thickness**: Thickness of compacted RCC pavement shall be as indicated on the Plans. If RCC pavements are to be constructed in a thickness greater than ~~10~~*8* inches (~~250~~*200* mm), the use of two lifts shall be utilized. No lift shall be less than 4 inches (100 mm).

(m) **Adjacent Lane Placement**: Adjacent paving lanes shall be placed within 60 minutes to avoid cold joints; 60 minutes may be increased or decreased depending on the use of admixtures or the ambient weather conditions of temperature, wind, and humidity. If cold joints are expected, they shall be handled in accordance with subsection 4.8(b).

(n) **Multiple Lift Placements**: For multiple lift placements, the total pavement thickness shall be as shown on the Plans, and the Contractor shall submit his method of placement and lift thickness as part of a paving plan subject to approval by the Engineer. In multiple lift construction, the second lift must be placed within 60 minutes of the completion of the first lift to avoid cold joints; 60 minutes may be increased or decreased depending on the use of admixtures or the ambient weather conditions of temperature, wind and humidity. The use of multiple pavers in tandem formation is advantageous to reduce the opportunity for cold joints to develop. If cold joints are expected, they shall be handled in accordance with subsection 4.8(b).

(o) **Hand Spreading**: Broadcasting or fanning the RCC material across areas being compacted will not be permitted. Such additions of material may only be done immediately behind the paver and before any compaction has taken place. Any segregated coarse aggregate shall be removed from the surface before rolling.

(p) **Segregation**: If severe segregation occurs in the RCC during paving operations the spreading shall be ceased until the cause is determined and corrected to the satisfaction of the Engineer; removed and replaced at no additional cost to the Department. Severe segregation is defined as a mixture or surface area which lacks homogeneity and cohesiveness where visible separation of ingredients is evident.

(q) **RCC placeme**nt shall be done in a pattern so that the curing water from the previous placements will not pose a runoff problem on the fresh RCC surface or on the subbase layer.

(r) **Paving Inaccessible Areas**: Areas inaccessible to either paver or roller may be placed by hand and compacted with walk-behind vibratory rollers or plate tampers (equipment specified in Section 3.3(b). Compaction of these areas must satisfy minimum density requirements as specified in Section 8.3. An alternate and preferred method for paving inaccessible areas is to use cast-in-place, air-entrained concrete with a minimum compressive strength of 4000 psi (27 MPa) or as specified by the Engineer. In areas that may be subjected to high load transfer, the Engineer may require the cast-in-place concrete to be doweled into the RCC.

13.6. **Weather Conditions**

(d) **Cold Weather Precautions**: RCC material shall not be placed on any surface containing frost or frozen material or when the air temperature is below 40°F (4°C). When the air temperature is expected to fall below 40°F (4°C), the Contractor must present to the Engineer a detailed proposal for protecting the RCC pavement. This proposal must be accepted by the Engineer before paving operations may be resumed. A sufficient supply of protective material such as insulating blankets, plastic sheeting, straw, burlap or other suitable material shall be provided by the Contractor at his expense. The methods and materials used shall be such that a minimum temperature of 40°F (4°C) at the pavement surface will be maintained for a minimum of five days. Approval of the Contractor‘s proposal for frost protection shall not relieve the Contractor of the responsibility for the quality and strength of the RCC placed during cold weather. Any RCC that freezes shall be removed and replaced at the Contractors expense.

(e) **Hot Weather Precautions**: During periods of hot weather or windy conditions, special precautions shall be taken to minimize moisture loss due to evaporation. Under conditions of excessive surface evaporation due to a combination of air temperature, relative humidity, concrete temperature and wind conditions, the Contractor must present to the Engineer a detailed proposal for minimizing moisture loss and protecting the RCC. Precautions may include cooling of aggregate stockpiles by use of a water spray, protective covers on dump trucks, temporary wind breaks to reduce wind effect, cooling of concrete mix water, and decreasing the allowable time between mixing and final compaction.

(f) **Rain Limitations**: No placement of RCC pavement shall be done while it is raining hard enough to be detrimental to the finished product. Placement may continue at the approval of the Engineer during light rain or mists that does not wash-out or damage RCC. Dump truck covers must be used during these periods. The Engineer will be the sole judge as to when placement must be stopped due to rain.

13.7. **Compaction**

(j) **Compaction** shall begin immediately behind the placement process and shall be completed within 60 minutes of the start of plant mixing. The time may be increased or decreased at the discretion of the Engineer depending on use of admixtures or ambient weather conditions of temperature, wind and humidity. Sufficient number of rollers shall be supplied to satisfy these criteria.

