TRC1201

# Design, Construction and Monitoring of Roller Compacted Concrete in the Fayetteville Shale Play Area

Stacy G. Williams

Final Report

2014

# Design, Construction and Monitoring of Roller Compacted Concrete Pavement in the Fayetteville Shale Play Area

Final Report

TRC-1201

by

Stacy G. Williams, Ph.D., P.E.
Director, CTTP
Research Associate Professor
Department of Civil Engineering
University of Arkansas

September 29, 2014

# 1. Introduction

Roller-compacted concrete (RCC) is a stiff, no-slump concrete mixture that contains less paste than conventional concrete, but provides similar structural support. The materials used in RCC are the same as that of traditional concrete mixtures, although RCC is a much drier mixture. After mixing, the mixture is placed on the roadway using an asphalt paver or high-density paver, and is then compacted using steel-wheel vibratory rollers. RCC is usually constructed without forms, dowels, reinforcing, or finishing, and does not require jointing. The substantial structural qualities of RCC, combined with its simplified construction process, make it an attractive paving alternative.

RCC has been used for many years in a variety of applications, including dams, lumber storage yards, heavy haul roads, loading docks, intermodal port facilities, and parking lots. Recently, RCC mixes have become more common in roadway applications, including city streets, highways, and roadway shoulders. *(Harrington et al. 2010, Kim 2007)* In this project, RCC pavement was used by the Arkansas State Highway and Transportation Department (AHTD) to rehabilitate a severely distressed two-lane highway in the Fayetteville Shale Play Area (FSPA).

The FSPA is an area in the north central portion of Arkansas that has experienced a large influx of natural gas drilling activity during the past eight years. The truck traffic associated with the drilling operations has caused rapid deterioration on more than 2500 miles of roadways, approximately half of which are considered lower volume highways. *(Meadors and Wright-Kehner 2013)* Typical pavements in the FSPA are composed of a crushed stone base and hot mix asphalt (HMA) surface layer(s), which suffer from a number of distresses including rutting, shoving, bleeding, fatigue cracking, potholes, slippage cracking, and edge failures. Although maintenance activities have attempted to keep these roadways in adequate condition, budget limitations have not allowed for the structural enhancements necessary to prevent recurring premature failures. In fact, typical asphalt overlays have failed in as little as six months.

Since standard overlays are not sufficient to sustain these roadways, a complete reconstruction or major rehabilitation is needed in many areas. However, these traditional alternatives are much too expensive to be implemented on a widespread basis. RCC pavements have been shown to provide significant structural support and can be constructed in a relatively short time period. The comparatively low cost allowed RCC to be considered as an alternative for mitigating damage in the FSPA. This paper presents a summary of the construction process, testing performed, and summarizes lessons learned from the experience that should be incorporated into future RCC pavement construction endeavors.

## 2. Problem Statement

More than 1,000 miles of roadways in Arkansas have been adversely affected by the increased traffic loadings in the Fayetteville Shale Play Area (FSPA), leading to a sharp acceleration of pavement distress. The accelerated pavement distress that has become prevalent in the FSP area illustrates the need to examine cost efficient rehabilitation strategies that can provide a long service life. Roller-Compacted Concrete (RCC) pavement is one such potential alternative. RCC pavement is a low-paste, zero-slump concrete mixture that is compacted with rollers and requires no forms, reinforcing, dowels, jointing, or finishing. The reduced cement content and ease of construction result in substantial cost savings. RCCP is very strong and well-suited for heavy traffic loadings, but the success of any pavement depends upon the quality of its foundation. Thus, base/subbase reconstruction should also be considered in this project.

## 3. Background

Roller-compacted concrete (RCC) pavements are generally described as zero-slump concrete mixtures that are constructed using techniques similar to that of hot-mix asphalt (HMA) pavements. RCC is made up of the same components as traditional concrete mixtures – cementitious materials, water, crushed aggregate, and sand; however, it is a much drier mixture that resembles damp aggregate. After mixing, the mixture is placed on the roadway using an asphalt paver, and is then compacted using steel-wheel vibratory rollers. RCC is usually constructed without forms, dowels, joint, or reinforcing, and does not require finishing.

RCC has been used for many years for a variety of applications including dams, lumber storage yards, heavy haul roads, loading docks, intermodal port facilities, and parking lots. The most prominent use of RCC has been in dam construction. In fact, RCC has been cited as being the single greatest improvement in recent history to the process of dam construction because of the significant reduction in construction time. (ACI 1999) More recently, RCC has received greater consideration for streets, highways, and airport paving.

<u>RCC Materials</u>
In general, the materials used for RCC are the same as those used in conventional concrete mixtures. These materials are coarse aggregate, fine aggregate, cementitious materials (including supplementary cementitious materials such as fly ash, blast furnace slag, and silica fume), and water. However, there are five major differences in the components of RCC as compared to conventional concrete mixtures. (ACI 2001)

1. RCC is generally not air-entrained
2. RCC has a lower water content
3. RCC has a lower paste content
4. RCC requires more fine aggregate to achieve proper compaction
5. RCC aggregates do not exceed a nominal maximum aggregate size (NMAS) of ¾ inch

The aggregates in RCC typically comprise 75 to 85 percent of the volume of the mixture. (ACI 2001, Adaska 2008) Crushed or uncrushed coarse aggregates may be used, although crushed aggregates are preferred. Uncrushed gravels usually require less water because they tend to naturally provide greater workability, however the increased angularity in crushed stone provides a more stable aggregate skeleton and generates higher flexural strength. Relative to size, coarse aggregates in RCC should not be larger than ¾ inch. Limiting the size of aggregate particles helps to reduce segregation and increase the smoothness of the pavement's surface.

In general, fine aggregates used in RCC pavements may be natural or manufactured, crushed or uncrushed. Crushed screenings are often considered a waste product by the asphalt industry, especially as Superpave mix design procedures have tended to encourage coarser gradations and limited quantities of screenings. Fine aggregate angularity is very important for fine aggregates used in asphalt mixtures because the aggregate skeleton is the primary source of strength and stability for flexible pavements. As a result, natural sands are not recommended. Although RCC pavements depend more upon aggregate interlock than their conventional concrete counterparts, the rigid nature of the paste allows some natural sand to be used without diminishing the structural quality of the RCC pavement. (Harrington et al. 2010) In addition, a small portion of natural sand helps to improve the workability of the RCC mixture, while also helping to maximize the density of the mixture.

The desired strength of the pavement is a deciding factor in determining the type of cementitious materials used. Most RCC pavements use Type I or Type II Portland cement. Fly ash is also commonly used in RCC mixtures; most commonly Class F or Class C fly ash. Fly ash is used to increase the fine material needed to achieve appropriate compaction efforts, and generally provide 15 to 20 percent of the volume of the cementitious material in the RCC mixture.

Admixtures have been used sparingly in RCC mixtures. Air entraining admixtures (AEA) are used in most conventional concrete mixes to improve pavement durability and reduce the detrimental effects of freezing and thawing, but are not required for use in RCC. Most RCC mixtures address frost concerns by proportioning mixtures with a low water cement ratio, which reduces the permeability of the paste. When the pavement is properly compacted, the amount of entrapped air voids decreases and strength increases, providing increased frost resistance. Retarding agents are not typically used in RCC unless a longer set time is required in order for the pavement to be fully compacted. High-range water reducers are rarely used, and are typically dependent upon the percentage of fines passing the No. 200 sieve.

<u>RCC Mixture Design</u>

There are two primary approaches used to proportion RCC mixtures. The first is proportioning by use of soil compaction (modified proctor) tests, and the second is a consistency or workability approach, which employs proportioning by the use of concrete consistency tests. The most commonly used RCC mix design method is the modified proctor method, in which an aggregate structure and cement content are chosen, and RCC samples are compacted using a series of moisture contents to develop a proctor curve. Based on the parabolic relationship of density and moisture content, the optimum moisture content is chosen as that which corresponds with the maximum density (i.e., the peak of the parabola). This portion of the mix design is performed in accordance with AASHTO T 180 or ASTM D 1557. After the optimum moisture content is determined, RCC cylinders are prepared using a range of cement contents. The minimum cement content that is capable of generating the desired compressive strength is selected for the design. (PCA 2004, Amer et al. 2004)

<u>RCC Construction</u>

RCC pavements are constructed much like asphalt pavements. The general process consists of the placement and compaction of a zero-slump concrete mixture where large amounts can be placed rapidly with minimal labor and equipment. When preparing the subgrade/subbase for the placement of RCC pavements, the same requirements must be met as those of conventional concrete. The subbase and subgrade must provide a way to drain excess water from under the pavement to prevent saturation and subsequent problems associated with freeze/thaw cycles. When RCC is placed on top of a subbase, the subbase is saturated to prevent it from “robbing” the moisture from the RCC mixture.

RCC mixtures are typically batched in a continuous mixing pugmill or a rotary drum plant. In some cases, RCC has been mixed in revolving drum mixers as it is transported to the jobsite. The continuous mixing pugmill is used most frequently, and is preferred because it produces adequate mixing efficiency, can be easily constructed on site, and provides a relatively large output capacity.

The placing of roller-compacted concrete is much like that of asphalt pavement construction. In some recent cases, pavers have been modified by adding a tamping bar to the screed to provide additional consolidation. This results in additional compactive effort and can lead to increased smoothness and density of the finished pavement. In some cases, cracks have formed as a result of the extra compactive effort provided by heavy-duty screeds. Although these superficial defects may be removed during the rolling process, care should be exercised when using heavy-duty equipment.

The timing of RCC placement and compaction is critical to the quality of the finished RCC pavement. Placement and compaction should occur while the concrete is still fresh and workable, usually within 45 to 90 minutes of mixing. Thus, proximity of the mixing operation to the jobsite, as well as the consistency and coordination of production and construction speeds are critical to pavement quality. For these reasons, the timing for placement of additional lifts and joint construction techniques are also important.

Compaction of RCC is usually accomplished by use of a 10-ton dual-drum vibratory roller, which immediately follows the paver. (ACI 2001) Two passes in the static mode are typically used to “set” the surface before primary compaction is performed in the vibratory mode. Finish rolling is then accomplished by either a static steel-drum roller or a rubber-tire roller.

Joint construction is probably the most important part of the placement of RCC. Excellent joint construction produces adequate smoothness and density for the RCC pavement structure. Longitudinal joints are constructed parallel to the direction of paving between adjacent lanes, and transverse joints are produced at the ends of the paving lane perpendicular to the direction of paving. Depending on weather conditions, approximately one hour is the maximum time frame for constructing a monolithic bond between lanes. Thus, paving in echelon is the best method for construction. However, this method is not often a practical option due to traffic considerations. Thus, construction joints, or “cold joints” are formed when one lane has hardened to the extent that it can no longer be compacted with the fresh lane. To properly form a cold longitudinal joint, the hardened lane should be sawed to produce a clean vertical face, and the fresh lane should be place such that it slightly overlaps the hardened lane. Next, the overlap should be raked toward the fresh lane, forming a “hump” at the joint that is compacted by the static roller as it travels along the joint to form a smooth and solid joint.

Curing is important for RCC pavements because of its low water content. Moist curing is often used because it aids in the development of design strength, and helps to prevent scaling and raveling of the hardened surface. In some cases, it is recommended that RCC pavements be moist cured and protected from traffic for 7 to 14 days; however, RCC pavements are more commonly opened to traffic after 24 hours. This practice is more desirable because it offers obvious advantages relative to traffic management during construction.

Quality Control/Quality Assurance Testing

During construction of the RCC pavement, quality control and quality assurance (QC/QA) testing is performed by determining a number of properties of the compacted mixture, including gradation, moisture content, density, smoothness, strength, and thickness. The most common items monitored during construction are density and thickness. The nuclear gauge (in direct transmission mode) is used to measure the in-place density, which is then compared to the proctor value (maximum density from the mix design) and a minimum of 98 percent compaction is typically required. Another method used to monitor the density of RCC during construction is to place a test strip that can be used as a basis for QC/QA measures of RCC density. This practice is logical in that the compaction achieved in a full-scale test section should truly represent the compaction that can be achieved throughout the project. However, the level of compaction achieved on the test strip is often based on experience, making the quality of the constructed pavement solely a function of the density achieved on the test strip.

RCC Performance

Most references to RCC pavement performance are linked to properties of the surface of the pavement, including items such as surface condition, skid resistance, smoothness, rideability, durability, and load transfer. Surface defects may include joint condition, weathering or raveling, joint sealant damage (if jointed), patched areas, and shattered areas. In general, these distresses result primarily from freeze/thaw damage. In a research study performed by the USACE, these types of distresses were evaluated for 11 sites in the U.S. and Europe. (ACI 2001) In general, performance of all sites was good, ranging in status from “fair” to “very good”.

Skid resistance is another concern for RCC pavements, particularly in high-speed applications. Because early uses of RCC included heavy-duty industrial applications, speeds were generally low and skid resistance was not a prime consideration. Skid resistance testing of RCC has been done both in the U.S. and in Australia, where poor to marginal test results were obtained. (ACI 2001) The low friction characteristics were attributed to the macrotexture and microtexture of the RCC surface. For conventional concrete surfaces, texture is added to the surface by brooming, dragging, or tining. These surfacing techniques create avenues for water to escape from the pavement’s surface during rain events to prevent vehicle hydroplaning. RCC pavements, however, do not include these steps to generate additional skid resistance, and the surface texture is believed to be highly dependent upon mixture proportions and compaction methods.

Smoothness and roughness are also considerations affecting the performance of RCC. Smoothness describes the deviation of the pavement surface from a plane, such that smoother pavements have less deviation. Lack of smoothness is primarily a function of the construction procedure, and has been the primary reason for RCC pavements being limited to low-traffic, low-speed applications. Roughness is a descriptor of the ride sensation felt by a vehicle passenger traveling on the pavement. In limited testing, the roughness of RCC pavements has been deemed unacceptable; however, it has been suggested that with experience, roughness can be reduced and RCC pavements may be acceptable for high-speed wearing surfaces. Diamond grinding is typically used to generate a proper surface, or an additional wearing course, such as a dense-graded HMA mix, may be placed on top of the RCC.

Freeze-thaw durability has been of some concern with respect to RCC pavements. Although very little evidence exists to suggest that RCC is susceptible to freeze-thaw damage, the fact that most RCC is not air-entrained tends to create worry regarding this topic. In a study performed at the U.S. Army Corps of Engineers Waterways Experiment Station (WES), it was determined that RCC mixtures that did not contain AEAs were susceptible to frost damage, and those containing AEAs were not susceptible to frost damage. As a result of this study, it was determined that RCC mixtures could be successfully air-entrained in the laboratory. (ACI 2001) Other studies have reported RCC mixtures to have good resistance to frost damage.

Load transfer is another important consideration in the performance of RCC. Because no load transfer devices are placed in RCC pavements, all load transfer is derived from the aggregate interlock in the mixture. Thus, crack widths critically affect the load transfer capacity of the mixture, and can be expected to vary seasonally. Average crack widths have been reported as 0.05 inches to 0.06 inches. (ACI 2001) Other sources have reported that although cracks may develop within the first few days after paving, they remain tight and are not considered to create performance problems.

<u>Structural Design of RCC</u>

Because the primary use for RCC pavements originated with heavy-duty haul roads and other industrial applications, many design procedures were developed accordingly, focusing on the heaviest vehicle and number of load repetitions expected on the pavement. Design procedures employing this approach include the Portland Cement Association (PCA) procedure (the RCC-PAVE computer program), and the US Army Corps of Engineers procedure.

For traditional roadways, the designs must often provide for mixed traffic streams, and require a different approach. Design tables for pavements with mixed traffic are given by the American Concrete Institute (ACI). Specific procedures include the Guide for Design of Jointed Concrete Pavements for Streets and Local Roads (ACI 325.12R-02) and Guide for the Design and Construction of Concrete Parking Lots (ACI 330R-08). RCC pavements may also be designed using conventional concrete pavement design software such as WinPAS or StreetPave. However, it is recommended that the design reliability level be increased by 5 percent in order to achieve proper results for RCC. (Harrington et al. 2010) The StreetPave computer program was developed by the American Concrete Pavement Association, and is basically an update to the 1984 PCA design procedure. It can also be used to generate comparable flexible pavement designs using the Asphalt Institute procedure. When using the StreetPave program, material properties are used as input values, although limited data is available regarding the fatigue performance of RCC. One approach for managing this risk is to increase the design reliability in order to increase the conservatism of the design.

For multi-layer pavement systems serving high-speed traffic, the StreetPave or WinPAS programs may be used, but designs of this type are more commonly performed using either 1) the American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures (1993, 1998) or 2) the AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG). (Harrington et al. 2010) A summary of design procedures and applicable uses is included in Table 1.

**Table 1.** Summary of RCC Structural Design Procedures and Uses (ACI 1999)

| | USACE | RCC-Pave | ACI Streets | ACI Parking Lots | StreetPave | WinPAS | AirPave | AASHTO 1993/98 | MEPDG |
|---|---|---|---|---|---|---|---|---|---|
| Ports | X | X | | | | | | | |
| Intermodal Facilities | X | X | | | | | | | |
| Logging Facilities | X | X | | | | | | | |
| Heavy Industrial | X | X | | | | | | | |
| Light Industrial | X | X | X | X | X | X | | | |
| Airport Pavements | X | X | X | X | X | X | X | | |
| Arterial Streets | | | X | X | X | X | | | |
| Local Streets | | | X | X | X | X | | | |
| Widening/ Shoulders | | | X | | X | X | | | |
| Multi-Layer Systems | | | | | | | | X | X |

<u>Full-Depth Reclamation</u>

Full-Depth Reclamation (FDR) is a rehabilitation strategy that has been used for approximately 20 years. (Nantung et al. 2011) FDR involves pulverizing the existing deteriorated pavement structure (aged asphalt and/or base and subbase), mixing it with a stabilizing agent such as an emulsion or cement and water, then compacting in place, providing a new and more stable base for a pavement surface. The process can be completed in a single pass, allowing traffic to be immediately returned to the roadway, or for paving of subsequent layers to begin. Originally, FDR was considered to be a method for recycling deteriorated asphalt pavements, but is gaining recognition as an alternative method for base construction/reconstruction and is often used in value engineering concepts. (Nantung et al. 2011, Asphalt Institute 2007) Since its inception, FDR has become a reasonable consideration for preserving the structural integrity of the pavement's substructure, while also serving as an environmentally friendly and economically feasible method for recycling an asphalt pavement surface.

Because a pavement is truly only as strong as its supporting structure, the use of FDR presents certain advantages over traditional overlay, or "mill and fill" maintenance strategies because it addresses concerns of reflective cracking. The addition of the stabilizing agent provides additional structure, and is performed quickly, resulting in approximately 30-60 percent cost savings over traditional remove and replace methods. Since the process can be completed in just one pass, additional savings are realized because of the shortened construction time. In fact, one study performed in the city of Las Vegas, Nevada, reported that FDR allowed for the project to be completed in 40 days rather than the scheduled 120 days. (Finberg et al. 2008) After the material is pulverized and mixed, it is shaped and graded in place so that no material is wasted (i.e., it is sustainable), and cost savings result because less material must be brought in to replace the failed material. The resulting surface is immediately passable for low speed traffic, and it can be quickly traversed by construction equipment for subsequent paving operations.

A base material constructed using FDR is most often contains cement and water as the stabilizing agent. Cement contents typically range from 3 to 7 percent, resulting in a product that somewhat resembles a cement- treated base (CTB). (Abdo, 2010) Traditional CTB materials often have slightly greater strength and stiffness values than that of FDR. However, CTB may also be prone to greater cracking failures that may reflect through the upper pavement layers. One of the advantages of FDR is that it is slightly more flexible than CTB and may be better able to resist subbase movements due to freeze-thaw cycles.

In terms of cost, FDR ranges from \$0.60 to \$0.90 per square yard per inch depth. (Abdo 2010) Typical depths are in the range of six to nine inches, resulting in a cost of \$4.50 to \$7.00 per square yard. Costs for comparable materials used in Arkansas (cement-treated base and cement stabilized crushed stone base) range from \$4.50 to \$10.73 per square yard. Although some monetary savings may be immediately evident, additional savings would be associated with the speed of construction offered by FDR.

The advantages of FDR and RCCP have been combined in a limited number of instances with reported success. The efficient process of FDR quickly prepares a subbase for placement of RCCP, upon which RCCP can be placed quickly. A complete reconstruction using this combination of techniques can take place in as little as two days, allowing traffic on a completely rehabilitated pavement section.

<u>Fayetteville Shale Play Area</u>

The Fayetteville Shale Play area (FSPA) is a 7,400 square mile area located in the north central portion of Arkansas, and approximately 2.5 million acres within that area have been leased to energy companies for the purpose of natural gas well drilling. The FSPA and gas well locations are shown in Figure 1. These drilling activities began in 2006, with over 1,100 gas wells drilled within one year. By 2010, the number of active wells had grown to 3,575. (Meadors and Wright-Kehner 2013) Approximately 2,580 miles of highways are located within the FSPA, and over half of those are considered to be lower volume highways. Approximately 10 percent of highways in the FSPA were also weight-restricted because of structural limitations.

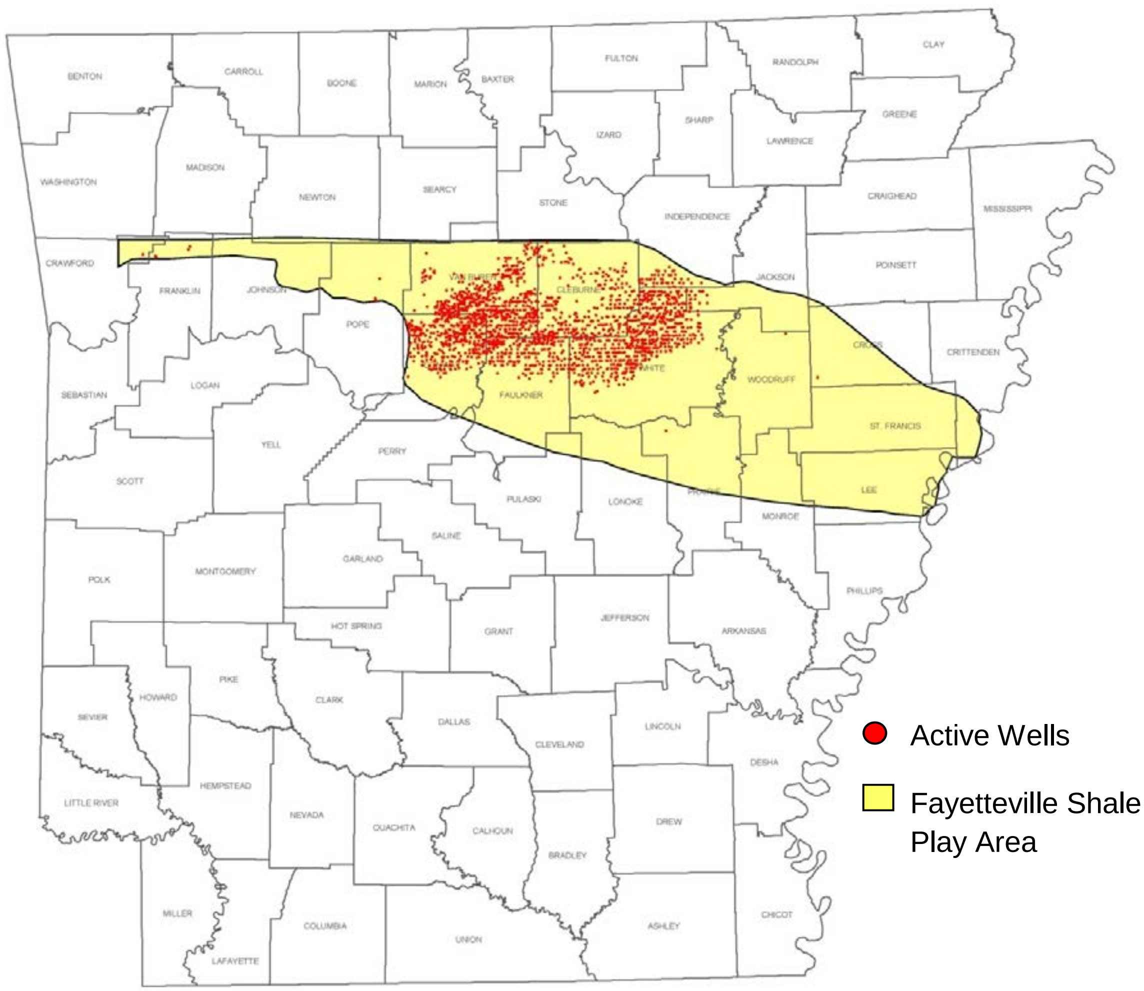



**Figure 1. Map of the Fayetteville Shale Play Area and active wells as of May 2011 (Bennett 2011)**

The drilling activities caused heavy truck traffic loadings on the FSPA roadways to increase at unprecedented rates. In some cases, anticipated 20-year accumulated traffic loadings were exceeded in less than one year. The extreme traffic loadings quickly led to accelerated pavement deterioration, with many roadways exhibiting major damage and extreme roughness, as well as generating significant public complaint. These roadways were often characterized as having, International Roughness Index (IRI) values exceeding 400 in./mile, and rut depths greater than 0.5 inches. (Meadors and Wright-Kehner)

The sudden deterioration of such a large portion of the rural highway network placed a seemingly insurmountable burden on maintenance budgets, and it was quickly realized that typical maintenance procedures, such as a 2-inch asphalt overlay, did not provide sufficient structure to significantly slow the rates of roadway deterioration. In fact, some overlays failed in as little as 6 months. Some typical failures are shown in Figures 2 through 5. Figure 6 illustrates the rate of deterioration of a single location over time.