(k) **Rolling**: The Contractor shall determine the sequence and number of passes by vibratory and non-vibratory rolling to obtain the minimum specified density, compressive strength, and surface finish without excessive segregation to the satisfaction of the engineer at the initial placement of RCC on the project and whenever a new mix design is used.

(l) **Rollers** shall only be operated in the vibratory mode while moving/ compacting; operation of rollers in the vibratory mode while stopped or reversing direction is not allowed.

(m) **Pneumatic-tire rollers** may be used during compaction to knead and seal the surface.

(n) **Final compaction** shall remove all roller marks; a smooth steel drum roller in static mode shall be used.

(o) **Speed of the rollers s**hall be slow enough at all times to avoid displacement of the RCC pavement. Displacement of the surface resulting from reversing or turning action of the roller shall be corrected immediately.

(p) **Rolling Longitudinal and Transverse Joints**: The roller shall not operate within 12 in. (300 mm) of the edge of a freshly placed lane until the adjacent lane is placed. Then both edges of the two lanes shall be rolled together within the allowable time. If a cold joint is planned, the complete lane shall be rolled and cold joint procedures, as specified in subsection 4.8(b) shall be followed.

(q) **Longitudinal joints** shall be given additional rolling with a vibratory roller as necessary to produce the specified density for the full depth of the lift and a tight smooth transition across the joint. Any uneven marks left during the vibrating rolling shall be smoothed out by non-vibrating steel wheel roller. The surface shall be rolled until a relatively smooth, flat surface, reasonably free of tearing and cracking is obtained.

(r) **Areas inaccessible** to large roller shall be compacted with walk-behind vibratory rollers or plate tampers (as specified in Section 3.3(b) and 4.5(j)).

13.8. **Joints**

Joints shall be constructed such as to assure continuous bond between new and previously placed RCC. Fresh joints do not require any special treatment but cold joints would need careful preparation.

(e) **Fresh Joints:** A joint shall be considered a fresh joint when an adjacent RCC is placed within 60 minutes of placing the previous, with the time adjusted depending on use of retarders or ambient conditions.

i. **Vertical** joints are between two vertical faces such as adjacent lanes

ii. **Horizontal** joints are considered for multi-layer construction when a subsequent RCC lift is placed over the previous lift. The surface shall be cleaned of all loose material and moisten prior to placement of the subsequent lift.

(f) **Cold Joints**: Any planned or unplanned construction joints that do not qualify as fresh joints shall be considered cold joints. In joining fresh concrete to set concrete, the work already in place shall have its surface roughened and thoroughly cleaned of any loose or foreign material in horizontal and vertical faces. Both the horizontal and vertical surfaces shall be washed and scrubbed with wire brooms when necessary to remove substances that will interfere with bonding. Concrete of the preceding placement shall be thoroughly wetted prior to placement of the next unit of fresh concrete.

i. **Longitudinal and Transverse Cold Joints**: Formed joints that do not meet the minimum density requirements of Section 8.3 and all unformed joints shall be cut vertically for the full depth. The vertical cut shall be at least 6 in (150 mm) from the exposed edge. Cold joints cut within two hours of placement may be cut with an approved wheel cutter, motor grader or other approved method provided that no significant edge raveling occurs. Cold joints cut after two hours of placement shall be saw cut 1/4 to 1/3 depth of the RCC pavement with the rest removed by hand or mechanical equipment. Any modification or substitution of the saw cutting procedure must be demonstrated to and accepted by the Engineer. All excess material from the joint cutting shall be removed.

ii. **Note**: Vertical joints that are constructed utilizing a drop extension or edging shoe are exempt from the above requirement when placed up to 15 degrees from vertical.

(g) **RCC Pavement Joints at Structures**: The joints between RCC pavement and concrete structures shall be treated as cold vertical joints.

(h) **Control Joints~~(Optional)~~**: Control joints ~~may~~ *shall* be constructed in the RCC pavement to induce cracking at pre-selected locations. Joint locations shall be shown on the Plans or as directed by the Engineer. Early entry saws should be utilized as soon as possible behind the rolling operation and set to manufacturer's recommendations. Conventionally cut control joint width shall be 1/8 inch (3 mm) and saw cut to 1/4 depth of the compacted RCC pavement. Joints shall be saw cut as soon as those operations will not result in significant raveling or other damage to the RCC pavement. Joints shall be formed at ~~25 and 20~~*15* ft apart.