**Figure 2. Typical Roadway Distress in the Fayetteville Shale Play Area (Rutting, Shoving)**


**Figure 3. Typical Roadway Distress in the Fayetteville Shale Play Area (Rutting with Patches)**


**Figure 4. Typical Roadway Distress in the Fayetteville Shale Play Area (Edge Failures)**


**Figure 5. Typical Roadway Distress in the Fayetteville Shale Play Area (Shoving, Slipping)**

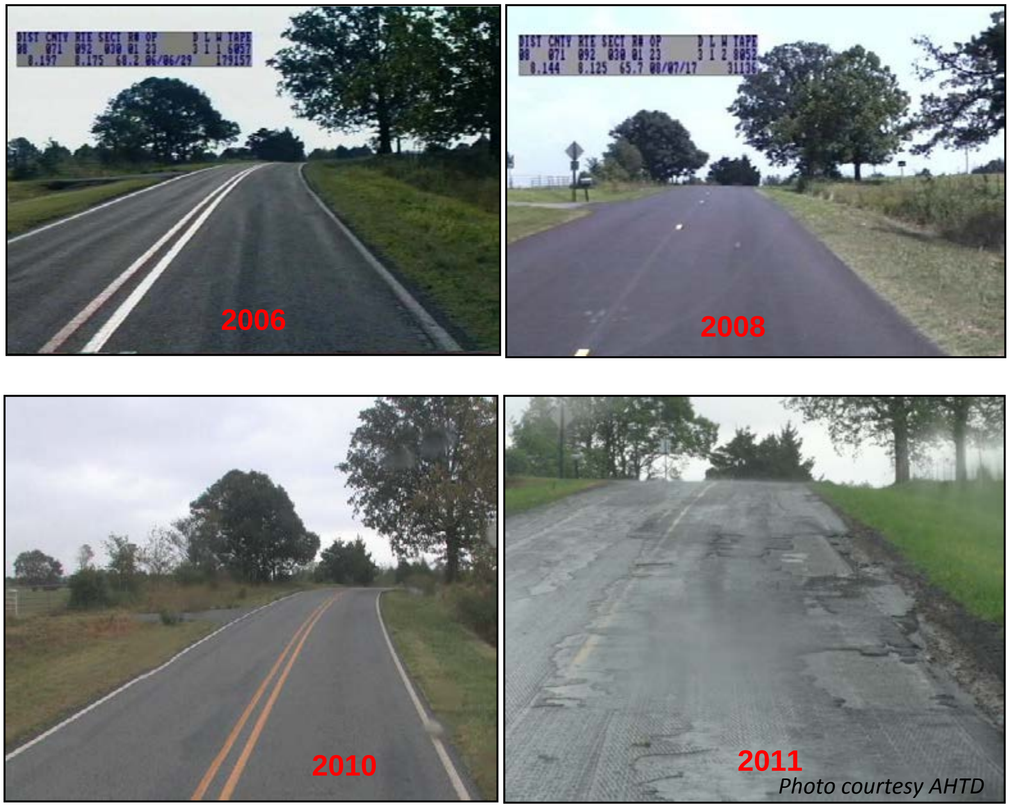



**Figure 6. Typical Deterioration in the Fayetteville Shale Play Area (2006 - 2011)**

# 4. Literature Review

The first RCC pavement in North America was an airport runway at Yakima, Washington, which was constructed in the early 1940s, and a similar type of paving was reported in Sweden as early as the 1930s. (ACI 2001) In 1976, an RCC pavement alternative was presented in British Columbia, Canada. The success of this pavement was followed by several more projects within Canada, and as a result, the U.S. Army Corp of Engineers (USACE) decided to further investigate potential uses of the material. The first full-scale RCC pavement in the U.S. designed and built by the USACE was a 3.75 acre facility at Ft. Hood, Texas, in 1984. The project specified a slab thickness of 10 inches, and the RCC mixture had a flexural strength of 800 psi. Information on specific topics was generated by this project, including maximum aggregate size, single vs. multiple lift construction methods, compaction, curing, and sampling of RCC. This project was deemed a success and other industries began to implement RCC pavements, including the Burlington Northern Railroad intermodal facilities in Houston and Denver, the Port of Tacoma in Washington State, and the Conley and Moran Marine Terminals in Boston, Massachusetts.

Large parking lots have also been paved with RCC. In the late 1980's, a 134-acre area was paved at the General Motors Saturn automobile plant near Spring Hill, Tennessee, and an 89-acre area was placed at Ft. Drum, New York. (ACI 2001) These pavements were 8 and 10 inches thick, and had compressive and flexural strengths similar to that of traditional concrete pavements. Later, a 207-acre area was placed at the Honda manufacturing facility in Alabama. (Adaska 2008)

The use of RCC for traditional roadway paving has since expanded, and has been implemented by a number of agencies, being used for municipal streets and secondary highways in Portland, Oregon and Columbus, Ohio, as well as a number of Canadian cities. The states of Missouri, Tennessee, South Carolina, and Georgia have also used RCC for roadway paving. (Kim 2007, cement.org 2010, Missouri DOT 2008)

<u>Experience with RCC</u>

The Missouri Department of Transportation (MoDOT) began investigating RCC as an alternative material that could be used to combat the rising costs of conventional pavement overlays on low-volume highways in the state. (MoDOT 2008) In October of 2008, a 6-inch overlay of RCC was placed on a rural route in Boone County, just south of Columbia. The test section was 2000 feet long and consisted of two 10.5-foot wide lanes. Although the route had low traffic (ADT = 694), an increase in truck traffic was expected after a new overpass was completed nearby. Extensive testing was performed for the test section, including the nuclear density test for in-place density, compressive strength of cores, compressive strength of cylinders, rapid chloride permeability of cores, coefficient of thermal expansion (CTE) of cores, freeze/thaw durability of beams sawed from the pavement, thickness of extracted cores, calculated density of cores and cylinders, moisture content on the mixture sampled from the paver, and macrotexture and smoothness of the compacted surface. Initial strength testing results are shown in Table 2.

**Table 2. Strength Data From Boone County RCC Project by MoDOT (2008)**

| | | |
|---|---|---|
| | From Day 1 Construction | From Day 2 Construction |
| 1 day | 2030 | 2765 |
| 3 day | 3500 | 3940 |
| 7 day | 5040 | 4570 |
| 14 day | 5240 | 5465 |

The $143,000 overlay was constructed in two days, with traffic allowed on the overlay within 24 hours of placement. Initial findings indicate that the project was successful. Further evaluations will be performed to determine the performance of the RCC through changing seasons. Performance through the winter months is of particular interest.

In February 2008, MoDOT began allowing RCC as an optional material for new shoulder construction, but has not yet formalized a specification for mainline paving. (MoDOT 2008) The shoulder specification requires a specific gradation, a design compressive strength of at least 3500 psi at 28 days, a minimum water cement ratio of 0.25, and a minimum cementitious content of 400 pounds per cubic yard. Supplementary cementitious materials are allowed, but do have specific limitations, as shown in Table 3.

**Table 3. SCM Requirement from RCC Shoulder Specification by MoDOT (2008)**

| Supplementary Cementitious Material (SCM) | |
|---|---|
| SCM Type | Max.% of Total Cementitious Material |
| Fly Ash (Class C or Class F) | 25 |
| Ground Granulated Blast Furnace Slag (GGBFS) | 30 |
| Silica Fume | 8 |
| Ternary Combinations | 40 |

MoDOT requires that the RCC be mixed in a mixing plant capable of meeting production rates that are consistent with rates of placement, and that the RCC be placed using a high-density or conventional asphalt type paver. Vibratory rollers are required for primary compaction, and static steel drum rollers or rubber-tired rollers shall provide finish rolling. The shoulders may be opened to light traffic after 3 days, and to unrestricted traffic after 14 days. Quality control testing includes deleterious content, aggregate gradation, coarse aggregate absorption, thin or elongated pieces, shoulder thickness, and in-place density. The core density is required to be at least 95 percent of the maximum laboratory density, and the core thickness must be at least 90 percent of plan thickness. (MoDOT 2008)

The South Carolina Department of Transportation (SCDOT) also has a specification for RCC pavements, and allows RCC for mainline paving. (SCDOT 2001) The gradation specification is similar to that of MoDOT, but is slightly more restrictive. SCDOT requires a design compressive strength of at least 2000 psi at 3 days, and 5000 psi at 28 days. The mixing plant may be a pugmill plant (central plan type) or a rotary drum batch mixer, must be capable of providing a homogeneous mixture at a rate consistent with placement, and must be located within a 30-minute haul time of the jobsite. RCC must be placed with an asphalt-type paver that provides a minimum of 90 percent of maximum laboratory density. Subsequent rolling shall provide primary compaction by vibratory steel rollers and finish rolling by either static steel drum or rubber-tired roller, and in-place density shall be not less than 98 percent of maximum laboratory density, tested no more than 30 minutes after rolling has been completed. Lanes may be opened to light traffic after 24 hours, provided the compressive strength of the RCC mixture reaches 2000 psi. Unrestricted traffic is allowed on the pavement after 4 days unless the temperature drops below 40 °F, in which case this time will be extended. Pavement thickness is used as a basis of payment.

South Carolina has been very innovative in implementing various uses of RCC. Two notable projects have incorporated RCC, both as the driving surface and as a base in an integrated pavement system. (cement.org 2010) The first project was a 4-lane, 1-mile long section of failed asphalt pavement in Aiken, South Carolina. A 10-inch RCC pavement was chosen as the replacement for the failed asphalt roadway because of a desire to provide a long-term solution with minimal traffic disruption and low cost. To generate an acceptable surface for high-speed traffic, the RCC surface was diamond ground. The target International Roughness Index (IRI) for high-speed roadways was 85 inches per mile or less. Prior to grinding, the RCC placed on a weak subgrade had an average IRI of 200 inches per mile, and the RCC placed on a stiff subgrade had an IRI ranging from 100 to 200 inches per mile. After grinding, this value was reduced to 50 to 60 inches per mile, which was well within the target range. The option of diamond grinding was believed to provide considerable cost savings as compared to the use of a HMA overlay for rideability. A savings of approximately $10 per square yard was estimated by SCDOT. Although there have been a few instances of surface raveling, the RCC is considered to be performing well.

In a second project near Charleston, SCDOT decided to repair a heavily rutted 5-lane section of US78 with an integrated pavement system composed of a 10-inch RCC base and a 2-inch asphalt surface. All construction was performed while maintaining at least one open lane at all times to serve the 40,000 AADT with 10 percent truck traffic. The speed of construction was a great advantage for the project, with the asphalt surface being placed in as little as two days after placement of the RCC base.

South Carolina has implemented at least ten projects to date, and has used RCC as structural and wearing courses on low and high volume highways. After diamond grinding, ride quality has been reported to be similar to that of an interstate. The life-cycle cost of the RCC in South Carolina has been estimated as approximately 30 percent less than that of an equivalent HMA structure, and construction times can be cut in half. (Zollinger and Johnson 2011)

In 2001, the Tennessee Department of Transportation (TDOT) drafted a special provision for the use of RCC for mainline paving. (Tennessee DOT 2001) In addition to a gradation specification, the design compressive strength of the mixture must be at least 4000 psi at 28 days. Central batch plants are required for mixing, such that the mixing process generates a homogeneous mixture at a rate that is consistent with the capabilities of the placement equipment. RCC lift thickness is restricted to a minimum of 4 inches and a maximum of 8 inches. The density of each lift is required to be at least 98 percent of the average maximum laboratory density, with no test below 95 percent. Transverse joints may be placed, but are not required. The pavement may be opened to traffic after reaching a minimum compressive strength of 3000 psi.

In 2004, the first usage of RCC in the U.S. interstate system was performed, as the Georgia Department of Transportation used RCC for a 17.3-mile shoulder reconstruction project on Interstate 285 in Atlanta. (Kim 2007) Six-inch and eight-inch thick sections were constructed with minimal interruption to traffic, and both have performed well to date. The mixture was designed using a 0.5-inch maximum aggregate size and a 4000 psi design compressive strength. Field density was required to be at least 98 percent of the maximum wet density (as determined in the laboratory). The RCC mix design is shown in Table 4.

**Table 4. RCC Mix Design for I-285 Shoulder in Atlanta, Georgia (Kim 2007)**

| Component | Quantity (lb) | Weight Ratio (%) |
|---|---|---|
| Cement | 500 | 12.3 |
| Aggregate | 3300 | 81.2 |
| Water | 266 | 6.5 |
| Total | 4066 | 100.0 |

Extensive testing was performed on the project, with focus placed on density, thickness, and strength. Density measurements were taken at various locations, at five points spaced transversely across the width of the shoulder. The middle portion of the shoulder width exhibited the greatest average wet density. Densities to the left and right of the middle were very close to the middle densities. The density of the left joint section was slightly less than that of the right section, and the density of the right edge had the lowest average value, which was approximately 96 percent of the density in the middle of the shoulder. In terms of variability, the middle showed the least variation and the right edge showed the greatest variation. When comparing the densities of the 6-inch and 8-inch sections, the 8-inch section displayed slightly greater densities.

The compressive strengths of cylinders were tested at five different ages, and the trends of strength gain over time were very similar to that of conventional concrete. The average early strength of cylinders after 4 days was approximately 3000 psi, which surpassed the 2000 psi required for the RCC pavement to be opened to traffic. The average 28-day strength was 4099 psi, and the average core strengths of the middle section were in close agreement with the design strength of 4000 psi. The average core strengths from the left joint and right edge were reasonable - 97 and 89 percent, respectively, of that from the middle section. The average core strength of the 8-inch sections was higher than that of the 6-inch sections. Core strengths and cylinder strengths did not correlate, and only a weak correlation was developed between strengths and densities.

A performance evaluation was also conducted to determine the presence of shrinkage cracks. Overall, the RCC shoulders were in excellent condition. In the 6-inch sections, only two shrinkage cracks were noted, while 23 shrinkage cracks were noted in the 8-inch sections. The average shrinkage crack width was 1/16 inch and exhibited some minor erosion. The most unpleasant features were noted around the transverse cold joints, where rough surfaces, corner cracks, and spalls were observed. Surface smoothness and skid resistance data were collected, but were adversely affected by the presence of debris and rumble strips that had been previously installed.

The costs associated with the Georgia Interstate shoulder construction were reported to be approximately $8 million, which was slightly higher than that estimated for an equivalent placement of asphalt shoulders. The cost reported for the RCC was $115 per cubic yard, which was compared to a 2004 current asphalt cost of $42 per ton. The asphalt alternative represented an initial cost savings of about 10 percent, which was believed to be easily offset by the savings in long-term maintenance costs.

In Colorado, a research study was performed to investigate the performance of RCC pavements. (Damrongwiriyanupap et al. 2012) Three sections were placed such that comparisons were made between the compacted RCC surface and diamond grinding, and between jointed and non-jointed sections. Overall, the diamond-ground sections performed much better than those that were not ground. The unground sections experienced a significant level of surface deterioration, including raveling and chipping. The diamond ground surfaces experienced some wearing and loss of fine surface material, but the coarse aggregate remained embedded in the pavement. For sections that were not jointed, significant cracking was noted in both the longitudinal and transverse directions. For the jointed sections, cracking was greatly reduced. In addition to field observations, a number of laboratory tests were performed. The results indicated that RCC was very similar to conventional concrete with respect to compressive strength, splitting tensile strength, flexural strength, and drying shrinkage. The RCC also performed well in freeze-thaw resistance, and had low chloride permeability. Overall, RCC was determined to be a valid paving option, but significant concerns were expressed regarding surface integrity, and further research was recommended.

Agencies in Kansas have also used RCC successfully. In one project, 30 miles of RCC was laid as a base for an asphalt shoulder of a highway. (Harris 2012) This pavement has performed well thus far; however, the RCC was not jointed, which led to reflective cracking in the asphalt surface. The resulting recommendation was that RCC pavements should be jointed at a spacing of 15 to 20 feet.

In Texas, 45,000 square yards of RCC have been placed on city streets in San Angelo, and performance has been quite positive thus far. Although the initial costs of RCC were very similar to that of asphalt, it was estimated that maintenance costs would be reduced 30 to 40 percent over the 50-year lifespan of the pavement. (Moucka 2012) The city of Midland, Texas has also taken advantage of the benefits of RCC. Recently, the Lamesa Road project used RCC to rehabilitate a deteriorated roadway. City officials were pleased that traffic disruptions were minimized by short construction times and anticipated maintenance expenses were decreased. (Russo 2014)

## 5. Research Objectives

The primary objective of this research effort was to thoroughly evaluate a number of rehabilitation strategies for the Fayetteville Shale Play (FSP) area, and to determine whether RCC pavement could provide adequate pavement structure while minimizing maintenance expenditures. The experiences gained in other states were used as a basis for determining specification language, and special attention was given to lessons learned regarding design, performance, testing procedures, and associated costs. The pavement and mixtures designs were performed after site selection was completed, and testing was performed to determine existing roadway conditions, soil quality, etc. The constructability of the RCC pavement was also considered for the specific location.

Throughout the design and construction process, close communication was maintained with AHTD personnel. Testing was performed during and after construction to ascertain the relative effectiveness and performance of each RCC section, and distress surveys were performed at regular intervals to document early performance. Details of the construction process, performance, and cost were used to formulate recommendations as to the most advantageous use for RCC pavements.

## 6. Research Approach and Analysis

In the fall of 2012, two sections of RCC pavement were placed on Arkansas Highway 213. The project site was located in Conway County, Arkansas near the town of Hattieville, as shown in Figure 7. The route was a rural two-lane highway with 10-foot lanes and had no shoulders. The existing pavement was significantly distressed, affected by natural gas exploration activities, as well as logging truck traffic and heavy haul trucks from a local aggregate quarry. The primary distresses included rutting, fatigue cracking, and edge failures, as shown in Figures 8 and 9.

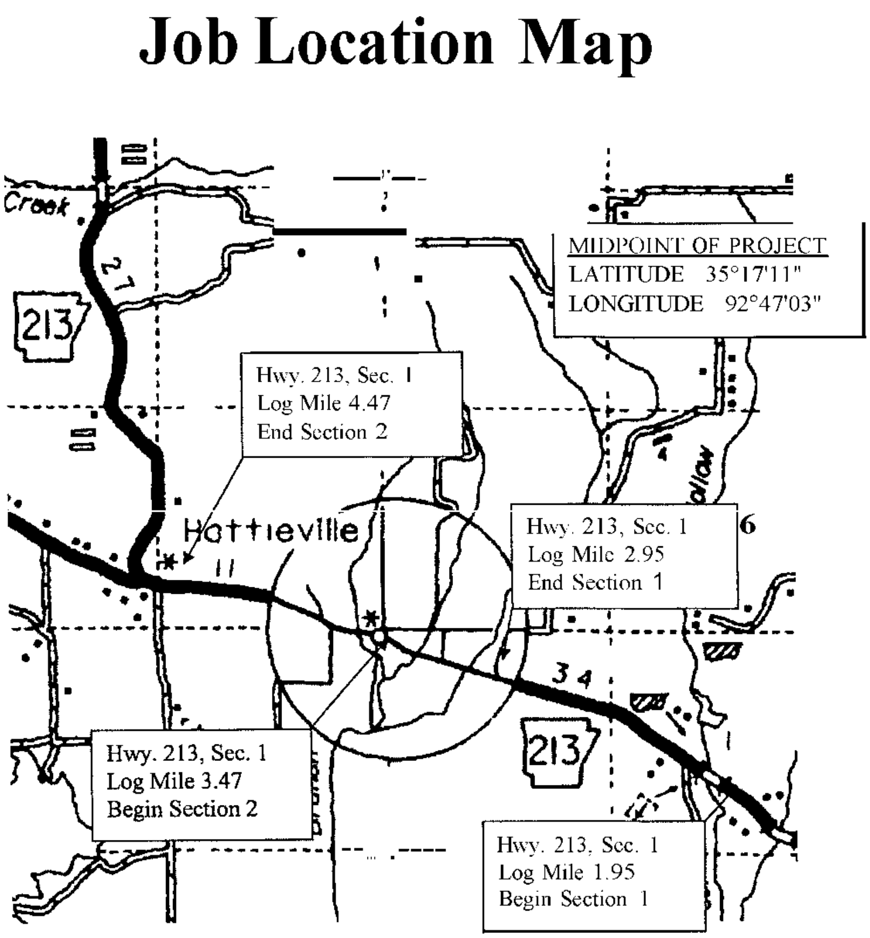



**Figure 7. Job Location Map**

**Figure 8. Rutting on Highway 213**

**Figure 9. Edge Cracking on Highway 213**

Coring was performed to determine the existing pavement thickness, and to obtain soil samples for testing. The existing pavement was generally a hot mix asphalt surface course place on a crushed aggregate base layer. Upon coring, pavement thicknesses were found to be approximately 3 inches, but were widely varied, ranging from 1.1 to 4.2 inches, with some sections containing multiple layers of thin asphalt treatments, patches, and chip seals that had been used in localized areas as an attempt to mitigate the accelerated distresses. See Figures 10 and 11.

**Figure 10. Hwy. 213 Core with Several Layers**

**Figure 11. Hwy. 213 Core of Minimal Asphalt Thickness**

Soil types were also varied throughout the length of the project, ranging from A-4(0) to A-6(6) (based on the AASHTO Soil Classification system). A summary of soil characteristics is given in Table 5.

**Table 5. Summary of Soil Characteristics – Hwy. 213**

| LogMile | 1.95 | 2.25 | 2.85 | 3.75 | 4.05 | 4.35 |
|---|---|---|---|---|---|---|
| Side | Rt | Lt | Lt | Rt | Lt | Rt |
| Section | 1 | 1 | 1 | 2 | 2 | 2 |
| Station | 102+96 | 118+80 | 150+48 | 198+00 | 213+84 | 229+68 |
| Code | 1123 | 1124 | 1126 | 1129 | 1130 | 1131 |
| AASHTO Classification | A-6(6) | A-4(0) | A-6(4) | A-4(3) | A-4(1) | A-6(6) |
| Color | Brown | Red/Br | Brown | Red/Br | Red/Br | Brown |
| %Passing | | | | | | |
| #4 | 100 | 100 | 100 | 100 | 100 | 100 |
| #10 | 96 | 97 | 95 | 95 | 96 | 95 |
| #40 | 89 | 94 | 84 | 87 | 91 | 83 |
| #80 | 82 | 85 | 73 | 80 | 81 | 75 |
| #200 | 67 | 70 | 63 | 63 | 64 | 63 |
| Liquid Limit | 30 | ND | 27 | 24 | 21 | 29 |
| Plasticity Index | 12 | NP | 11 | 9 | 6 | 15 |
| Max. Dry Density (pcf) | 104.9 | 116.1 | 115.1 | 114.1 | 117.7 | 113.3 |
| Opt. Moisture (%) | 19.2 | 13.9 | 13.2 | 13.5 | 12.8 | 13.9 |
| R-Value | 11 | 22 | 13 | 29 | 10 | 4 |

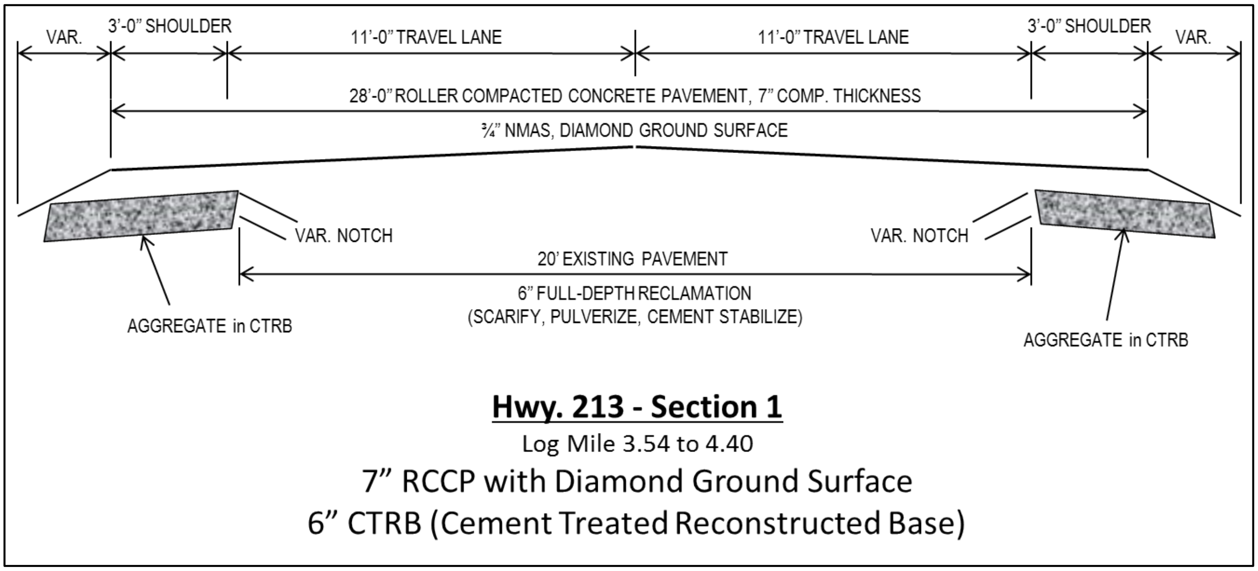
Because of the rural nature of the project location, the traffic volumes were quite low. However, gas drilling activities caused traffic volumes to increase significantly in a short timeframe. From 2007 to 2010, the traffic on Highway 213 increased from 770 vehicles per day (vpd) to 1,100 vpd, representing an annual growth of over 12 percent. This was much greater than the average annual statewide growth rate of 2 percent (Bennett 2011). At the time of construction, daily traffic totaled 1015 vpd, including 18 percent trucks, or approximately 36,600 Equivalent Single Axle Loads (ESALs) per year.

Life-cycle cost analysis (LCCA) had been previously performed to explore the feasibility of using RCC in Arkansas, and RCC was found to be a cost effective option by both the deterministic and probabilistic methods. (Williams and McFarland 2013) Based on these estimates and local conditions, RCC was selected for the Hwy. 213 project.

## DESIGN

Two sections were designed and constructed using RCC pavement as the wearing course. Each section was one mile in length and included HMA transitions, resulting in an actual RCC pavement length of approximately 0.86 miles in each section. The 1993 AASHTO Pavement Design method was used, which was consistent with typical design procedures used by AHTD.

The first section included a seven-inch section of RCC pavement placed on a Cement Treated Reconstructed Base (CTRB). Using the existing range of soil characteristics and the 6-inch CTRB base, design thicknesses ranged from 5.5 to 6.85 inches of RCC, and a design thickness of 7 inches of RCC was selected. The second section was an RCC section placed as an overlay of the existing asphalt surface. Design thicknesses ranged from 7.1 to 7.8 inches, and an 8-inch RCC design thickness was chosen. In each section, the lane width was increased to 11 feet, and three-foot shoulders were added. For composite pavements, a layer coefficient of 0.50 was used for the RCC. Typical sections are given in Figure 12. Special Provisions (SPs) were developed by AHTD for CTRB and RCC to govern the processes associated with design and construction. The details of the SPs were compiled based on literature review, prior research, the experiences of other states, and compatibility with existing state specifications. The special provisions pertaining to the RCC and CTRB are included in Appendix A.



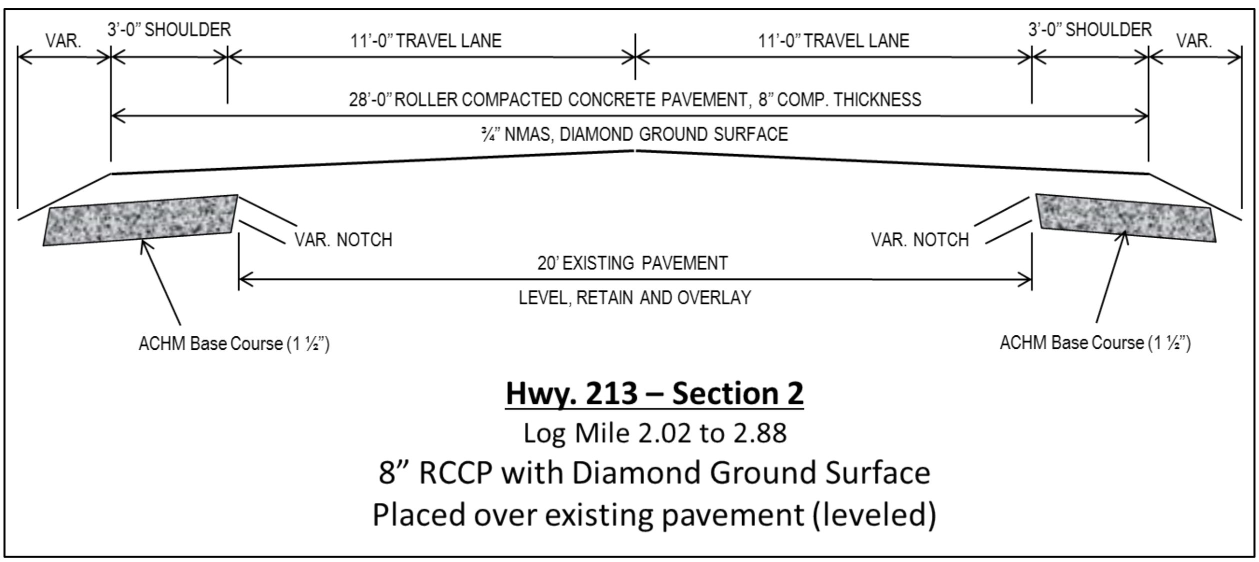




**Figure 12. Typical Sections for RCC Construction**

Because of the widening of lanes and addition of shoulders, the ditch and right-of-way dimensions were analyzed to ensure that these additions could be feasibly accommodated. The additional pavement thickness provided by the RCC raised the elevation of the driving surface, meaning that additional width was necessary for safe foreslope and backslope dimensions leading to existing ditches. The additional pavement width created a tight fit in some locations but no major modifications were required. Drainage structures were also reviewed to confirm that existing pipe lengths were adequate given the increase in pavement structure width. No changes were necessary to drainage structures.

**Cement Treated Reconstructed Base (CTRB)**

CTRB is similar to Full-Depth Reclamation (FDR), and employs pulverizing and mixing equipment to utilize the existing pavement structure in forming the base layer for the new pavement structure. The CTRB was designed using the modified Proctor method (AASHTO T180) to identify the maximum dry density and optimum moisture content of the pulverized material. Cement content was determined by selecting a percentage that would provide compressive strengths in the range of 300 to 500 psi. In this project, the CTRB had a laboratory maximum dry density of 126.9 pcf, an optimum moisture content of 7.6 percent, and a cement content of 4 percent. During construction the minimum in-place density was required to be 96 percent of the maximum dry density, as measured by the nuclear method outlined in AASHTO T310.

**RCC Mixture Design**

The RCC mixture design was performed using the modified Proctor method (AASHTO T180). The moisture content was optimized for the aggregate blend and cement content that provided the required minimum compressive strength of 5000 psi. A summary of the mix design generated for this project is shown in Table 6. The optimum moisture content was 6.9 percent, and the maximum dry density was 139.1 pcf. The mix contained approximately 15 percent cementitious materials, 20 percent of which was fly ash. Aggregate quality requirements for the RCC mixture were the same as those used for conventional concrete mixtures in Arkansas, as specified in Section 500 of the AHTD Standard Specifications for Highway Construction. (AHTD 2003) A different gradation, however, was specified for the RCC. To meet the gradation specification, coarse aggregate, fine aggregate, and intermediate screenings were blended. The coarse aggregate was a crushed sandstone, the fine aggregate was a natural sand, and the intermediate screenings were used to meet the gradation specification on the smaller sieve sizes. All aggregates were locally available. The resulting gradation for the mix, as well as the allowable specification band, is shown in Figure 13.

**Table 6. Summary of RCC Mix Design**

| Item | Description | Proportion | Wt. / $yd^3$ |
|---|---|---|---|
| Aggregate (% of Agg. Blend) | Coarse Aggregate #57 | 55% | 1893 lbs |
| | Fine Aggregate Sand | 35% | 1132 lbs |
| | Mfr. Screenings | 10% | 210 lbs |
| | | | |
| Cement Content (%) | Type 1 | 14.8% | 451 lbs |
| Replacement (% cementitious) | Class C Fly Ash | 20% | 113 lbs |
| Optimum Moisture (%) | | 6.9% | 28.4 gals |
| Density | Maximum Dry (Proctor) | 139.1 pcf | |
| | | | |
| w/c ratio | | 0.42 | |
| | | | |
| Compressive Strength (psi) | 3 days | 3240 | |
| | 5 days | 4410 | |
| | 7 days | 5330 | |

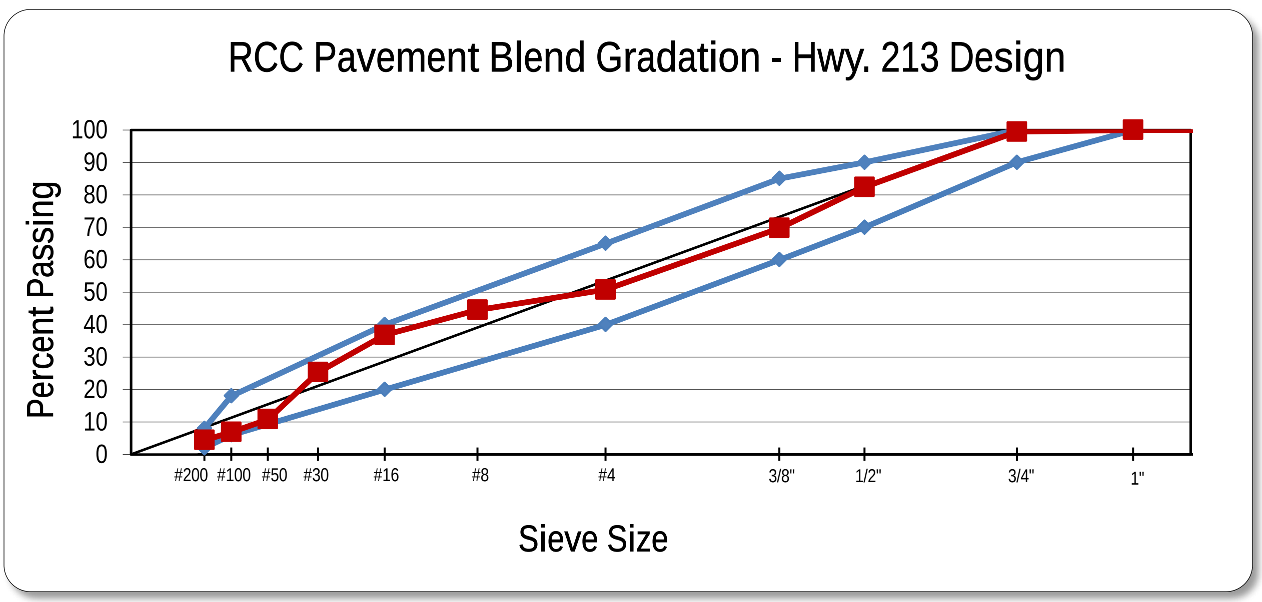



**Figure 13. RCC Gradation and Specification Band**

**CONSTRUCTION**

The project contract began in September 2012. The RCC plant was then set up and paving equipment was brought to the site in preparation for a test strip of the RCC mixture.

**RCC Production**

A pugmill mixer with a scalping screen was set up near the aggregate quarry which was located at the east end of Section 2. Because the mix design included three aggregate components, three cold feed bins were used at the plant. Two silos were used, one for cement and one for fly ash. After mixing, the RCC was transferred by conveyor to a hopper, from which dump trucks were loaded. The RCC plant is shown in Figure 14.

**Figure 14. RCC Pugmill Mixer Plant**

Approximately four weeks prior to construction, a test strip was placed (shown in Figure 15). The density behind the screed was lower than desired, and compressive strengths of cores were also low. A new paver (European Caterpillar high-density paver) was acquired and a second test strip was placed (Figure 16). After the modifications, 24-hour compressive strengths of cores were 1250 psi, on average. This test strip was successful in demonstrating the consistency of the plant production process and allowed the paving crew to develop a greater comfort level with the new equipment.

**Figure 15.  First Test Strip of RCC Placement (photo courtesy AHTD)**


**Figure 16.  Second Test Strip of RCC Placement (photo courtesy AHTD)**

**Cement Treated Reconstructed Base**

The existing asphalt and base materials were pulverized in place to a depth of 6 inches, such that 98 to 100 percent of the material passed a 2-inch sieve, at least 95 percent passed the 1.5-inch sieve, and 25 to 55 percent passed the #4 sieve. Next, cement and water were continuously distributed onto the pulverized material to reach the target cement and optimum moisture contents, and were then mixed and compacted in place. This process is shown graphically in Figures 17-21. The CTRB product was a sustainable solution in that it allowed the existing materials to be utilized to form a structurally desirable base for the RCC pavement layer, and the only materials that were required to be hauled in were cement and water. No aggregate haul trucks were needed, which sped the construction process, reduced construction traffic, and reduced vehicle emissions.

**Figure 17. Pulverizing Existing Asphalt Pavement**


**Figure 18. Pulverizing Existing Asphalt Pavement**

**Figure 19. Spreading Cement on Pulverized Material**


**Figure 20.  Mixing Pulverized Material with Cement and Water**


**Figure 21.  Compacting Mixed Base Material**

Samples of the pulverized material were obtained and tested for gradation. The results were very consistent, and met the gradation requirements contained in the SP for CTRB. The average gradation for each lane of the pulverized material is given in Table 7.

**Table 7. Average Gradation Results for CTRB by Lane**

| | | WB Lane | EB Lane |
|---|---|---|---|
| **Sieve Size (U.S. Std.)** | **Sieve Size (mm)** | **Average % Passing** | **Average % Passing** |
| 2 | 50 | 100 | 100 |
| 1-1/2 | 37.5 | 100 | 100 |
| 1 | 25 | 100 | 96 |
| 3/4 | 19 | 92 | 90 |
| 1/2 | 12.5 | 81 | 76 |
| 3/8 | 9.5 | 71 | 67 |
| #4 | 4.75 | 45 | 44 |
| #8 | 2.36 | 28 | 29 |
| #16 | 1.18 | 19 | 20 |
| #30 | 0.6 | 13 | 14 |
| #40 | 0.425 | 11 | 11 |
| #50 | 0.3 | 9 | 9 |
| #100 | 0.15 | 5 | 5 |
| #200 | 0.075 | 1.5 | 1.2 |

The CTRB for the westbound lane of Section 1 was completed in one day, and the eastbound lane was completed the next day. Two passes were used to pulverize each lane width, and then the cement and water were worked into the mixture in 1500-foot lengths. A grader and sheepsfoot roller were used to apply initial compaction, then two passes of a steel-wheel vibratory roller were used to accomplish intermediate compaction. Finish rolling was performed using a single pass of the steel-wheel roller in static mode. Densities were measured using the nuclear density gauge at various distances from the centerline of the roadway. The nuclear gauge used by the research team produced erratic (and suspect) results for the westbound lane, and so quality control was based solely on contractor testing. These results were marginal, ranging from 95 to 97 percent for the westbound lane. To increase densities in the eastbound lane, the vibratory passes were applied more quickly after the mixing process. A different nuclear gauge was used by the research team for the eastbound lane, and these density readings are shown in Figure 22.

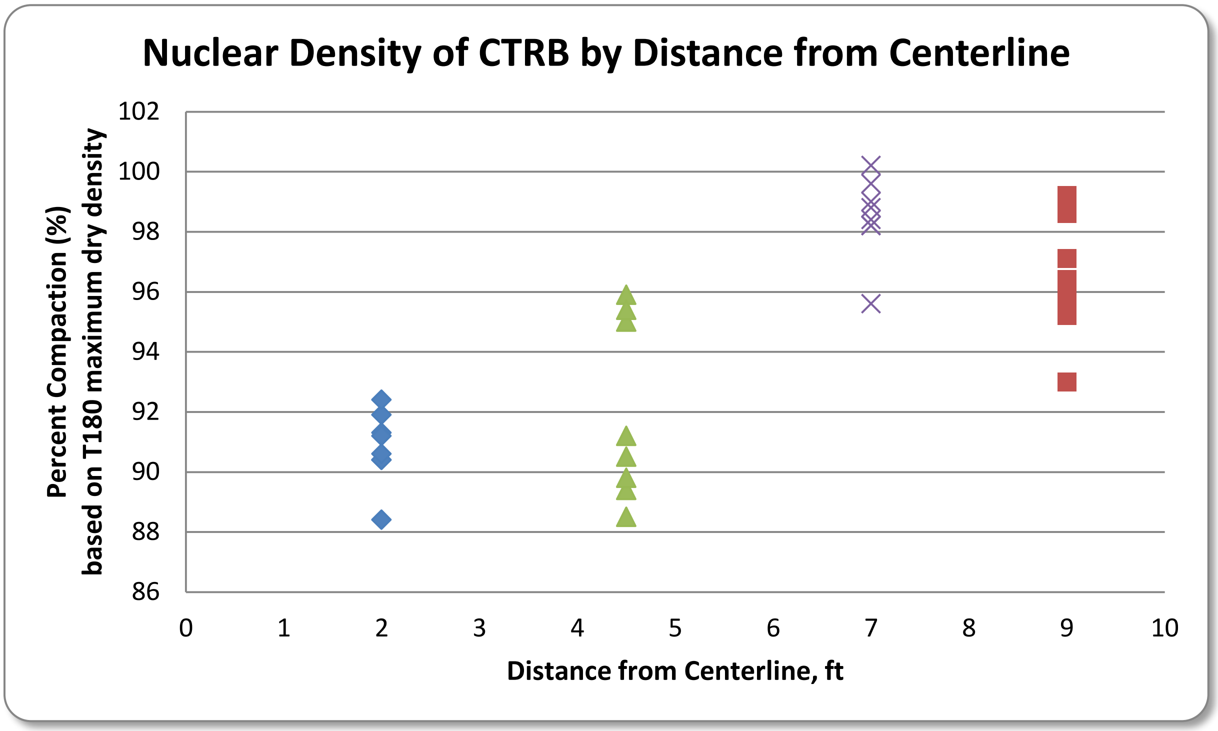



**Figure 22. Density of CTRB in the Eastbound Lane for Varying Distances from the Centerline**

The density varied across the width of the lane such that the highest densities were measured at about 7 feet from the centerline, and lower densities were measured near the centerline. Although the two edges had similar confinement during compaction, the lane edge was denser than the area near the centerline. Additional roller passes were applied in low density areas identified by quality control/quality assurance (QC/QA) testing.

At any given time during construction of the CTRB, a portion of one lane was inaccessible to traffic. Because this was a rural two-lane roadway with no shoulders, a pilot car was used to guide one-way traffic through the affected area. During the construction of the CTRB in the eastbound lane, vehicles were allowed to traffic the compacted westbound lane. The pilot car was successful not only in directing one-lane traffic, but also in limiting the speed of vehicles on the newly compacted CTRB to approximately 35 mph. The completed CTRB was left exposed to traffic until it was covered with RCC. After several days, the surface of the CTRB began to ravel, as shown in Figure 23, so the surface was graded immediately prior to the placement of the RCC. The unintentional benefit of this process was that the excess material collected during grading was later used as graded material at the edge of the paved shoulder.

**Figure 23. CTRB Surface After Several Days of Traffic**

The RCC was not placed on Section 1 until both lanes of the CTRB construction were complete. While the entire process could have been constructed (and disrupted) one lane at a time, the decision to first complete all of the CTRB allowed for a shorter time frame in which the 7-inch elevation differential at the centerline would be present, reducing potential safety risks.

**RCC – Section 1**

The SP for RCC pavement required a minimum design compressive strength (AASHTO T22) of 5000 psi at 28 days and a minimum in-place compacted density of 98 percent of maximum density, based on wet density obtained by the modified Proctor test (AASHTO T180). All in-place density testing of the RCC was performed using the nuclear density gauge in direct transmission according to ASTM C1040.

RCC paving commenced on Monday, November 5, 2012, at the east end of the westbound lane of Section 2. The paving process is displayed pictorially in Figures 24 - 29. During construction of the first section of RCC, several problems were encountered. Most were related to minor malfunctions or maintenance issues within the plant, such as blown gaskets or broken belts. Recurring problems that related specifically to the RCC were clogs throughout the process. The cement and fly ash feed lines were placed at an angle, making them prone to clogging, and the humidity in Arkansas exacerbated this problem. A screw auger was later added to the cement feed and vibrators were added at various points within the plant to correct this problem. The down time for repairs at the plant translated to delays at the paver, and resulted in limited paving time available each day. Additional difficulties were experienced due to rain delays and shortened daylight hours. Because the RCC placement began in early November and daylight savings time had just ended, the workday was shorter, further limiting the available paving time each day. Night paving was not considered.

A material transfer device (MTD) was initially used to transfer the RCC mixture from the dump trucks to the paver hopper. After a short time, the MTD experienced mechanical difficulties and was removed from the process.