13.9. **Finishing**

(d) **Surface Smoothness**: The finished surface of the RCC pavement, when tested with a 10 foot (3 meter) straight edge or crown surface template, shall not vary from the straight edge or template by more than 1/4 inch (6 mm) at any one point and shall be within 5/8 inch of the specified finished grade. When the surface smoothness is outside the specified surface tolerance the Contractor shall grind the surface to within the tolerance by use of self-propelled diamond grinders. Milling of the final surface is not acceptable, unless it is for the removal of the pavement.

(e) **Thickness**: The thickness of the RCC pavement shall not deviate from that shown on the plans or as directed by the Engineer by more than minus 1/2 inch (12.5 mm). Pavement of insufficient thickness shall be removed and replaced the full depth with conventional concrete (either high early strength or regular strength depending on the job requirements) at no cost to the Department. Skin patches shall not be accepted.

(f) When surface irregularities are outside the tolerances cited above, the contractor shall grind the surface to meet the tolerance at no additional cost to the Owner.

13.10. **Curing**

Immediately after final rolling and compaction testing, a curing method as mentioned below shall be applied to the surface of the RCC pavement. The Engineer will make the final decision on the selection of the curing method.

(e) **Water Cure**: Water cure shall be applied by water trucks equipped with misting spray nozzles, soaking hoses, sprinkler system or other means that will ensure a uniform moist condition to the RCC. Application of this moisture must be done in a manner that will not wash out or damage the surface of the finished RCC pavement. *Drying of the surface shall not be permitted during the curing period.*

(f) **Curing Compound**: The specified membrane curing compound shall be applied in accordance with VDOT specifications (VDOT Spec. section 316.04(j)). This application must ensure a uniform void-free membrane across the entire RCC pavement. If the application rate is found to be excessive or insufficient, the Contractor, with approval of the Engineer, can decrease or increase the application rate to a level which achieves a void-free surface without ponding.

(g) **Sheet Materials**: Curing paper, plastic and other sheet materials for curing RCC shall conform to ASTM C 171. The coverings shall be held securely in place and weighted to maintain a close contact with the RCC surface throughout the entire curing period. The edges of adjoining sheets shall be overlapped and held in place with sand bags, planking, pressure adhesive tape, or other Engineer-approved method.

(h) **Tack Coat**: If RCC is planned to be overlaid with asphalt, a tack coat shall be sprayed before the asphalt overlay in accordance with VDOT special provision for nontracking tack coat dated October 5, 2010c or a later version.

14. **Joint Sealing**

All joints shall be cleaned and sealed with hot poured elastic joint sealer in accordance to applicable sections of VDOT Standard Specifications if required by the Plans or directed by the Engineer.

15. **Opening to Traffic**

The Contractor shall protect the RCC from vehicular traffic during the curing period. Completed portions of the RCC pavement may be opened to traffic ~~after 12 hours of curing~~ if a compressive strength of at least 2000 psi (14 MPa) *or the strength permitted by the Engineer* is achieved. Strength can be determined by the maturity method or core strengths or control cylinders.

If required by the Plans or directed by the Engineer, joints shall be sealed before permitting vehicles or equipment on the pavement.

16. **Maintenance**

The Contractor shall maintain the RCC pavement in good condition until all work is completed and accepted. Such maintenance shall be performed by the Contractor at his own expense.

17. **Quality Control and Quality Assurance Requirements**

17.1. **Approval of Mix Design Proportions**

The Department will review concrete mix designs and will verify compressive strength development.

(c) **Materials and Proportions**: The Department will approve material combinations and mix designs using approved materials and complying with gradation requirements in Section 2, "Materials". *Supplementary cementitious material (such as Class F fly ash or slag cement) shall be used for durability as indicated in the VDOT Manual of Instructions.*

(d) **Compressive Strength**: The mix design shall demonstrate a compressive strength of 4000 psi (28 MPa) at 28 days. Six cylinders according to ASTM C 1435 shall be prepared and tested according to AASHTO T 22 to determine the 3 and 28 day compressive strength for RCC.

17.2. **Moisture Control**

At the Engineer's discretion, moisture content tests shall be run (either microwave or field stove) on the material in the truck before it is placed in the paver, and require that the moisture content be ~~+/- 1% from optimum~~ *above optimum up to1% without adversely affecting the stability during compaction*. If the material is mixed on-site, then the moisture content shall be checked coming off the belt at the pugmill. Suggested frequency of testing is the first 2 loads of the day and then whenever a weather change occurs or the consistency of the mixture changes.