**Figure 24. Loading the Paver Hopper Using the Material Transfer Device**


**Figure 25. Loading the Paver Hopper Directly from the Truck**


**Figure 26. RCC Mat Behind the Paver**


**Figure 27. Compacting the Edge of the RCC Mat with the Breakdown Roller**


**Figure 28. Rolling the RCC Mat**

**Figure 29. Spraying Curing Compound on the Fresh RCC Mat**

Paving progress in Section 1 was slow. Weather and equipment/maintenance issues prevented consistent progress, limiting paving to less than 1000 linear feet per day for the first three days. Although the SP required a heavy duty paver that could produce densities of at least 85 percent behind the screed, densities averaged 83 to 84 percent. Adjustments were made to the paver, resulting in an acceptable increase in density behind the screed. Compacted densities initially ranged from 90 to 95 percent, and so a larger steel-wheel vibratory roller was brought in, which resulted in compaction levels that met the 98 percent minimum requirement. A rubber-tire finish roller was also used for a short time, but the steel wheel roller was able to provide a smoother surface. The rolling pattern was established as two passes of the vibratory roller, followed by one pass in static mode. Approximately one inch of roll down was observed during breakdown, as shown in Figure 30.

**Figure 30.  Roll down of 1 Inch Achieved by Breakdown Roller**

After final compaction was completed, in-place densities were measured.  Then curing compound was sprayed onto the mat, and joints were sawn at 15-foot spacings using an early-entry saw.  Depth control was used to establish grade, which was based on the finished elevation of the CTRB.  Core measurements were used to confirm mat thickness.  During the first day of paving, the mat thickness exceeded the design thickness, sometimes being as thick as 11 inches (see Figure 31).  The increase in thickness made it more difficult for the paver and roller to produce adequate densities.

**Figure 31. Pavement Thickness of Approximately 11 Inches**

A "Safety Edge", as shown in Figure 32, was an innovative technology used on the project. The Safety Edge is one of the focal technologies of the Federal Highway Administration's Every Day Counts initiative. Although this technology is most often applied to asphalt pavements, it was identified as presenting a significant safety feature for this project. The safety edge was specified as having a maximum slope of 1:1, and was formed by a steel attachment on the screed, which assisted in providing confinement at the outer edge and provided an additional safety feature for the roadway.

**Figure 32. Safety Edge Attachment**

The centerline edge was not confined during paving (other than by the screed), so the longitudinal joint was sawed to remove approximately 4 inches of the mat and to provide a solid vertical face against which the eastbound lane could be compacted (see Figure 33). In some cases, poor mat quality required additional width to be removed so that the vertical face displayed adequate integrity, as shown in Figure 34. In these cases, a keyway pattern was used to minimize the effects of corners in the mat.

**Figure 33. Prepared Vertical Face at Longitudinal Joint**

**Figure 34. Keyway Cuts to Preserve Mat Integrity**

Paving in the eastbound lane was a bit smoother, progressing at an average rate of just over 1100 linear feet per day. Because paving was prohibited at temperatures below 40 F, paving was often delayed until 10:00am or later, resulting in an effective paving window of just seven hours each day. Given this constraint, the overall paving rate was approximately 150 feet per hour.

According to the SP for RCC, compressive strengths of 2500 psi were required for the pavement to be opened to traffic, which included construction traffic. Thus, paving in the eastbound lane could not begin until the westbound lane gained adequate strength to handle trucks delivering mix to the paver. The first section of the westbound lane was opened to traffic after four days.

During construction, and video camera was installed to provide live video feed of the area near the east end of Section 1. Using the camera IP address, AHTD and the research team could access live video of the activities on the site, including traffic control. This technology was very valuable for remotely monitoring construction progress, frequency of trucks, and pilot car activities. Examples of daytime and nighttime views of the camera are given in Figures 35 and 36.


**Figure 35. Real-Time Camera View**


**Figure 36. Real-Time Camera View at Night**

During production, in-place density of the compacted mat was measured according to ASTM C1040 using the nuclear density gauge in direct transmission. These results are shown in Figure 37. In Section 1, many of the test results did not meet the desired 98 percent density, particularly in the westbound lane. As stated earlier, some of the low densities were believed to be related to the excessive pavement thickness in some areas of that lane. It is evident that as greater familiarity was established with the overall paving process, the quality of compaction improved.

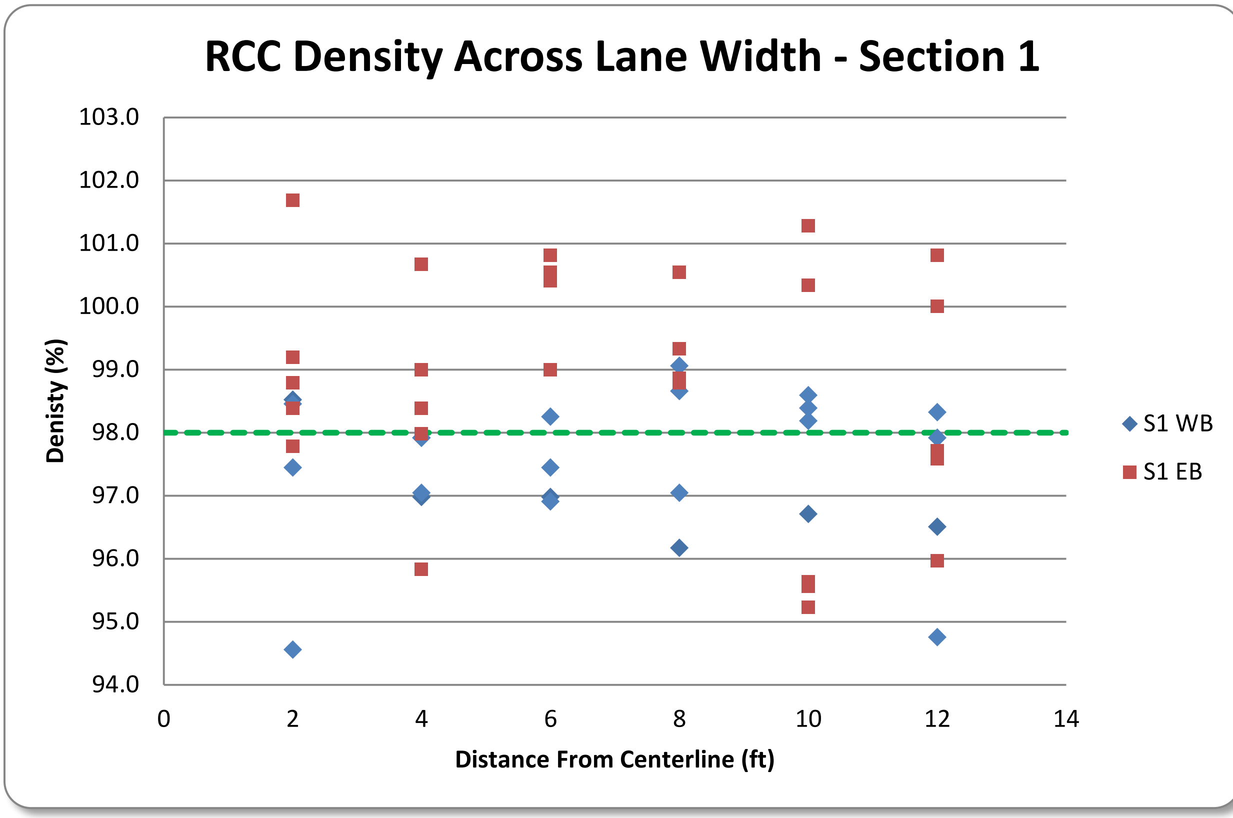



**Figure 37. Density of RCC at Varying Distances from the Centerline – Section 1**

In addition to density measurements, mix was sampled at the plant and used to fabricate sets of 12 cylinders according to ASTM C 1435. Initial curing took place at the job site in insulated curing boxes, and the cylinders were then transported to the laboratory for final curing in a tank. Specimen weights and dimensions were recorded for calculating density, and pairs of cylinders were tested for compressive strength at curing times of 24 hours, as well as 3, 7, 14, 28, and 90 days. These results are shown in Table 8.

**Table 8. Summary Strength and Density Data for Cylinders from Section 1**

| | Sta. 195 WB | | Sta. 216 WB | | Sta. 200 EB | | Sta. 211 EB | |
|---|---|---|---|---|---|---|---|---|
| Age at Break | Strength (psi) | Density (pcf) | Strength (psi) | Density (pcf) | Strength (psi) | Density (pcf) | Strength (psi) | Density (pcf) |
| 24 hr | 1612 | 149.4 | 1224 | 148.1 | 504 | 150.0 | 409 | 152.5 |
| 3 days | 2608 | 151.1 | 3356 | 149.8 | 1882 | 151.0 | 1791 | 150.4 |
| 7 days | 3276 | 148.1 | 3513 | 148.7 | 2774 | 150.7 | 2332 | 150.5 |
| 14 days | 3693 | 148.7 | 3316 | 146.4 | 2968 | 151.2 | 2826 | 149.6 |
| 28 days | 3870 | 149.5 | 3451 | 146.0 | 3393 | 151.1 | 3263 | 149.5 |
| 90 days | 4333 | 149.6 | 4756 | 149.9 | 4205 | 151.4 | 4071 | 149.7 |

Compressive strength values of the RCC cylinders increased with curing time, and these results are shown on a semi-logarithmic plot in Figure 38. The target strength value for opening the mat to traffic was 2500 psi, which was achieved after approximately 3 days, on average. The minimum required 28-day strength was 5000 psi, which was not met for any of the cylinders prepared in Section 1. Density values for cylinders prepared form Section 1 ranged from 146.0 pcf to 152.5 pcf. However, lower densities did not correlate with lower strengths. In fact, some of the lowest strengths were associated with higher densities in the eastbound lane (Stations 200 and 211), while higher strengths were achieved for the lower densities for the westbound lane (Stations 195 and 216). Thus, no apparent correlation was noted between the strength and density characteristics of the cylinders.

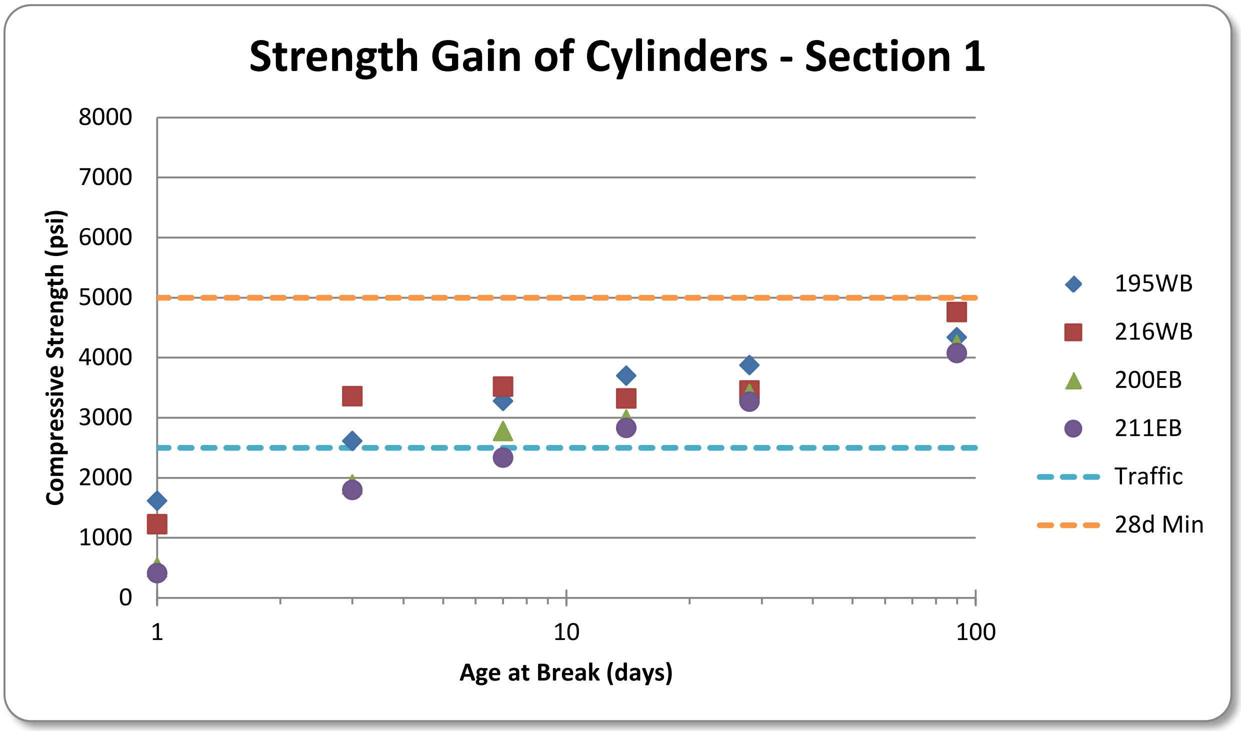



**Figure 38. Compressive Strength of Cylinders Over Time – Section 1**

Cores were also cut to assess the in-place strength of the RCC pavement. Triplicate cores were cut for 28-day strength determinations, and in some cases, additional cores were cut for early compressive strength assessments. The average core strengths are given in Table 9.

**Table 9. Average Core Strengths for Section 1**

| Station | Lane | Strength (psi) | Station | Lane | Strength (psi) |
|---|---|---|---|---|---|
| 193+01 | WB | 3307 | 188+77 | EB | 1741 |
| 196+93 | WB | 2792 | 192+89 | EB | 1927 |
| 203+75 | WB | 2899 | 199+90 | EB | 2413 |
| 207+60 | WB | 4182 | 209+48 | EB | 2999 |
| 217+96 | WB | 3347 | 213+66 | EB | 2476 |
| 223+17 | WB | 1032 | 221+83 | EB | 1219 |
| 230+30 | WB | 2135 | 230+89 | EB | 1950 |
| | | | 231+90 | EB | 2183 |
| **Average for WB Lane, Section 1** | | **2813** | **Average for EB Lane, Section 1** | | **2175** |

Clearly, core strengths did not meet the anticipated or desired levels, and were lower than the compressive strengths of cylinders made from the same locations. This is reasonable since the cylinders were cured in a controlled-temperature environment after the first 24 hours, while the cores were cured in ambient and more variable conditions. It was determined that changes were necessary to improve the mixture and the construction process.

**RCC - Section 2**

In Section 2, the RCC was placed as an 8-inch overlay. The existing deteriorated pavement was prepared by placing a leveling course, which served as a temporary driving surface for traffic. The completed levling course is shown in Figure 39.

**Figure 39. Leveling Course Placed Prior to RCC Overlay**

For Section 2, several changes were made to the construction process. First, fly ash was removed from the mix design and replaced with Type 1 cement, increasing the cost of the mix by approximately $3 per cubic yard. Also, a new pug mill plant system and paver were acquired, adding approximately $67,000 in rental and transport costs. The new plant was designed specifically for RCC, having a twin shaft mixer and vertical cement feed. The new paver was a heavier model, an ABG Titan, which had a heavier screed and more aggressive vibration. Progress was smoother and more consistent, and greater distances were paved each day. Weather and daylight length still impacted the number of paving hours available in a day, but production was increased to an average of over 1700 feet per day, with individual rates as high as 330 feet per hour. Mat densities as high as 97 percent were obtained behind the screed prior to rolling, and final compacted densities more easily met the 98 percent minimum requirement. Density results in Section 2, as determined by ASTM C1040, are given in Figure 40. Overall, the density readings were much improved over Section 1, with over 85 percent of the readings meeting the required minimum of 98 percent. In general, the greatest difficulty in meeting the desired level of density was experienced near the centerline, while relatively few issues were noted at the edge of the mat. This suggests that the safety edge was successful in providing confinement of the RCC mixture, allowing for adequate compaction.

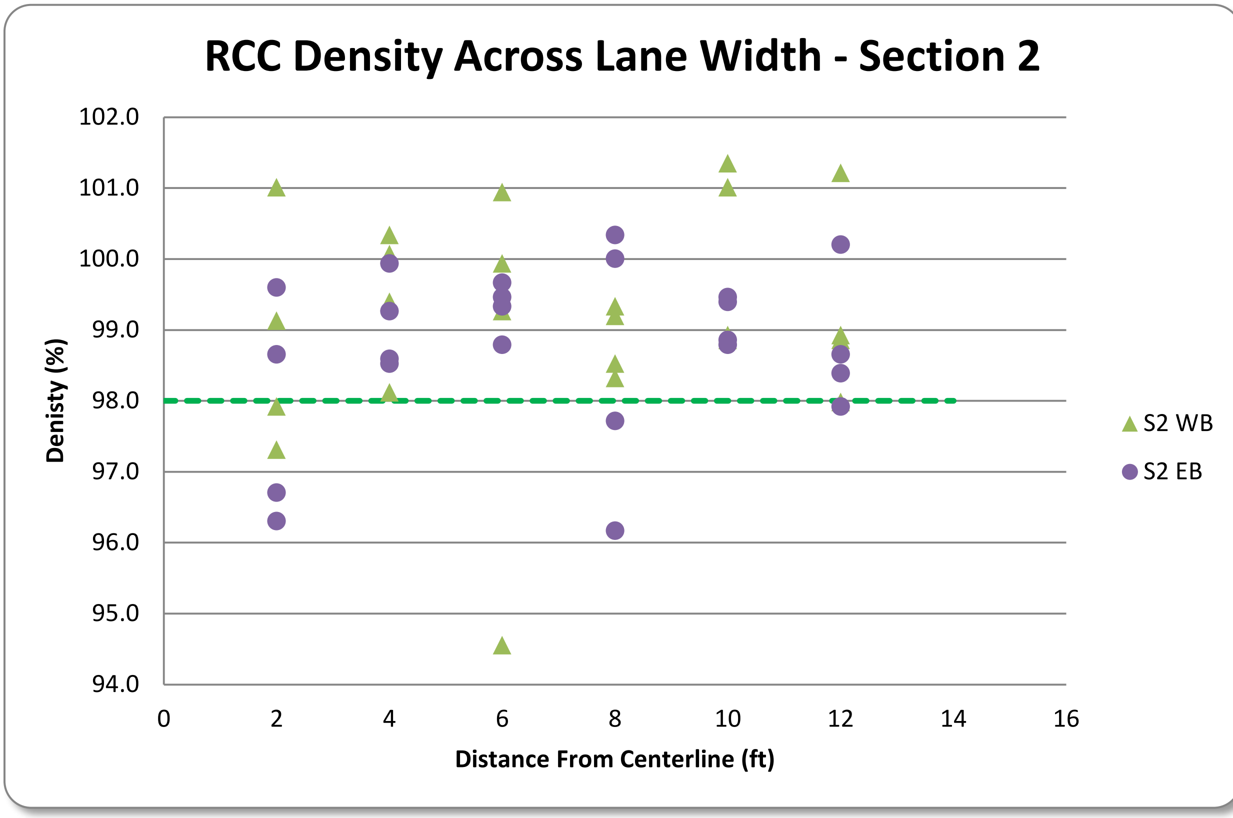



**Figure 40. RCC Density at Varying Distances from Centerline – Section 2**

Again, cylinders were prepared for compressive strength determination according to ASTM C1435, and tested at various ages. Density for each cylinder was also calculated. The results are given in Table 10.

**Table 10. Summary Strength and Density Data for Cylinders from Section 2**

| | Sta. 114 WB | | Sta. 127 WB | | Sta. 119 EB | | Sta. 143 EB | |
|---|---|---|---|---|---|---|---|---|
| Age at Break | Strength (psi) | Density (pcf) | Strength (psi) | Density (pcf) | Strength (psi) | Density (pcf) | Strength (psi) | Density (pcf) |
| 24 hr | 2424 | 148.5 | 1729 | 147.7 | 4784 | 151.1 | 3421 | 151.7 |
| 3 days | 3956 | 148.8 | 3790 | 147.9 | 5909 | 151.6 | 4706 | 152.8 |
| 7 days | 4477 | 148.1 | 4081 | 148.2 | 6504 | 151.0 | 6445 | 152.8 |
| 14 days | 4558 | 147.8 | 4893 | 148.0 | 6371 | 152.0 | 5662 | 152.7 |
| 28 days | 4859 | 148.2 | 5028 | 148.7 | 6586 | 149.7 | 5991 | 150.0 |
| 90 days | 5459 | 147.7 | 5108 | 148.3 | 7698 | 151.4 | 6288 | 148.7 |

Obviously, compressive strengths were much improved in Section 2, with 24-hour strengths ranging from 1729 to 4784 psi. Density values ranged from 147.7 to 152.8 pcf. The densities of the eastbound lane were generally higher than those of the westbound lane. Strength values were also higher in the eastbound lane, indicating a possible correlation. The strength gain characteristics are shown in Figure 41. In many cases, the strength requirement for trafficking the mat was met after just 24 hours, and was easily met within a 3-day window. On average, the mat could be opened to traffic in 24 to 48 hours, which is consistent with the available literature for RCC pavements. While most of the strength gain was achieved during the first three days, additional increases were noted throughout the 90-day testing period. With the slight exception of Station 114WB, all 28-day strength requirements of 5000 psi were met, which was a drastic improvement over Section 1.

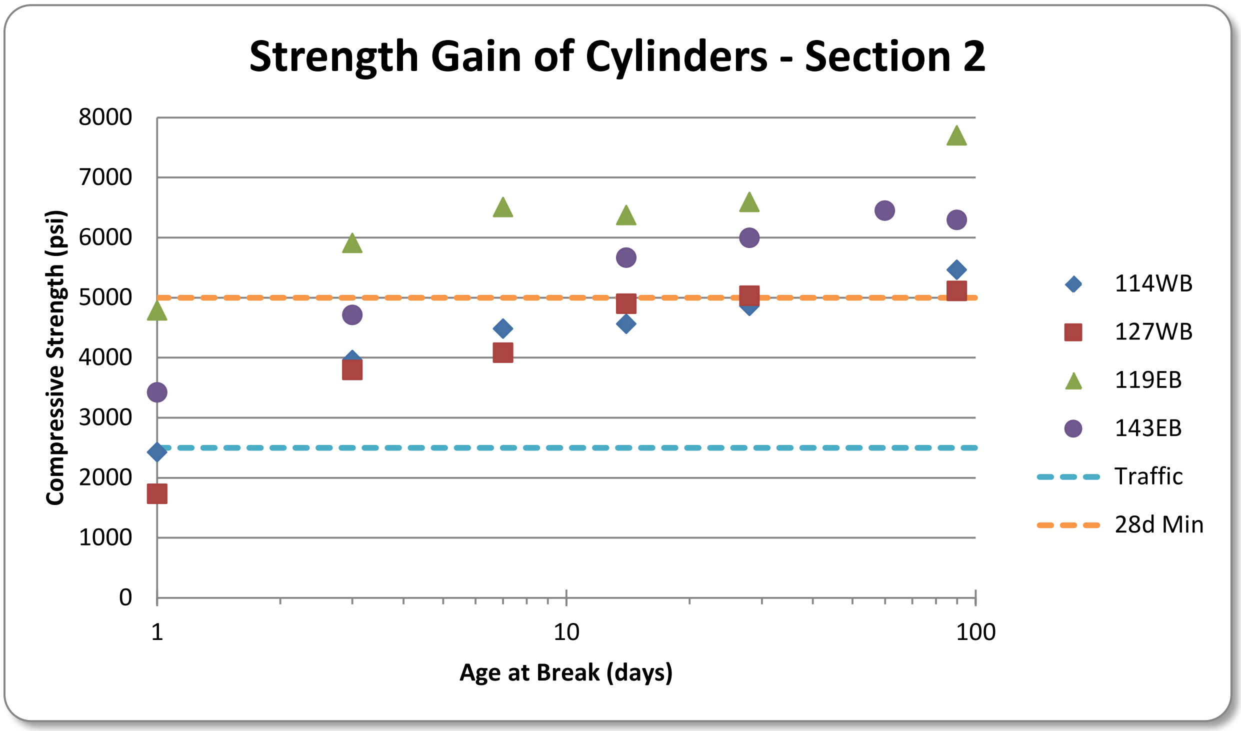



**Figure 41. Compressive Strength of Cylinders Over Time – Section 2**

Triplicate cores were also cut at various locations in Section 2. These cores were used to verify that adequate mat thickness was achieved, and to assess 28-day compressive strength. This data is given in Table 11.

**Table 11. Average Core Strengths for Section 2**

| Station | Lane | Strength (psi) | Station | Lane | Strength (psi) |
|---|---|---|---|---|---|
| 110+31 | WB | 3357 | 108+25 | EB | 3556 |
| 115+45 | WB | 4686 | 118+27 | EB | 5109 |
| 121+04 | WB | 2862 | 122+90 | EB | 4759 |
| 132+23 | WB | 2775 | 131+58 | EB | 4099 |
| 134+87 | WB | 3836 | 134+41 | EB | 2971 |
| 143+55 | WB | 4143 | 143+54 | EB | 4589 |
| 150+30 | WB | 1703 | 145+09 | EB | 3244 |
| | | | 151+43 | EB | 3173 |
| **Average for WB Lane, Section 2** | | **3337** | **Average for EB Lane, Section 2** | | **3938** |

While the core strengths were higher than those in Section 1, they still did not meet the desired compressive strength of 5000 psi. The likely reason for this difference was the difference in curing conditions experienced by the cylinders and cores.

**Replacement of Section 1**

As previously shown, the 24-hour strengths of cores taken from the eastbound lane of Section 1 were very low (approximately 500 psi), and the cylinders appeared very green. Strengths after 3, 7 and 14 days were also less than desired. Cool night time temperatures and the presence of fly ash were believed to have contributed to the slow strength gain in this section. Due to the poor strength levels, the contractor opted to remove and replace the majority of Section 1.

On December 8 through 13, approximately ½ of the westbound lane and all of the eastbound lane were removed and replaced. Again, the advantages of familiarity led to more consistent and productive paving speeds, which were almost 300 ft/hr, on average. Following final compaction, nuclear density testing was performed, and the resulting values are given in Figure 42. Only one test results near the centerline failed the minimum requirement of 98 percent.

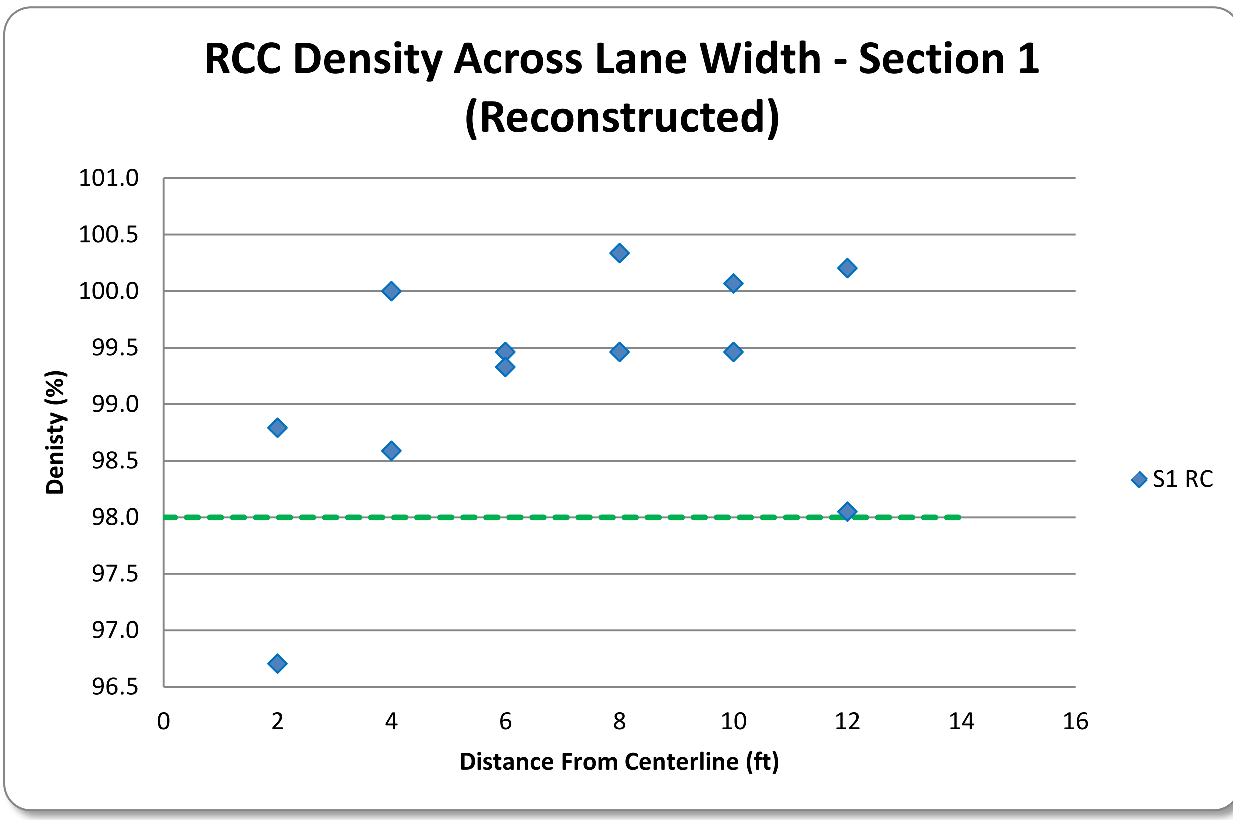



**Figure 42. RCC Density at Varying Distances from Centerline – Section 1 (Reconstructed)**

One set of cylinders was prepared using the plant-produced mix from the reconstructed section. Compressive strength and density data is shown in Table 12, and the strength gain plot is shown in Figure 43. The cylinder strengths indicated that the mat could be opened to traffic within 2 days, and the cylinders easily gained the required 5000 psi strengths within 28 days.

**Table 12. Summary Strength and Density Data for Cylinders from Section 1 (Reconstructed)**

| | Sta. 194 WB | |
|---|---|---|
| Age at Break | Strength (psi) | Density (pcf) |
| 24 hr | 2096 | 152.0 |
| 3 days | 4340 | 151.4 |
| 7 days | 4837 | 148.8 |
| 14 days | 5174 | 147.7 |
| 28 days | 5722 | 149.3 |
| 90 days | 6212 | 149.5 |

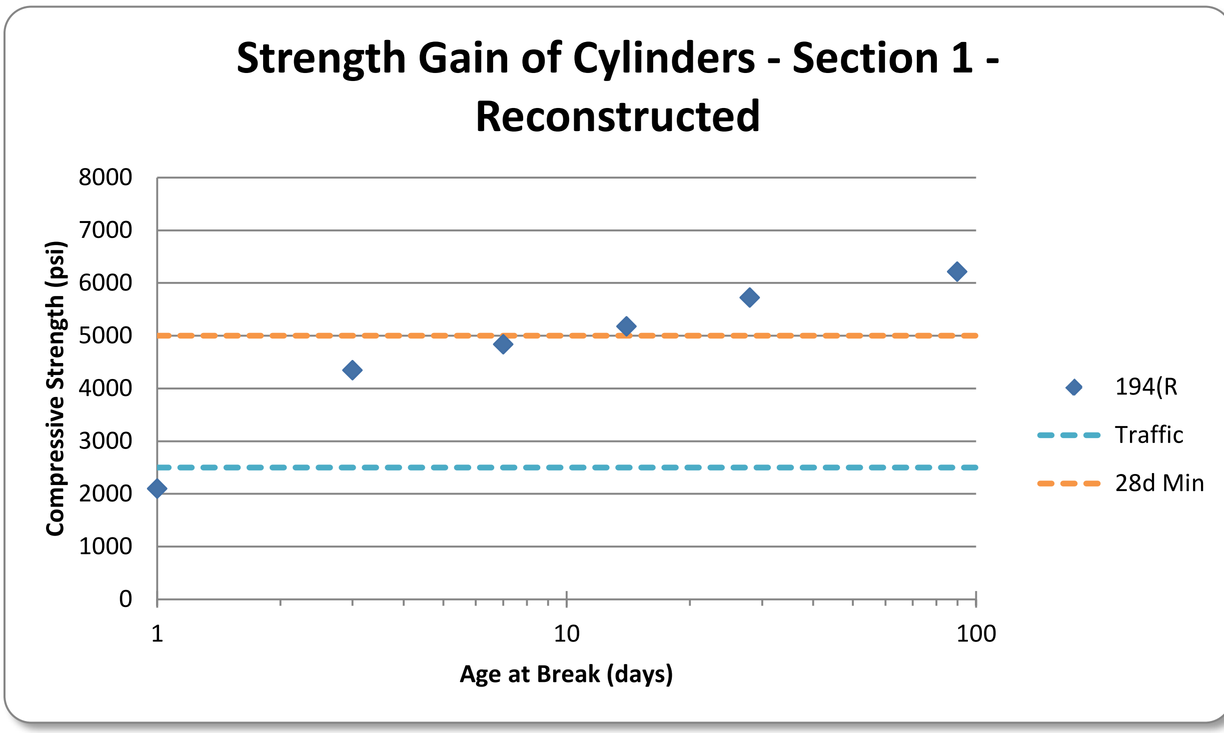



**Figure 43. Compressive Strength of Cylinders Over Time – Section 1 (Reconstruced)**

Again, triplicate cores were cut to assess 28-day compressive strengths in the reconstructed area. These results are given in Table 13.

**Table 13. Average Core Strengths for Section 1 (Reconstructed)**

| Station | Lane | Strength (psi) | Station | Lane | Strength (psi) |
|---|---|---|---|---|---|
| 217+96 | WB | 5025 | 188+77 | EB | 5130 |
| 223+17 | WB | 4675 | 192+89 | EB | 4167 |
| 230+30 | WB | 4628 | 199+90 | EB | 5676 |
| | | | 209+48 | EB | 4900 |
| | | | 213+66 | EB | 3851 |
| | | | 221+83 | EB | 3445 |
| | | | 230+89 | EB | 3848 |
| | | | 231+90 | EB | 4720 |
| **Avg for WB Lane, Section 1R** | | **4776** | **Avg for EB Lane, Section 1R** | | **4467** |

**Compressive Strength**

To further compare the compressive strengths of cores and cylinders, graphs were prepared for each lane of each section, as shown in Figures 44 through 48. The reconstructed portions of Section 1 are shown on a single graph.

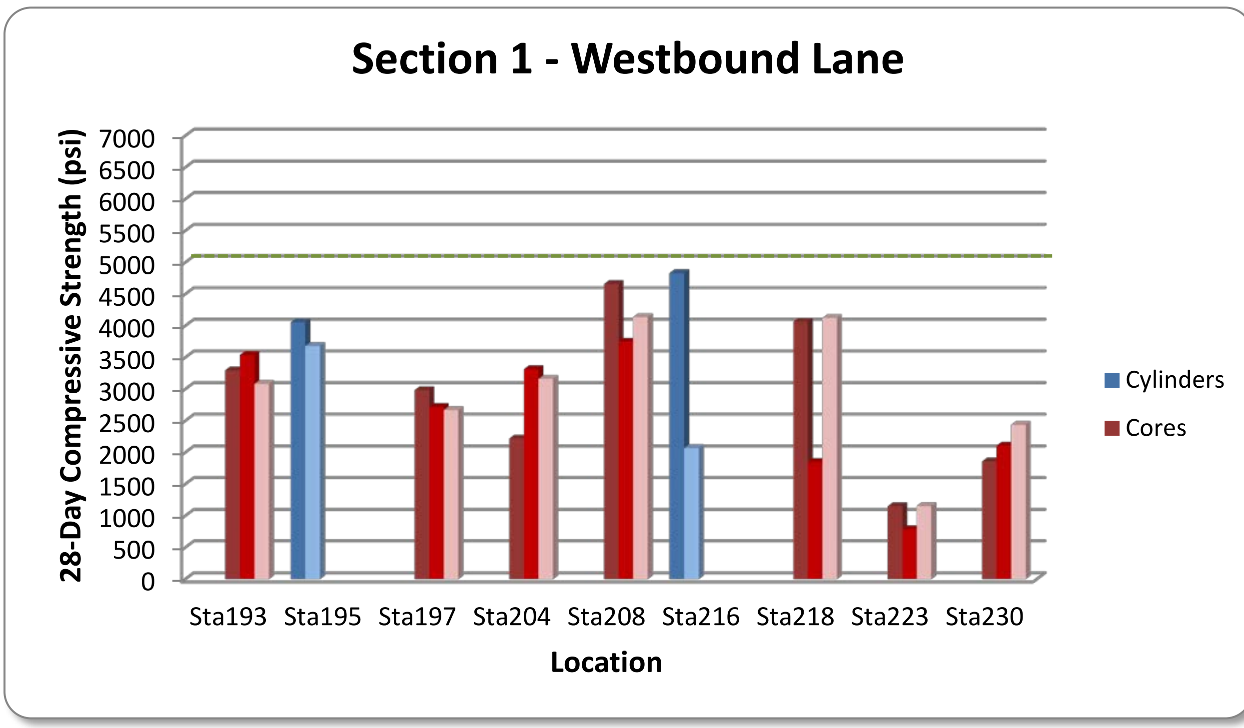



**Figure 44. Compressive Strength Comparison of Cylinders and Cores – Section 1 WB**

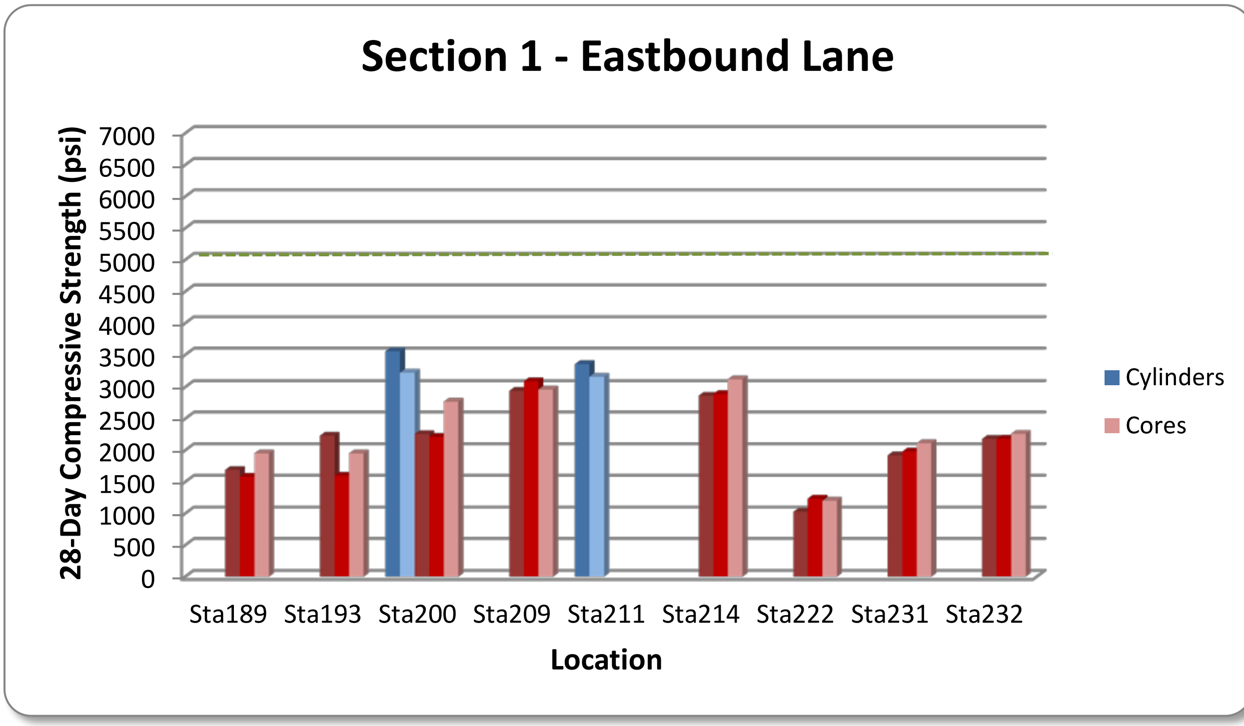



**Figure 45. Compressive Strength Comparison of Cylinders and Cores – Section 1 EB**

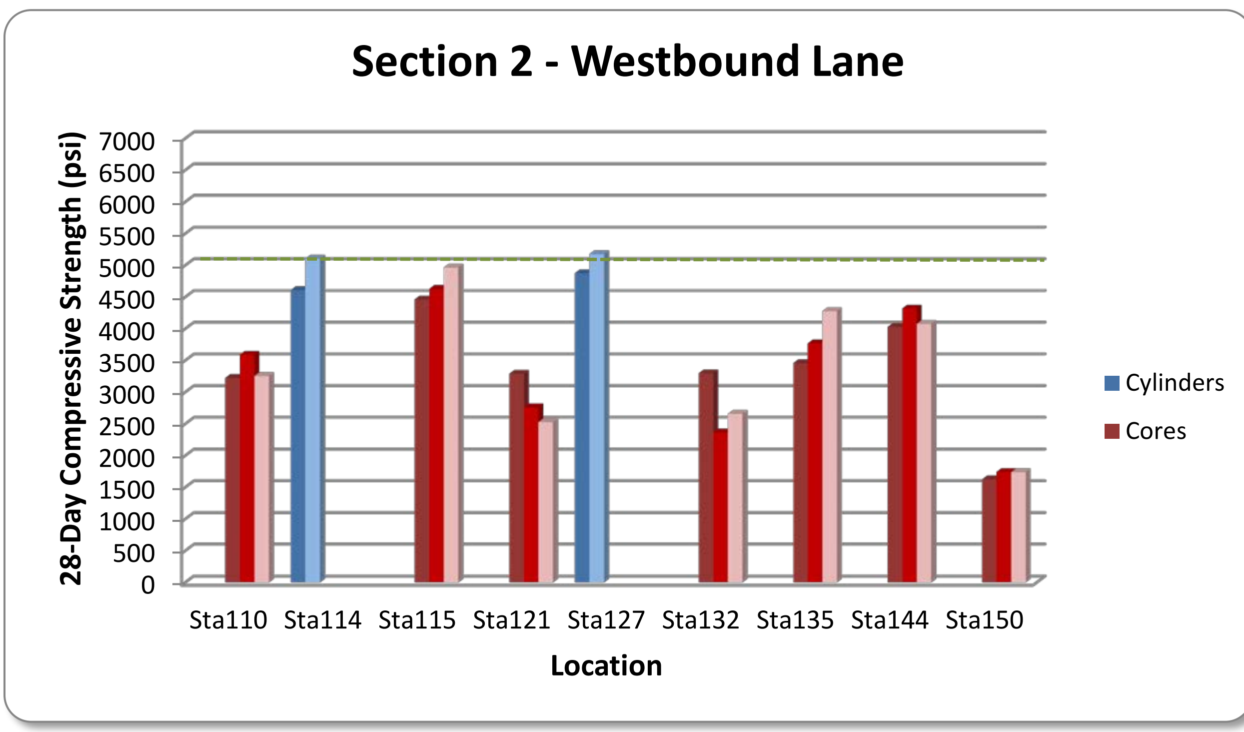



**Figure 46. Compressive Strength Comparison of Cylinders and Cores – Section 2 WB**

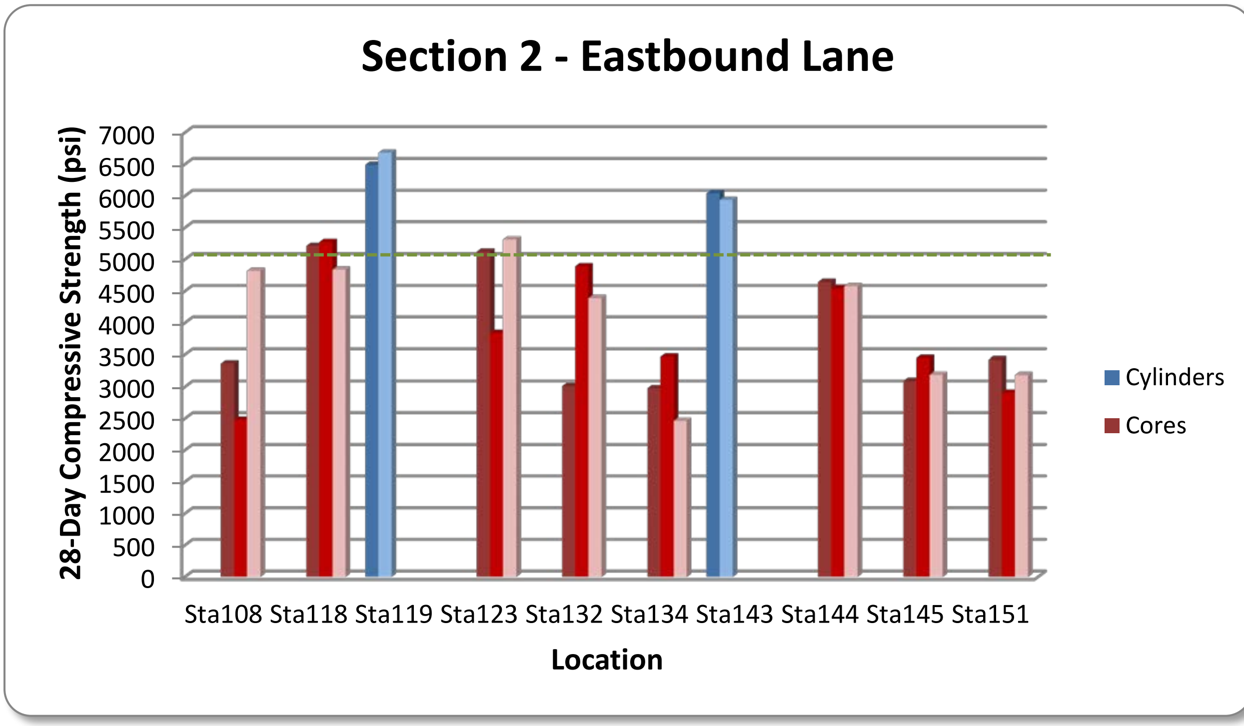



**Figure 47. Compressive Strength Comparison of Cylinders and Cores – Section 2 EB**

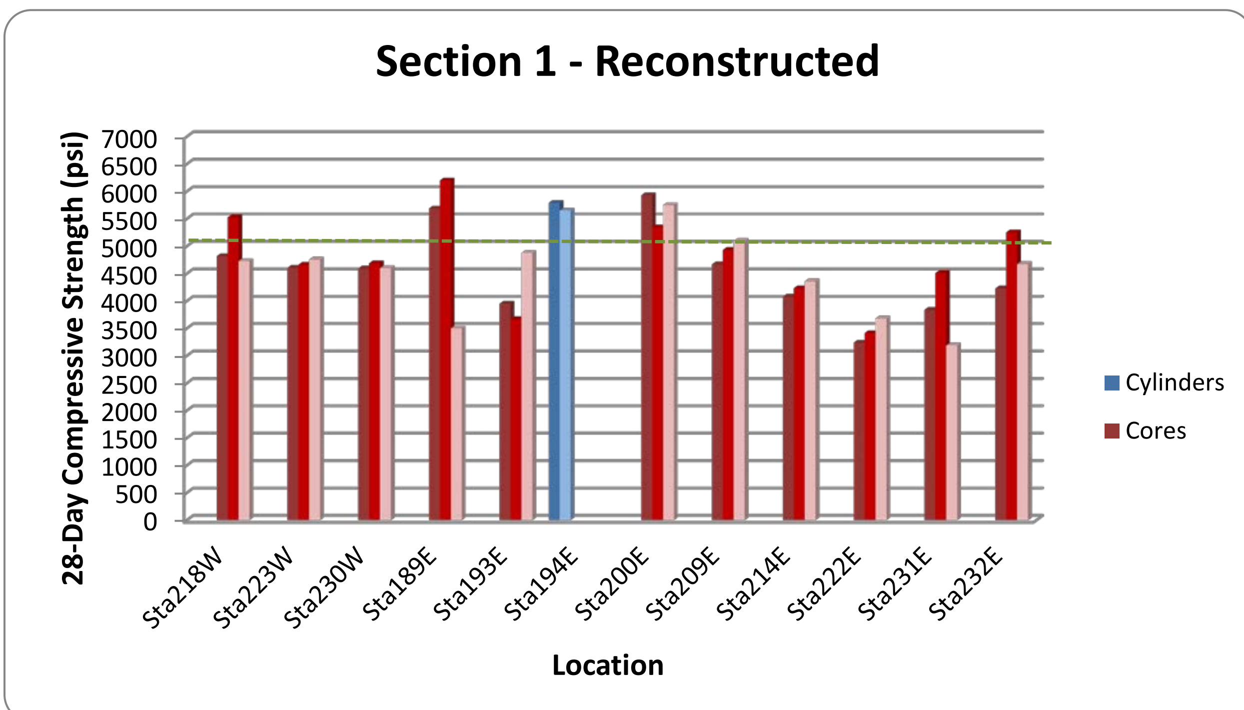



**Figure 48. Compressive Strength Comparison of Cylinders and Cores – Section 1 - Reconstructed**

Clearly, the original paving of Section 1 did not meet the desired compressive strength of 5000 psi. If the specification limit had been 4000 psi (as is required by AHTD for conventional concrete pavement), then a few individual test results for cylinders and cores in the westbound lane would have been considered acceptable, but no test results in the eastbound lane met this strength level. In Section 2, all cylinders and approximately one-third of the cores in the westbound lane had a compressive strength of at least 4000 psi. In the eastbound lane, all of the cylinders had a compressive strength of at least 4000 psi, and almost half of the cores exhibited this strength level. In the reconstructed portions of Section 1, approximately ¾ of the cores had compressive strengths of at least 4000 psi. There appears to be some collapse of strength between the design and construction of the RCC mixture. So, although the original mix design easily met the required design compressive strength of 5000 psi (and actually achieved that strength level within 7 days), those strengths were not achieved in the field. Therefore, differences in laboratory conditions during design and actual conditions during construction were believed to have significantly influenced strength levels.