17.3. **Compressive Strength of Field Samples**

For each day's production, up to 1000 cubic yards of mix produced, Department will prepare two sets of 3 test specimens in accordance with ASTM C 1435. A set of specimens consists of three cylinders *and two sets shall be collected from two different trucks*. Two cylinders from each set will be tested for compressive strength in accordance with ASTM C 39 at 3 and 28 days. If the measured compressive strength between two cylinders varies by more than 10 percent of the stronger cylinder, the third cylinder will be tested and the average of the three cylinders will be taken. Otherwise, average compressive strengths of the two cylinders tested at 28 days will be considered as the compressive strength of the lot.

(d) If the compressive strength measured at 3 days indicates that the 28-day compressive strength will be less than 3500 psi based on trial section results, production shall be stopped immediately. The potential causes of the low strengths shall be investigate and rectified to the satisfaction of the Engineer within 24 hours.
(e) The compressive strength target at 3 days may be adjusted by the engineer as production continues based on field experience.
(f) Lot not meeting the 28 days compressive strength requirement of minimum 3500 psi shall be subjected to penalty (1 percent reduction for each 100 psi up to 3,000 psi). Engineer may decide to core and test according to subsection 8.5 for leaving the section in place.

17.4. **Density Requirements**

In-place field density tests shall be performed at five randomly selected locations for every 500 ft-lane in accordance with VTM 10, direct transmission, as soon as possible, but no later than 30 minutes after completion of rolling. Only wet density shall be used for evaluation. The required density shall be not less than 98% of the maximum wet density obtained by AASHTO T 180 or equivalent test method based on a moving average of five consecutive tests with no test below 96%. The contractor shall not proceed unless density meets the requirements.

17.5. **Core Strength Acceptance**

Engineer may decide to keep the RCC pavement, not meeting compressive strength or density requirements outlined in subsection 8.3 and 8.4, based on core strengths which must exceed the 3,500 psi at 28 days. ~~The Engineer may require a reduction in payment if removal and replacement is not required.~~

(d) Cores will be taken and tested by the Department but core holes will be filled by the Contractor.
(e) If tested area achieves the 28 day design compressive strength of 3500 psi from testing the cores, it will be paid for at full price.
(f) Areas that fail the strength test will be removed and replaced at no additional cost to the Department. Engineer may decide to keep the concrete at a reduced price (1 percent reduction for each 100 psi reduction of 28-day core strength up to 3,000 psi).

17.6. **Thickness**

Department shall take cores for thickness verification but the Contractor shall fill the core holes.

(e) The Engineer will designate pavement areas to be examined for depth measurement compliance with the Plan and Specifications. The thickness of the completed RCC is measured at staggered intervals not to exceed 500 feet in length for two-lane roads. Thickness of the core shall be measured to the nearest 1/8 inch at three different, evenly spaced locations and averaged.
(f) A small (approximately 1 inch diameter or greater) core shall be extracted to determine the pavement thickness.
(g) The Engineer will evaluate areas deficient by more than 1/2 in (13 mm) thick. If the Engineer requires removal, the pavement shall be removed and replaced in full cross

sections according to Plan requirements at no additional cost to the department. The Engineer may require a reduction in payment if removal and replacement is not required.

(h) Core holes shall be repaired using a packaged quick set ~~repair mortar such as SikaQuick 1000 or~~*patching material from VDOT* approved ~~equivalent or a Class 4000~~*list #31* or better ready mixed concrete. Repair materials shall be rodded and neatly striked off.

18. **Measurement and Payment**

18.1. **Measurement**

The work described in this document will be measured in square yards of completed and accepted RCC pavement of the specified thicknesses as determined by the specified lines, grades and cross sections shown on the Plans.

18.2. **Payment**

(c) **Paving**: The work described in this document will be paid for at the contract unit price per square yard, rounded to the nearest tenth of a square yard, of completed and accepted RCC pavement. There shall be separate pay items for each specified thickness. The price shall include mixing, hauling, placement, compaction, curing, inspection and testing assistance, and all other materials and incidental operations expenses. Any cores taken shall be filled by the Contractor and~~ this~~ expense shall be included in the unit price of concrete. Payment will not be made for wasted concrete, for concrete used for the convenience of the Contractor, or for concrete outside the neat lines shown on the drawing. Concrete will be measured in the completed and accepted pavements in accordance with the dimensions shown in the plan and cross section. Any areas of pavement with excess thickness will be counted as having the thickness shown on the plans.

(d) **Test Section**: If an acceptable test section is constructed, it will be paid for on a lump sum basis *per square yard*. Such payment shall constitute full reimbursement for all materials, labor, equipment, mobilization, demobilization, and all other incidentals necessary to construct the Test Section in accordance with Section 4.2.