**Effects of Temperature and Other Factors**

In addition to strengths during design and construction, significant differences were also noted between the cylinders and cores. The average 28-day cylinder strength in Section 1 was approximately 3500 psi, which was considerably greater than the corresponding average core strength of 2500 psi. For Section 2, the average 28-day cylinder strength was approximately 5600 psi, while the average core strength was approximately 3600 psi – a difference of 2000 psi. In the reconstructed portions of Section 1, the difference was 1200 psi, with the average cylinder strength being 5700 psi and the average core strength being 4500 psi. To further investigate this difference, curing temperatures were considered. After the first 24 hours, cylinders were cured in a controlled temperature curing tank, while the cores (not yet cut) were subjected to the cooler ambient temperatures during curing of the mat. In Figure 49, the daytime high and nighttime low temperatures are plotted by date, and annotated to indicate the paving days for each roadway segment, including the reconstructed portions. Nighttime low temperatures during the construction process averaged 35 degrees F and ranged from 19 to 60 degrees F, which was significantly cooler than the laboratory curing temperature of 73.5 ± 3.5 degrees F used for the cylinders.

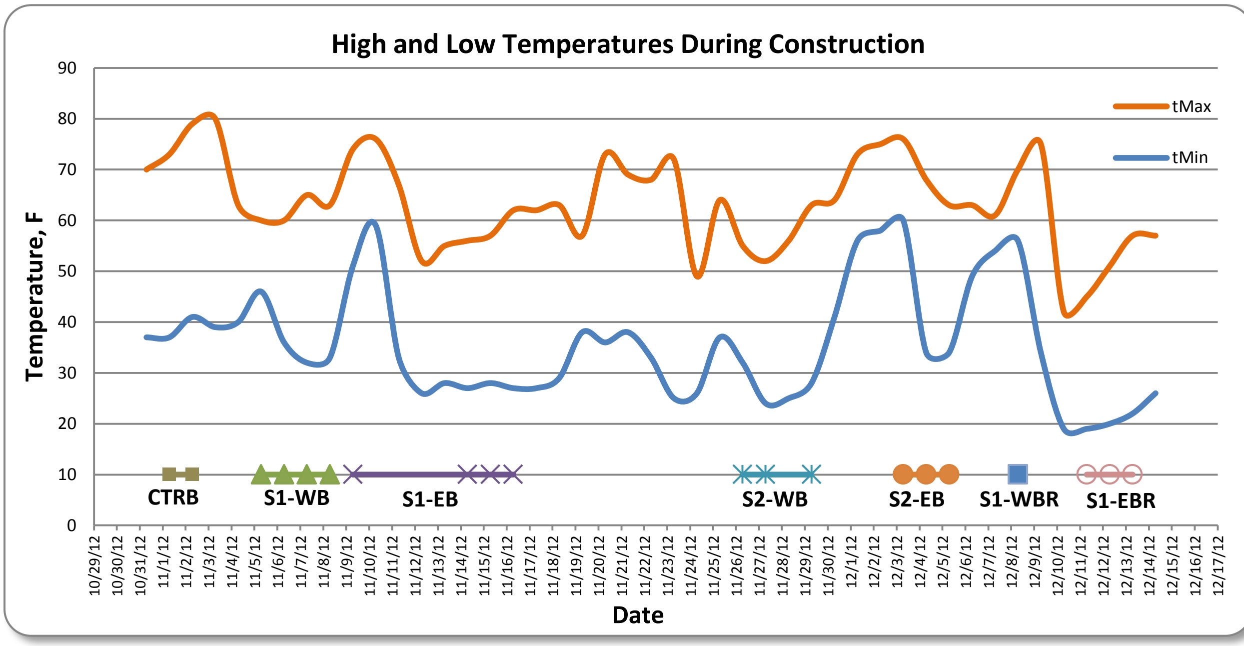



**Figure 49. Temperature Data for the Time Frame of Construction**

There were several significant temperature fluctuations during the time frame of construction. The eastbound lane was the portion that exhibited the poorest early strength results, and the paving dates also coincided with the first spell when nighttime temperatures routinely fell below the freezing mark. Thus, the cool temperatures were believed to have adversely affected the strength gain of the compacted mat. Next, the nighttime low temperatures were plotted against compressive strengths to assess whether or not a significant relationship existed. In Figure 50, 24-hour cylinder strengths were used as the measure of strength because the cylinders were field cured during that time frame, and could be more directly identified with a single low temperature. The data points were separated by Section since the mix designs were different for each. The data points for the reconstructed portions of Section 1 were included with the Section 2 data because the Section 2 mix design was used for the reconstruction.

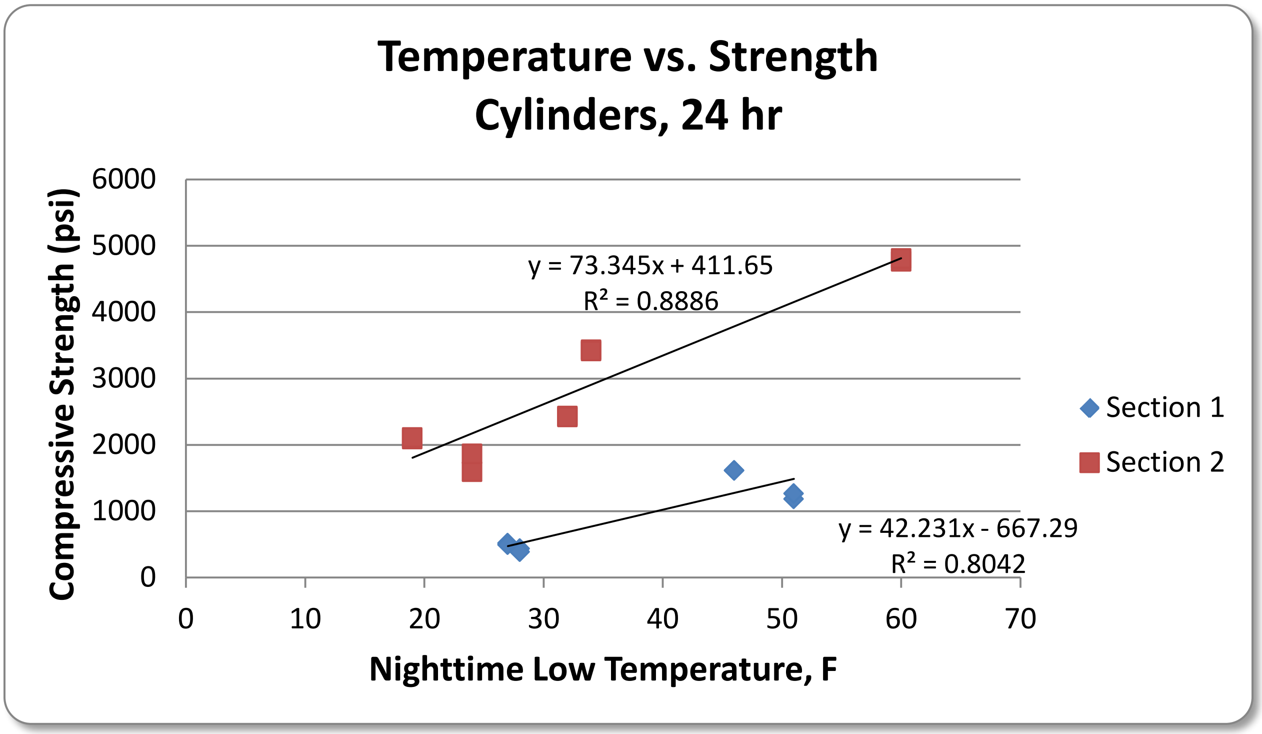



**Figure 50. Low Temperature vs. Compressive Strength at 24 hours**

Correlations were determined for each mix design, and significant relationships were present in each case. As the low temperature decreased, strengths also decreased. For Section 1, the $R^2$ value was 0.80, meaning that temperature was able to explain approximately 80 percent of the variability in 24-hour compressive strength. For section 2, a broader range of temperatures was experienced, and the $R^2$ value was 0.89, meaning that almost 90 percent of the change in compressive strength could be explained by temperature. The relationships for Section 1 and Section 2 differed significantly, however, such that the strength values were higher for Section 2. Because the primary difference between the mixes for the two sections was the removal of fly ash, it was concluded that the presence of fly ash suppressed strength gain during the first 24 hours of curing. In other words, the slope of the lines shows how temperature affects strength, and the relative position, or 'height' of each line represents the effect of fly ash on strength. Fly ash is known to retard strength gain in conventional concrete mixes, and based on the above relationships, the same appears to be true for RCC. It is noted that other factors may also play a role in the relationships.

To assess the effects of curing temperature, laboratory-prepared mix was used to form a set of cylinders that were cured in a 40 degree refrigerator. After 24 hours, the average compressive strength was 575 psi. This result was almost identical to that of the cylinders made in the field for the eastbound lane of Section 1. Thus, the low temperatures were believed to be at least partially responsible for the low strengths.

Other sources of variation could have a significant effect on the quality of RCC. Two in particular that could easily vary during construction are water content and cement content. The RCC mix design required 6.9 percent water and 14 percent cement. Cylinders were made in the laboratory using 0.6 percent increases and decreases in water, and reductions in cement content of 1 and 4 percent. Increases in cement content were not investigated because it is unlikely that additional cement would create a detrimental effect on strength. Duplicate cylinders were tested for compressive strength at 24 hours, 7 days, and 28 days. The results, shown in Figure 51, included variations of cement and water content, as well as the strengths for the cylinders cured at 40F. The design mix was the best performer, exhibiting the highest strengths at 24 hours and 28 days. The mix with the reduced water content performed well during the first 7 days, but did not gain strength after that. It is possible that not enough water was present to facilitate further strength gain. The mix with additional water gained strength quickly, but did not perform well at 28 days, indicating that RCC mixes are indeed sensitive to fluctuations in water content. Specimens with reduced cement content were poorer performers, particularly at 28 days, lacking the strength of the design mix. The mix that was cured in cold conditions was extremely weak after 24 hours, but quickly gained strength as age increased. Since one of the primary advantages of RCC is to be able to open it quickly to traffic, 24-hour strength is important. This data suggests that 40F may be too cool for RCC to gain the necessary early strength.

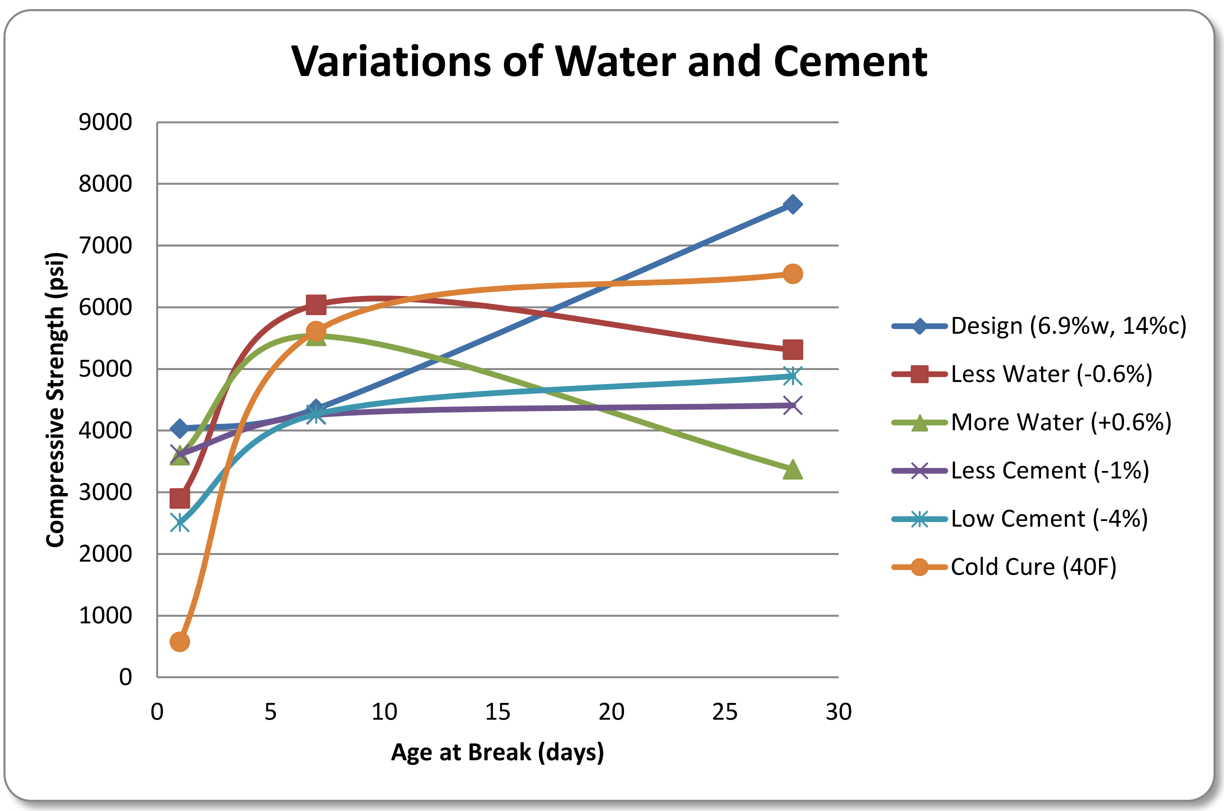



**Figure 51. Comparison of Compressive Strength for Variations in Water Content, Cement Content, and Curing Temperature**

**Paving Rate**

Despite two holidays, the entire RCC paving process was completed in just over one month. Paving progress in Section 1 was slow, and was affected by a number of challenges, including weather, shortened daylight hours, and equipment malfunctions. As familiarity with the process increased, paving speeds also improved. In addition, the changes in the plant, paver, and mix design proved to be beneficial not only to the RCC material properties, but also helped increase the efficiencies of the paving process. A summary of RCC paving progress is contained in Table 14. Paving rates as low as 129 feet/hour, and as high as 333 feet/hour were achieved. If the maximum rate of 333 ft/hr were maintained consistently on a summer day with 14 hours of daylight, a distance of over 4600 ft., or 0.88 miles, could be paved in a single day. At that rate, the entire project could have been paved in as little as 4 paving days.

**Table 14. Paving Rate Summary**

| Date | Beginning Station | Ending Station | Length Paved (ft) | Paving Time (hr) | Rate (ft/hr) | Comments |
|---|---|---|---|---|---|---|
| | **SECTION 1** | | | | | |
| 11/5/12 | 187 WB | 197 WB | 1000 | 5 | 200 | Rain / equipment issues |
| 11/6/12 | 197 WB | 205 WB | 800 | 4 | 200 | Plant issues |
| 11/7/12 | 205 WB | 210 WB | 500 | 3.5 | 143 | Cement clogged |
| 11/8/12 | 210 WB | 232 WB | 2200 | 11 | 200 | Intermittent plant issues |
| 11/9/12 | 187 EB | 194 EB | 700 | 4 | 175 | Equipment issues |
| 11/12/12 | | | 0 | 0 | | Holiday |
| 11/13/12 | | | 0 | 0 | | Plant issues |
| 11/14/12 | 194 EB | 205 EB | 900 | 7 | 129 | |
| 11/15/12 | 205 EB | 218 EB | 1300 | 5.5 | 236 | |
| 11/16/12 | 218 EB | 232 EB | 1400 | 8 | 175 | |
| | **SECTION 2** | | | | | |
| 11/26/12 | 106 WB | 117 WB | 1100 | 7 | 157 | |
| 11/27/12 | 117 WB | 134 WB | 1700 | 8 | 213 | |
| 11/28/12 | | | 0 | 0 | | Paver problems |
| 11/29/12 | 134 WB | 152 WB | 1800 | 8 | 225 | |
| 12/3/12 | 106 EB | 129 EB | 2300 | 8 | 288 | |
| 12/4/12 | 129 EB | 135 EB | 600 | 2.5 | 240 | Rain |
| 12/5/12 | 135 EB | 152 EB | 1700 | 6 | 283 | |
| | **RECONSTRUCTION OF SECTION 1** | | | | | |
| 12/8/12 | 210 WB | 232 WB | 2200 | 8 | 275 | |
| 12/11/12 | 187 EB | 199 EB | 1200 | 3.6 | 333 | |
| 12/12/12 | 199 EB | 218 EB | 1900 | 6.5 | 292 | |
| 12/13/12 | 218 EB | 232 EB | 1400 | 5 | 280 | |

**MONITORING & PERFORMANCE**

By the time construction was complete, some isolated distresses had already begun to appear. For example, in the westbound lane of Section 1, a full lane width crack formed, and an additional area was patched to repair a failed transverse construction joint (see Figure 52). Some areas of raveling were also evident, and epoxy and concrete patches were placed in order to mitigate this problem. These patches are shown in Figures 53 and 54. It was noted that these early distresses appeared in the westbound lane of Section 1, which was the first portion of RCC pavement placed.

**Figure 52. Full Lane-Width Crack in Section 1 – Westbound Lane**

**Figure 53. Epoxy Patch at Construction Joint**

**Figure 54. Epoxy and Concrete Patches**

Six months after construction, a manual distress survey was performed to assess the condition of each section and lane of the RCC pavement. Additional distress surveys were also performed 9 months and 12 months after construction.

In section 1, the primary distresses noted were transverse joint spalls, longitudinal joint deterioration, cracking, and low areas. Section 2 experienced minimal cracking, but was more susceptible to popouts, raveling and segregation.

**Transverse Joint Deterioration**

Transverse joints were cut as soon as was practical after paving using an early entry saw. Joint sealant was used to aid in preventing deterioration due to water and incompressibles entering the joints. In most cases, the early deterioration of these joints was observed as a small crack along the edge of the joint, approximately 3 to 6 inches in length, as shown in Figure 55. Then, the edges of the joint gradually deteriorated to a more severe condition as shown in Figures 56 – 58.

**Figure 55. Early Transverse Joint Deterioration**

**Figure 56. Transverse Joint Deterioration**

**Figure 57.  Transverse Joint Deterioration**

**Figure 58.  Transverse Joint Deterioration**

Transverse joints were observed, and if cracking or spalling was present, then the joint was noted to be defective. Distresses were considered separately for each lane of each Section. However, since the reconstruction of Section 1 involved the entire eastbound lane and a portion of the westbound lane, it was not reasonable to separate Section 1 by lane. Instead, the length of Section 1 that was originally placed (and left in place) was considered as one length, and the reconstructed segments of Section 1 were considered as another portion. Since the lengths of the segments varied, all distresses were considered as a percentage of the given segment, or length. In the case of transverse joint spalling, distresses were considered as the percent of transverse joints that were defective, as given in Figure 59. The original westbound portion of Section 1 exhibited the greatest percentage of defective joints, which was expected. Except for the original segment of Section 1, joint deterioration did not advance between the 6-month and 9-month surveys (which was during the summer months), but deterioration did increase between the 9-month and 12-month surveys. This is reasonable since the 12-month survey was performed in colder weather when the joint spacings were largest, allowing for more breakage.

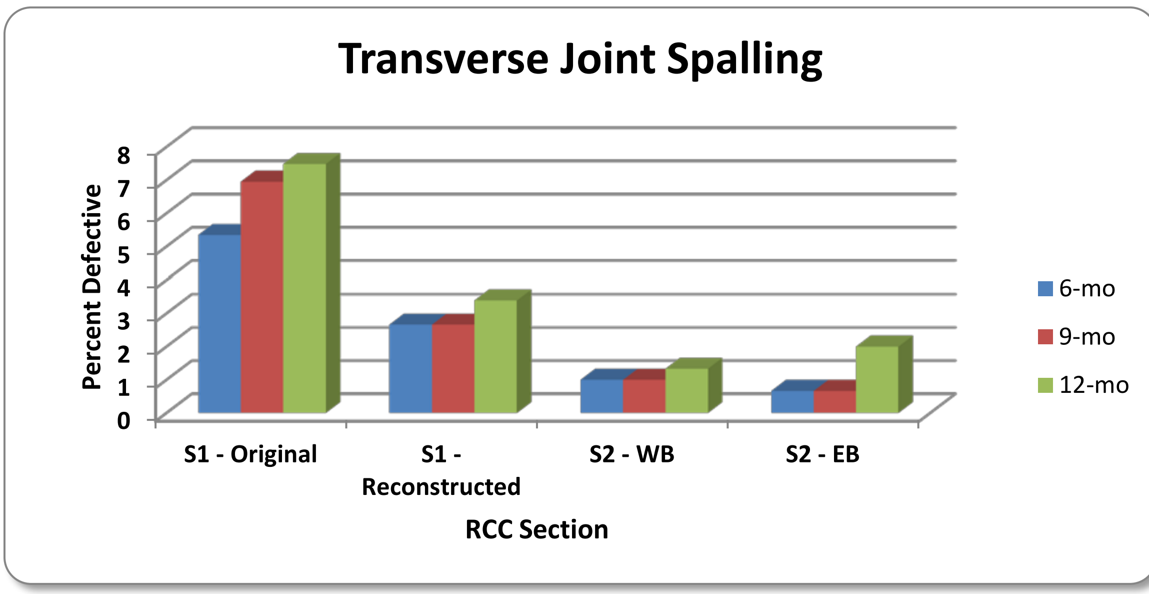



**Figure 59. Transverse Joint Spalling by Section**

**Longitudinal Joint Deterioration**

Longitudinal joint deterioration was also a significant concern. Because two adjacent lanes of RCC could not be placed at the same time, one lane was allowed to harden, and a minimum of 4 inches of the mat was sawed from the centerline area in order to form a solid surface against which to compact the second lane. Forming a dense, tight and smooth centerline joint proved to be somewhat of an art form, and was one of the most difficult features of the RCC paving process. As a result, early signs of deterioration began to appear along the longitudinal joint, and epoxy sealant was placed in an effort to slow the distress (see Figures 60 and 61). Unfortunately, in many locations, the sealant was not successful, and distresses continued to worsen, as shown in Figures 62 through 65. In some cases, the deterioration was more severe on one side of the joint than the other, creating a vertical differential as great as 1-1/2 inches.

**Figure 60. Centerline Longitudinal Joint with Sealant**

**Figure 61. Centerline Longitudinal Joint with Sealant**

**Figure 62. Deteriorated Longitudinal Joint**

**Figure 63. Deteriorated Longitudinal Joint**

**Figure 64. Deteriorated Longitudinal Joint**

**Figure 65. Deteriorated Longitudinal Joint**

Longitudinal joint deterioration was considered as a percent length of the joint, and is shown in Figure 66. The lanes for each Section were not considered separately because the joint in question is located between lanes. The original and reconstructed segments of Section 1, were considered separately, and again the original portion of Section 1 displayed the most severe centerline deterioration. In Section 1, most of the centerline joint deterioration occurred during the first 6 to 9 months, with the rate slowing somewhat between the 9 and 12 month surveys. Rates were steady in Section 2.

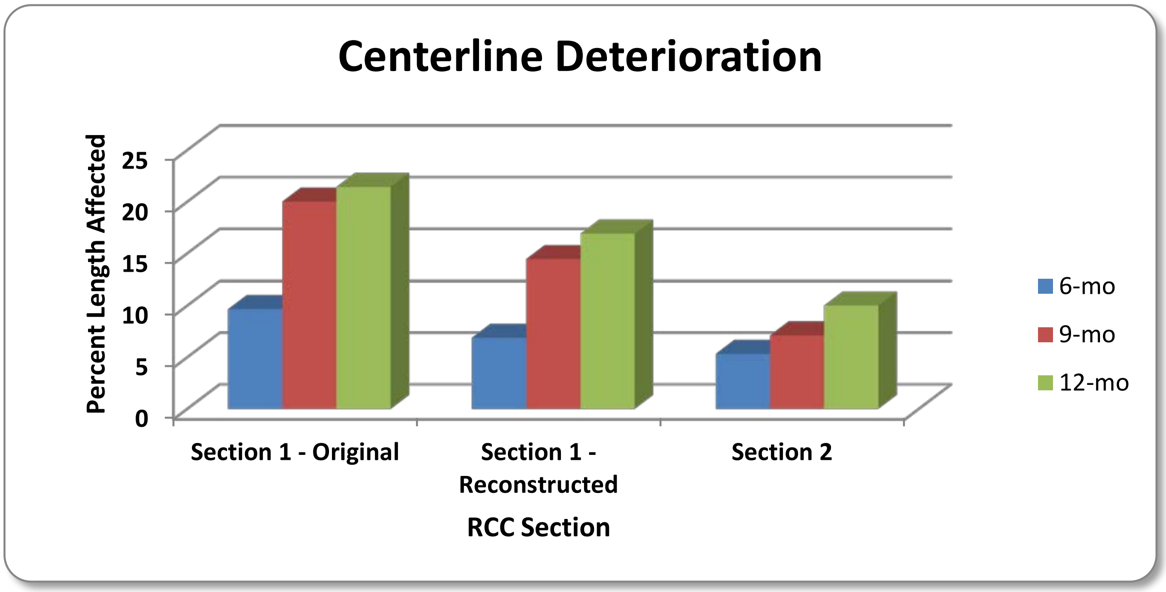



**Figure 66. Centerline Deterioration by Section**

### Cracking

Cracking was of great interest due to the decision to include jointing in the RCC paving plan. RCC does not require jointing; however, it is often preferable to include joints for aesthetic reasons and to control the location of inevitable cracks. Because RCC contains relatively little paste, the aggregate structure is important for load transfer. While the RCC (as with traditional concrete) is expected to crack, the cracks are expected to remain tight enough for the aggregate particles to provide the necessary load transfer. Jointing was simply used to force the desired location of cracks. 15-foot crack spacings were used for most of the project, although a short section (approximately 300 feet) was used to investigate the performance of a 30-foot joint spacing. This section was at the east end of Section 2. No cracks formed in that area, and only one crack formed in the entire length of Section 2. Thus, no certain comparisons could be made, though further investigation should be considered to confirm whether a 30-foot joint spacing would perform adequately.

As previously stated, one full-width crack was evident in the original westbound lane of Section 1 before the RCC construction was complete. No specific cause was determined for this crack; however, this crack was in the same general location that areas of low densities were previously identified. After 6 months, a total of 4 cracks were identified in the westbound lane of Section 1, as shown in Figures 67 - 70.

**Figure 67.  Eighteen Inch Corner Crack – Sta. 187+00 WB**

**Figure 68. Full Lane Width Crack – Station 199+90**

**Figure 69.  18-Inch Crack and Large Popout – Station 206+80**

**Figure 70. 2-Foot Crack – Station 212+00**

One full-width crack was identified in the reconstructed section of the eastbound lane of Section 1 during the 9-month survey. The other new cracks in the later surveys were best described as corner breaks. Only one crack was identified in Section 2, and it was also a corner break. The cracking distress summary is shown in Figure 71. In addition to the cracks totaled in the figure, two cracks were identified in the safety edge.

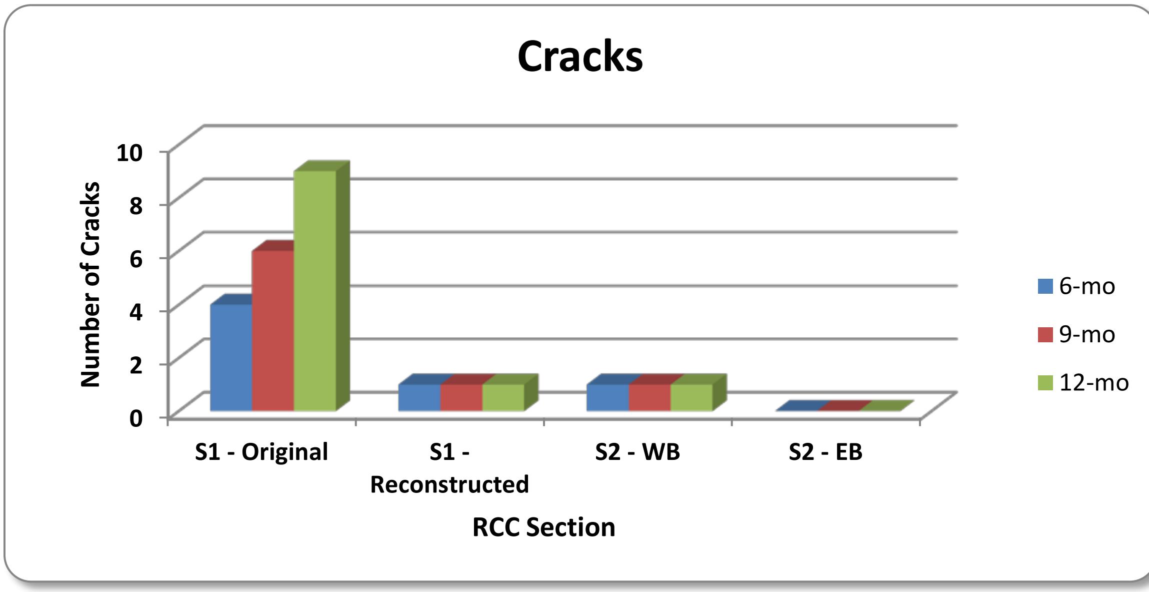



**Figure 71. Cracking Distress Summary by Section**

### Popouts

When considering joint deterioration and cracking, Section 2 to performed better than Section 1. However, Section 2 was prone to suffer from a different set of distresses, including popouts and segregation. The popouts were believed to be a function of the aggregate type and surface density, rather than a structural problem. Popouts ranged from 1 inch in diameter to almost 6 inches in diameter after the first year of service. In general, small popouts (those measuring less than 3 inches in diameter), were not included in the count for the distress survey, but medium and large popouts were. Medium popouts were considered to be 3 to 5 inches in diameter, and anything larger than 5 inches was considered a large popout. The various sizes are shown in Figures 72 – 74.

**Figure 72. Small Popout**

**Figure 73. Medium Popout**


**Figure 74. Large Popout**

Popouts were counted as the number of medium and large popouts, and were totaled per section. The progression of popout distresses are shown in Figure 75. Popouts were most prevalent in the westbound lane of Section 2 and the reconstructed portion of Section 1. While the original portion of Section 1 suffered from more overall distresses than any other section, it was not prone to popouts. The number of popouts did not increase dramatically throughout the first year of service. While a portion of the popouts grew from medium to large, most remained in the medium size category during the year of analysis.

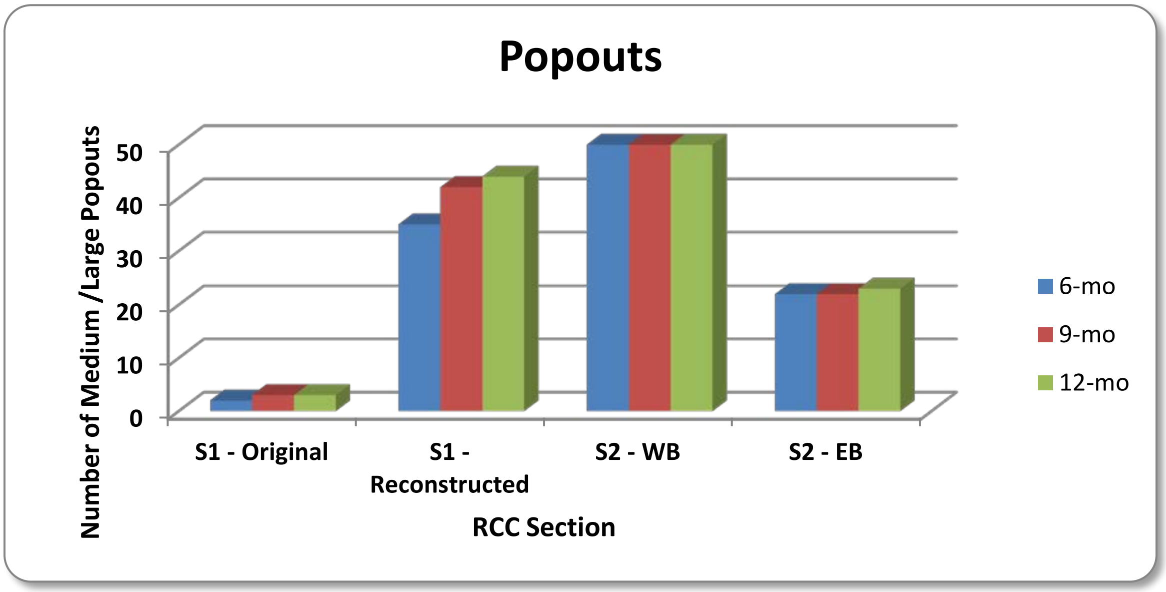



**Figure 75. Popout Summary by Section**

### Raveling

Raveling was another of the common distresses noted throughout the project. In some cases, raveling appeared to be the result of a deteriorated popout, and in others, it was generated by a segregated area of the mat with low surface integrity. Typical areas of raveling are shown in Figures 76 – 79.

**Figure 76. Raveling in the RCC Surface**

**Figure 77. Raveling in the RCC Surface**

**Figure 78. Raveling in the RCC Surface**

**Figure 79. Raveling in the RCC Surface**

As shown in Figure 80, raveling was most prevalent in the original portion of Section 1. Raveling was described as the percent of lane length affected. No true pattern was detected regarding which time of year the increases in raveling were greatest.

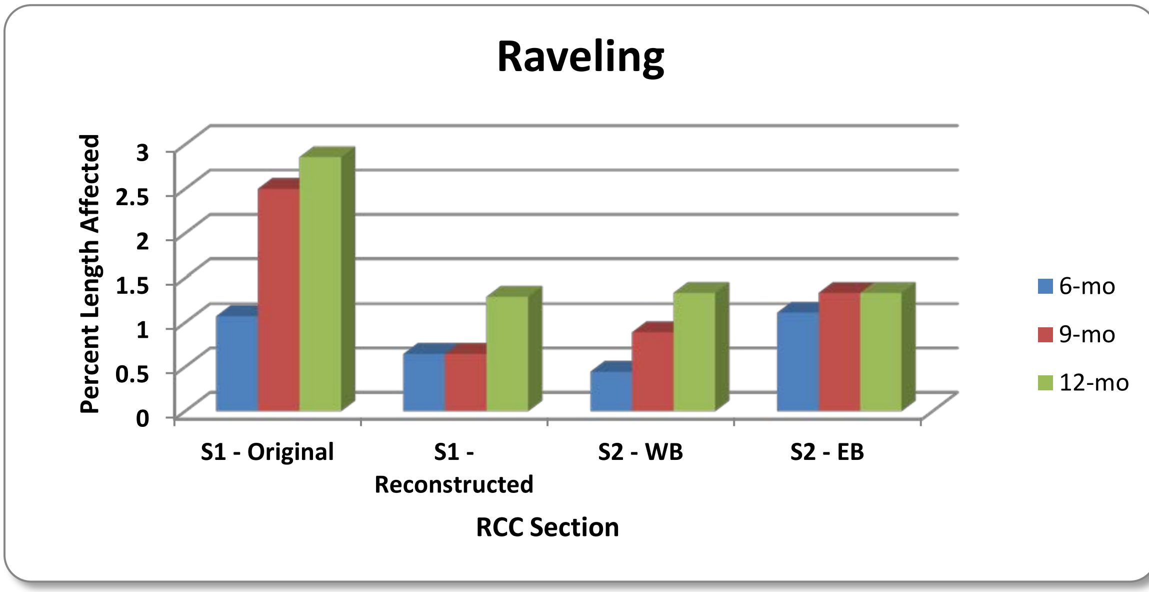



**Figure 80. Raveling Summary by Section**

When raveled areas continued to worsen, patch material (either epoxy or concrete) was placed to prevent further deterioration. The number of patches in a given segment during each distress survey is shown in Figure 81. Again, the original segment of Section 1 was the poorest performer. Minimal patching activities were required in Section 2 and the reconstructed portion of Section 1.

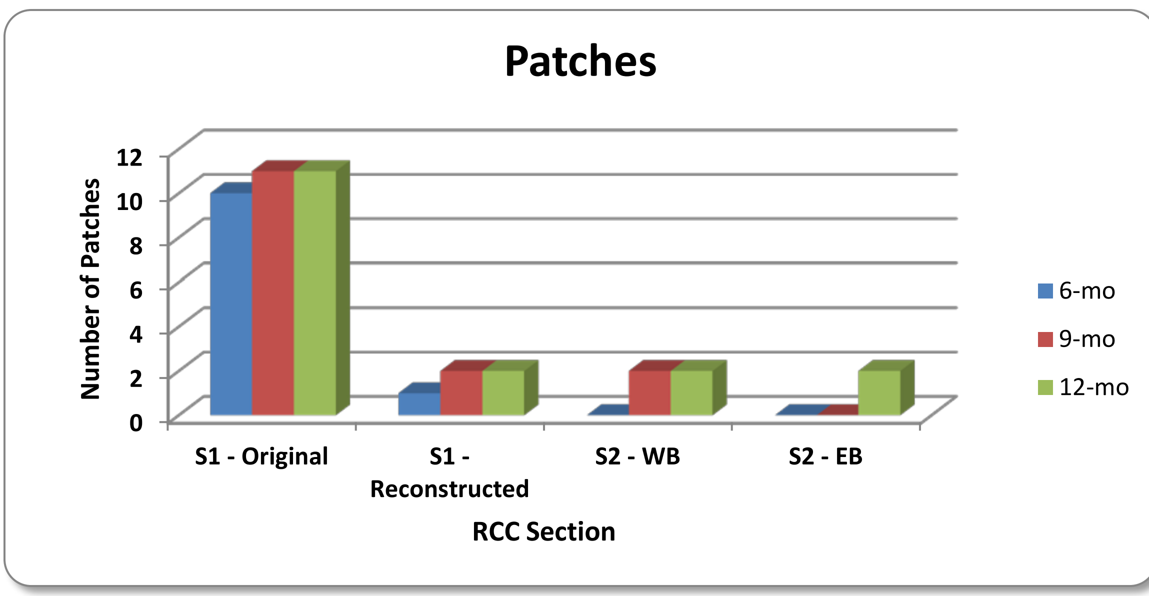



**Figure 81. Patch Summary by Section**

**Segregation**

Segregation was another feature that adversely affected the surface quality of the RCC mat. During paving of Section 1, the screed extensions sometimes left a strip of segregated material that appeared to be caused by a "dragging" of the screed on the mat, and preventing the paste from being evenly distributed across the mat. However, after rolling and diamond grinding, these areas were minimized. After the paver change was made and paving in Section 2 began, a segregated strip was occasionally evident, which was possibly due to the auger not evenly distributing mix throughout the width of the screed. The affected areas were deep enough to be visible even after diamond grinding the surface. Examples of the segregated areas are shown in Figures 82 – 84.

**Figure 82. Segregation in the RCC**

**Figure 83. Segregation in the RCC**

**Figure 84. Segregation in the RCC**

In these locations, popouts and raveling were more likely to occur and to have greater severity. The analysis of segregation is shown in Figure 85, in which the percent of length in each section is plotted for each distress interval. The vast majority of the segregated lengths were located in the westbound lane of Section 2, which was the first section of paved after the paver change was made.

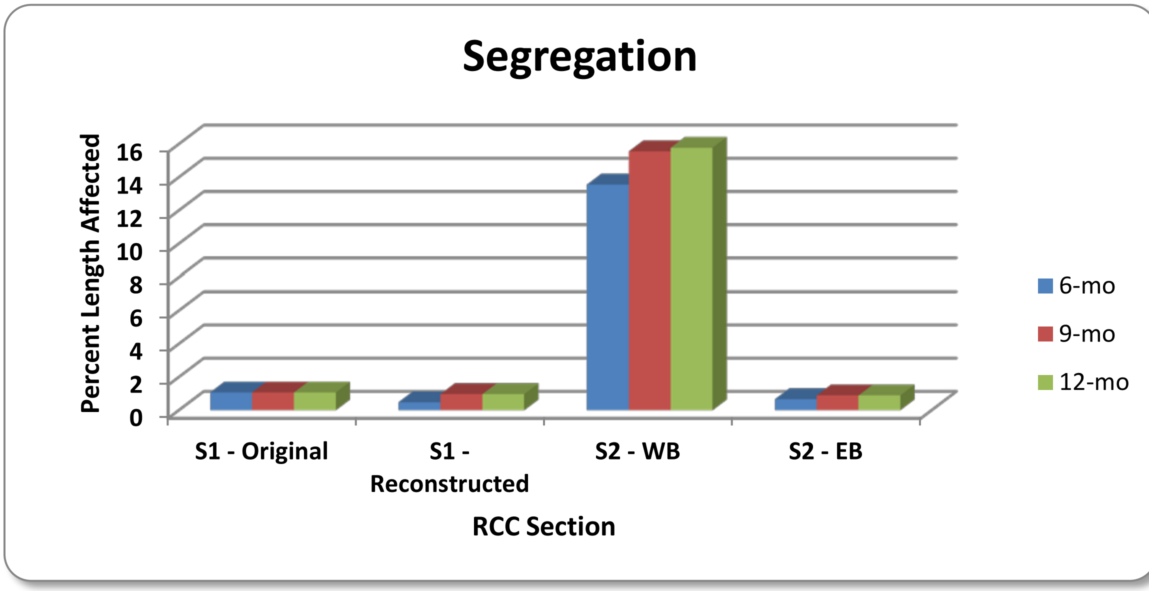



**Figure 85. Segregation Summary by Section**

**Checking**

An additional distress, checking, was noted in two areas. This distress was identified by a slight tearing of the mat, caused by roller pickup during compaction. An example of checking is shown in Figure 86.

**Figure 86. Checking of the RCC Mat**

**Low Areas**

The final distress considered was the presence of low areas. This characteristic is actually more of a defect than a distress, but affected the appearance of the finished mat. Low areas were most commonly noted as a shadowy area at the outer edge of the lane or on the shoulder, but could also be seen at any location on the mat. The cause of this issue at the outer lane edge was possibly the lack of formal grade control (other than basic depth control). At the areas more near the centerline, or when the low spot extended throughout the majority of a lane width, this cause was most likely that the roller had remained stationary for an extended period and settled slightly into an area of the mat that was too wet or lacked the stiffness necessary to hold the roller. In most cases, the low areas were ¼-inch to ½-inch in depth, such that a roller mark or unground section was still visible after diamond grinding. Examples of these areas are shown in Figures 87-89.

**Figure 87. Low Areas Remaining After Diamond Grinding**

**Figure 88. Low Areas Remaining After Diamond Grinding**

**Figure 89. Low Areas Remaining After Diamond Grinding**

The low areas were tallied by the percent length affected in each segment of paving, as given in Figure 90. The greatest number of low areas was noted in the reconstructed portion of Section 1, while these areas were minimal in Section 2. Although the percentage of low areas appeared to increase over time, this did not seem reasonable. It was determined that either some of the areas were not noticed in the first distress surveys, or some settling occurred, making them more visible.

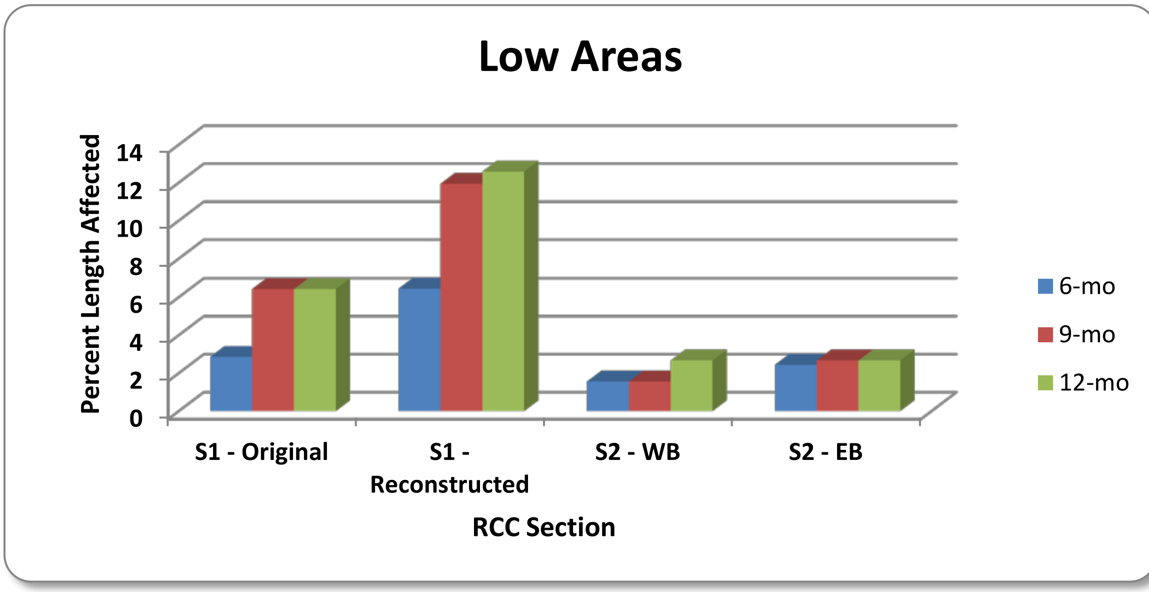



**Figure 90. Low Areas Visible by Section**

Overall, the performance of Section 2 and the reconstructed portions of Section 1 was better than that of the original pavement placed for Section 1, particularly regarding structural performance. When comparing the effectiveness of RCC placed as an overlay versus the RCC placed on CTRB, only the reconstructed portions of Section 1 were considered. No major differences were noted, suggesting that both treatments have performed adequately thus far.

**Smoothness**

Smoothness was another performance concern. Based on the literature, it was determined that the RCC surface would likely not provide adequate smoothness for the driving surface unless it was topped with an asphalt wearing course, or was diamond ground. Diamond grinding was chosen as the method for achieving smoothness, and a goal of 48 inches/ mile was set. To investigate, the Ames Lightweight Profiler was used to determine the International Roughness Index (IRI), at 3-month intervals.

During construction, the profiler was used to determine the smoothness of the newly constructed mat, prior to diamond grinding. Eleven measurements were performed after various portions were constructed. The results ranged from 219 to 360 in/mi, having an average value of 279 in/mi. Suspicions were confirmed that the rolled RCC surface did not provide adequate smoothness and that an additional technique would be required for finishing the surface. After diamond grinding, IRI values were measured, and the results are given in Table 15. Although the goal of 48 in/mi was not achieved, the results were certainly consistent with typical IRI values for a good-quality conventional concrete pavement, and have remained relative constant throughout the first year of service. The surface distresses previously noted do not appear to have significantly impacted the rideability of the roadway.

**Table 15. Smoothness Summary After Construction**

| Time After Construction | Section | Lane | IRI (in/mi) | Average IRI (in/mi) |
|---|---|---|---|---|
| 3 weeks | 1 | WB | 72.4 | 69.5 |
| | 1 | EB | 73.6 | |
| | 2 | WB | 67.1 | |
| | 2 | EB | 64.8 | |
| 3 months | 1 | WB | 71.2 | 76.0 |
| | 1 | EB | 88.8 | |
| | 2 | WB | 72.3 | |
| | 2 | EB | 72.6 | |
| 6 months | 1 | WB | 72.1 | 71.6 |
| | 1 | EB | 71.3 | |
| | 2 | WB | 67.8 | |
| | 2 | EB | 73.5 | |
| 9 months | 1 | WB | 72.1 | 70.8 |
| | 1 | EB | 71.6 | |
| | 2 | WB | 71.2 | |
| | 2 | EB | 67.6 | |

**Skid Resistance**

The British Pendulum Tester and sand patch tests were used to establish the skid resistance of the RCC mat. After 9 months in service, Section 1 was tested in two locations. The BPT test results were 54.8 and 59.0, having an average value of 56.9. The macrotexture was assessed using the sand patch test at the same locations, and the results were 0.58 and 0.57 mm, yielding an average value of 0.575 mm. While these results would not indicate "high friction" characteristics, they were certainly adequate for providing skid resistance to the traveling public.

**Cost**

The original estimate for the cost of the entire project was $1,983,072. Although the bid price was $1,723,267, change orders were made during the project to provide for additional jointing, additional pilot car time, and a guardrail, resulting in an actual total project cost of $2,010,550. Approximately 52 percent of the project cost was attributed to Section 1, and the remaining 48 percent to Section 2. Not including the asphalt transitions, a total of 3.44 lane miles of RCC were placed at a cost of $1,666,489, resulting in an average cost per lane mile of $484,444. This is approximately 5 times greater than the average cost for a traditional 2-inch asphalt overlay, which is $88,000 per lane mile. Though the overlay option was much less expensive, significantly greater structural capacity was achieved with the RCC. Structurally, a direct comparison of the costs of the RCC and an overlay is not a fair comparison.

However, to achieve a 20-year design life, an 8-inch asphalt overlay would have been required, with an estimated total cost of $1,427,657 or $415,017 per lane mile.

It is also important to remember that the roadway width was increased one extra foot per lane in lane width and three-foot shoulders. These advantages would not be present with the typical asphalt overlay option. Thus, this project would be most similar to a rural reconstruction project, which would provide additional structural capacity and include minor widening. For these reasons, a more accurate comparison would be with that of a rural non-freeway reconstruction project, which averages $1,500,000 per lane mile. In this case, the RCC alternative represented a savings of over $1 million per lane-mile. Apart from correcting surface deficiencies, the RCC pavement should not require any planned maintenance for at least 20 years.

**Customer Satisfaction**

Following the completion of construction, a customer satisfaction survey was provided to residents in the area. In the survey, users were asked to rate two items:

1) The quality of the newly constructed roadway as compared to the old roadway
2) The ability of the construction crew to minimize traffic delays during construction

Relative to the new roadway quality, most users rated the new pavement as "greatly improved". On a scale of 1 to 5, with 5 being the best rating, the average score was 4.4. Only one user felt that the new pavement was not an improvement. Relative to maintenance of traffic during construction, most agreed that delays and disruptions were minimized during the construction process, and provided an average rating of 3.3. Although some concerns were expressed regarding how long the new roadway would withstand the heavy truck traffic, the overall consensus was that the roadway was a definite improvement. One user even referred to the new roadway as "the Hattieville Freeway".

# 7. Conclusions and Recommendations

In this project, two sections of RCC pavement were constructed on a rural two-lane highway in central Arkansas in an effort to rehabilitate the deteriorated route in a manner that could withstand the marked increase in traffic within the FSPA. Although there were some issues experienced in the early stages of construction, confidence and quality clearly improved with experience. A number of struggles were encountered during the construction of Section 1, and those problems were also evident in the resulting distresses that were noted up to one year post-construction. Section 2 and the reconstructed portions of Section 1, however, have performed quite well. It is recommended that RCC pavement be considered as an alternative for future roadway maintenance and rehabilitation activities, particularly in the FSPA.

*Design and Construction*

The following items should be considered during the design and construction of RCC pavements, and are included in the proposed revisions to the CTRB and RCC Special Provisions given in Appendix B as appropriate:

- Structural designs should be performed using the 1993 AASHTO Pavement Design procedure. For composite pavements, a layer coefficient of 0.50 should be used for the RCC. Further research is needed to incorporate RCC into the DARWin-ME design procedure.
- RCC mixture design should be performed using the modified Proctor method, according to AASHTO T180. The maximum wet density and optimum moisture content should be used as target values during construction.
- Fly ash should not be used in an RCC mix unless it can be shown through laboratory testing that adequate compressive strength can be achieved for the anticipated ambient curing temperature.
- Although many of the cores did not exhibit satisfactory compressive strengths, performance does not appear to have suffered. While a minimum compressive strength of 5000 psi should be required during design, the field compressive strength requirement should be relaxed to a minimum of 4000 psi. This is consistent with specifications used by other agencies, as well as the AHTD requirement for conventional concrete pavement.
- A twin-shaft pugmill mixer should be required for RCC projects. Due to the limited paste quantity in RCC, thorough mixing is critical to the consistency of the RCC product. The plant must be approved by AHTD inspectors prior to construction.
- Measures should be required to ensure consistent addition of cement to the RCC mix. Vertical cement feed lines are preferred to prevent clumping.
- A test strip should be placed and cores should be cut for compressive strength determinations prior to beginning construction.
- RCC paving should not be performed at temperatures below 50 ˚F.
- RCC paving should not be performed when nighttime low temperatures are expected to drop below 40 ˚F.

- In order to avoid cold temperature issues, seasonal limitations should be placed on RCC pavement construction such that paving is allowed only during the months of April through September.
- Contractors selected to perform RCC paving should be able to demonstrate familiarity with the paving process by providing documentation of having previously and successfully performed main-lane RCC paving on at least two projects. In addition, the crew members performing the work must have experience with at least two successful main-lane RCC pavement projects.
- A maximum IRI of 100 inches per mile should be specified, which is consistent with AHTD smoothness requirements for conventional concrete pavements.

*Cost*

The total cost for the RCC project was $2,010,550, resulting in an average cost for the RCC pavement of $484,444 per lane mile. This is approximately five times greater than the average cost for a traditional 2-inch asphalt overlay, which is $88,000 per lane mile. However, since the roadway width was increased and a significantly greater amount of structural capacity was achieved with the RCC, a better comparison would be with that of a rural non-freeway reconstruction project, which has an average cost of $1,500,000 per lane mile. Thus, the RCC pavement alternative represented a savings of over $1 million per lane-mile.

*Performance*

When considering RCC as an alternative, it is important to consider the intended function of the roadway. RCC should not be expected to perform in exactly the same way as a conventional concrete pavement, particularly in terms of appearance and surface characteristics. Although the RCC has similar strength characteristics to conventional concrete, the appearance of RCC may not be as aesthetically pleasing. With the exception of the original portion of Section 1, the RCC sections have performed admirably and have withstood substantial truck traffic with almost no cracking. This suggests that it is structurally capable of meeting the needs for additional traffic loadings. The RCC placed on CTRB and the RCC placed as an overlay have performed similarly. The raveling and popouts were surface defects, and have not affected the structural capacity of the pavement. The surface issues do, however, create unscheduled maintenance needs in order to keep them from affecting ride quality, and if left untreated, could affect long term structural integrity.

*Surfacing*

The primary undesirable feature of the constructed RCC pavement was its surface quality. This characteristic is important for long-term performance and must be addressed. Several options exist for surfacing RCC pavements:

- Use the diamond-ground RCC as the driving surface
- Place a thin asphalt overlay over the compacted RCC surface (no diamond grinding)
- Chip seal over the compacted RCC surface (no diamond grinding)

- Provide a chip seal surface over the diamond ground RCC
- Place a thin asphalt overlay over the diamond ground surface
- Other surface treatments

Diamond grinding has been used successfully in other states and is a viable option to serve as the wearing course for an RCC pavement. Based on this project, some maintenance may be required to correct surface deficiencies relating to popouts and poor joint quality, even when diamond grinding is employed. Popouts may be related to aggregate quality, which could be a lesser problem for other aggregate sources. Smooth joints are difficult to construct for RCC, but may become more achievable as contractors gain greater confidence and skill with the RCC paving process.

An alternative surface treatment, such as a chip seal or thin overlay, could be used as the wearing course instead of diamond grinding. In this case, creating a smooth surface during placement and rolling of the RCC would be critical. Typical IRI values for the freshly paved, unground RCC were in the range of 200 to 250, which is not acceptable for a new pavement. Without grinding, the surface treatment would have to mask this lack of smoothness. Uneven segments would likely reflect through the surface/wearing course, and could create difficulties in properly placing a chip seal.

A final and most desirable alternative would be to place a thin surface treatment over the diamond ground surface before popouts and other surface defects have begun to appear. In this case, a smooth, structurally sound foundation is available for the surface treatment. This is optimal because most surface treatments are not capable of providing long term integrity unless the underlying pavement layers are structurally sound. Viable surfacing options in this case would include chip seals, microsurfacing treatments, a 4.75mm overlay, or traditional asphalt overlay. Slurry seals and fog seals might also be successful in this case. While this alternative poses the greatest benefit, it also incurs the greatest cost. For example, diamond grinding with a chip seal would include the cost of diamond grinding (approximately $21,000 per lane mile) and the cost of the chip seal (approximately $13,000 per lane mile). The additional processes would also mean additional construction time and traffic maintenance needs.

*Constructability*

For each potential RCC project, consideration should be given to the feasibility and constructability at the given location. Pertinent issues include the number of driveway access points and the availability of detour routes. RCC paving can certainly accommodate driveway access, though as with any paving project, there are short time frames where traffic may be prohibited. Detour routes should be considered, and used if possible. The RCC mat can be expected to open to unrestricted traffic within 48 hours, and appropriate traffic control must be implemented during that time. Most rural routes in the FSPA are two-lane highways, and do not offer the flexibility of simple lane closures that would be possible on multi-lane roadways.

*Safety Edge*

No significant issues were experienced with the Safety Edge during construction. After construction, however, there were some areas in which the aggregate material at the edge of the slope had receded, exposing the Safety Edge. Also, two cracks were discovered in the Safety Edge during the post-construction distress surveys. It was noted that the smooth concrete edge could make it difficult for the aggregate material to adhere to the slope. However, aggregate shoulder material at the edge of any concrete pavement may be prone to recede. Therefore, it was determined that the Safety Edge was more advantageous than a vertical edge for traffic that may accidentally depart from the pavement, allowing for smoother roadway re-entry, and that it did provide a safety benefit.

*Conclusion*

RCC pavements provide a viable solution for increasing the structural capacity of roadways that are being forced to carry much greater traffic loadings than originally intended, and should be considered for highways that are in need of reconstruction, rehabilitation, or have significant recurring maintenance needs. Based on the experiences derived during the research, RCC pavements are recommended for the following applications:

- Low to medium traffic volume roadways
- Rural highways and roadways
- City streets
- Roadways carrying relatively high percentages of truck traffic (> 10%)
- As a base for roadways in medium to high traffic areas (non-freeway)

RCC pavements are <u>not yet</u> recommended for use on the following roadway types:

- Freeways
- High traffic volume highways
- Urban areas
- Arterials

RCC pavements offer the potential for substantial cost savings while also achieving substantial increases in structural capacity within a reasonably minimal time frame for construction. RCC pavements should be considered for use as a rehabilitation strategy in the future for the FSPA as well as other roadways in Arkansas.

## 8. Acknowledgments / Disclaimer

This document contains recommendations for the implementation of research conducted for the Arkansas State Highway and Transportation Department (AHTD) under project TRC 1201, *Design, Construction and Monitoring of Roller Compacted Concrete Pavement in the Fayetteville Shale Play Area*. Funding for a portion of the construction project was acquired through the Highways for Life (HfL) grant program administered by the Federal Highway Administration (FHWA). The research was conducted at the project site in Conway County, the AHTD District 8 Materials laboratory, and at the University of Arkansas by the Department of Civil Engineering in Fayetteville, Arkansas. The author is grateful for the assistance of the many who took part in the research project, including AHTD employees from the Systems Information and Research Section, Resident Engineer office #86, District 8, and the State Materials Laboratory.

The author gratefully acknowledges the talents and efforts of undergraduate research assistants Thomas Moss, Derec Bass and Sanjay Selvam. Industry partners Koss Construction Company and Materials Testing of Arkansas are also greatly appreciated for their roles in the successful completion of this project.

# References


1. Abdo, F., "Full-Depth Reclamation and Roller-Compacted Concrete Pavements", presentation at the Arkansas meeting of the American Concrete Pavement Association (ACPA), Little Rock, Arkansas, August, 2010.
2. Adaska, W., "Roller-Compacted concrete Design and Construction", presented at the ACPA 2008 Professor's Seminar, Skokie, Illinois, June 19, 2008.
3. Amer, N., Delatte, N., and C. Storey, "Using Gyratory Compaction to Investigate Density and Mechanical Properties of Roller-Compacted Concrete", Transportation Research Record: Journal of the Transportation Research Board, No. 1834, Transportation Research Board, National Research Council, Washington D.C., 2003, pp. 77-84.
4. Amer, N., Storey, C., and N. Delatte, "Roller-Compacted Concrete Mix Design Procedure with Gyratory Compactor", Transportation Research Record: Journal of the Transportation Research Board, No. 1893, Transportation Research Board, National Research Council, Washington D.C., 2004, pp. 46-52.
5. American Concrete Institute Committee 207, *Roller-Compacted Mass Concrete*, ACI technical committee document 207.5R-99, Farmington Hills, MI. 1999.
6. American Concrete Institute, *Compaction of Roller-Compacted Concrete*. Technical Paper 309.5R-00, ACI Committee 309, Farmington Hills, Michigan, 2000, pp. 3-12.
7. American Concrete Institute Committee 325, *Report on Roller-Compacted Concrete Pavements*, ACI technical committee document 325.10R-95, reapproved in 2001, Farmington Hills, MI. 2001.
8. Arkansas State Highway and Transportation Department, *Standard Specifications for Highway Construction*, 2003 Edition, AHTD, Little Rock, Arkansas, 2003.
9. Asphalt Institute. *The Asphalt Handbook*. 7th edition. 2007.
10. Bennett, S., "Highways for Life – Highway 213", 2011 Discretionary Grant Programs, Highways for Life (HfL), Proposal, Arkansas State Highway and Transportation Department, May 2011.
11. Damrongwiriyanupap, N., Liang, Y.C., and X. Yunping, "Application of Roller compacted Concrete in Colorado's Roadways", Report No. CDOT-2012-11, Colorado Department of Transportation DTD Applied Research and Innovation Branch, October 2012.
12. Finberg, C., D. Quire, T. Thomas. Granular Base Stabilization with Emulsion in Las Vegas, Nevada. In *Transportation Research Board*. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C., 2008.
13. Harrington, D., Abdo, R., Adaska, W., and C. Hazaree, "Guide for Roller-Compacted Concrete Pavements", Portland Cement Association, Skokie, IL, August 2010.
14. Harris, L., "Experiences with Roller Compacted Concrete in Kansas", KS LTAP Newsletter, Kansa Local Technical Assistance Program (LTAP) at the Kansas University Transportation Center, Spring 2012.
15. Kim, Y.S., "Roller-Compacted Concrete Shoulder Construction on Interstate Highway in Georgia", Transportation Research Record: Journal of the Transportation Research Board, No. 2040, Transportation Research Board, National Research Council, Washington D.C., 2007, pp. 71-79.

16. Meadors, A. and E. Wright-Kehner, "Accelerated Damage to Low-Volume Highways Due to Natural Gas Well-Drilling Activities in Arkansas", presented at the 2013 Annual Meeting of the Transportation Research Board, Washington D.C., January 15, 2013.
17. Missouri Department of Transportation, *Optional Roller Compacted Concrete Shoulders*, Jefferson City, Missouri, 2008.
18. Missouri Department of Transportation Organizational Results, "Central District Uses Roller Compacted Concrete for Overlay", Advancements publication, Missouri Department of Transportation, Jefferson City, Missouri, November 2008.
19. Moucka, L. "Roller Compacted Concrete Making Inroads in West Texas", *Texas Contractor*, May 2012, pp. 60-63.
20. Nantung, T., Ji, Y., and T. Shields, Pavement Structural Evaluation and Design of Full-Depth Reclamation (FDR) Pavement, presented at the Transportation Research Board Annual Meeting, Transportation Research Board of the National Academies, Washington, D.C., 2011.
21. Portland Cement Association , "Roller-Compacted Concrete Density: Principles and Practices", Skokie, Illinois, 2004.
22. Portland Cement Association, "Roller Compacted Concrete", PCA website, http://www.cement.org/pavements/pv_rcc.asp, accessed March 31, 2010.
23. Russo, Nick, "New Pavement type could save Midland Time and Money", http://www.permianbasin360.com, accessed June 12, 2014, Permian Basin 360, uploaded June 10, 2014.
24. South Carolina Department of Transportation, *Roller Compacted Concrete Pavement, Supplemental Specification*, Charleston, South Carolina, May 22, 2001.
25. Tennessee Department of Transportation, *Special Provision Regarding Roller Compacted Concrete Pavement*, SP501RC, Nashville, Tennessee, August 22, 2001.
26. Williams, S.G., and McFarland, A.M., "Roller Compacted Concrete for Roadway Paving", Final Report TRC-1005, Arkansas Highway and Transportation Department, August 14, 2013.
27. Zollinger, C., and Johnson, A., "Benefits of Roller Compacted Concrete for Local Roads", http://www.youtube.com/watch?v=CP8zjaT35X8, accessed April 26, 2012, Cemex, Inc., uploaded May 16, 2011.

# APPENDIX A

# SPECIAL PROVISIONS USED DURING CONSTRUCTION

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**CEMENT TREATED RECONSTRUCTED BASE**

**<u>DESCRIPTION</u>:** Cement Treated Reconstructed Base (CTRB) shall meet the requirements of Section 305 of the latest edition of the AHTD Standard Specification for Highway Construction except as modified herein. This item shall consist of pulverizing and mixing the existing asphalt pavement and base with additional base, Portland cement, and water to produce a uniform mixture meeting the requirements specified herein and in substantial conformity with the lines, grades, compacted thickness, and typical cross section shown on the plans.

**<u>MATERIALS</u>:** Additional aggregate shall meet Section 303 of the latest edition of the *AHTD Standard Specifications for Highway Construction* for Class 7 aggregate base course. Water and cement shall meet the materials requirement of Section 307.03.

**<u>EQUIPMENT:</u>** The pulverizing and mixing shall be done with one or more machines that produce the required degree of pulverization and uniformity. The pulverization equipment shall be capable of cutting and pulverizing uniformly to the proper depth with cutters that will plane to a uniform surface over the entire width of the cut and uniformly mix the materials. Other pieces of equipment that may be required are a motorized grader, cement spreading unit, water truck, and compaction equipment. The Engineer will not approve specific equipment for this work prior to its use on the project but will require the Contractor to use equipment that will produce a base course mixture meeting the requirements of these specifications.

**<u>CONSTRUCTION REQUIREMENTS:</u>** Sufficient equipment shall be available so that the work may proceed in proper sequence to completion without unnecessary delay. Equipment, tools, and machinery used shall be maintained in a satisfactory working condition. The pulverizing mixing and compaction shall be a continuous operation. The specified quantity of cement shall be applied on the material to be pulverized, mixed and compacted and shall not exceed that which cannot be processed in the same working day. Spreading of cement will be allowed after scarification of the existing asphalt pavement and prior to the pulverization and mixing for the entire thickness of the stabilized course. When bulk cement is used the equipment shall be capable of handling and spreading the cement in the required amount. The moisture content of the material to be processed shall be sufficiently low to permit a uniform and intimate mixture of the aggregate material and cement. The compaction of the mixture of water, cement and roadbed materials shall begin within 30 minutes after the final mixing.

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**CEMENT TREATED RECONSTRUCTED BASE**

Prior to joining a previous day's work, or work more than two hours old, a vertical construction joint, normal to the center-line of the roadway shall be made in the old work. The joint shall be moistened if dry. Additional processing shall not be started until the construction joint has been approved by the Engineer.

All longitudinal joints shall be constructed parallel to the centerline by cutting into the existing edge for a sufficient distance to provide a vertical face for the depth of the course. The material cut away may be disposed of by spreading in a thin layer on the adjacent lane to be constructed, or otherwise disposed of in a satisfactory manner. If dry, cut joints shall be moistened immediately in advance of placing fresh mixture adjacent to them.

The first section of each cement treated course constructed will serve as a test section. The length of the test section (not less than three hundred fifty (350) linear feet, not more than five hundred (500) linear feet for the designated width) will be determined by the capability of the equipment provided to perform the work. The Engineer will test and evaluate the performance of the test section. The test section must be determined to be acceptable by the Engineer before work can proceed.

In case the Engineer determines the work is not satisfactory, the Contractor shall revise his procedures and augment or replace equipment as necessary to assure work completion in accordance with the contract, and shall correct all deficient work at no additional cost to the Department.

**CONSTRUCTION METHODS:** Pulverizing and Mixing: The width and depth of the required pulverizing and mixing will be shown on plans. The depth of pulverizing shall be controlled to ensure that only the existing base and surface are pulverized. Care should be taken to avoid pulverizing and mixing existing subgrade soil during construction. This may require thickness adjustment at the direction of the Engineer. Pulverizing and mixing may be accomplished in one or more passes subject to meeting the pulverization and uniformity requirements of these specifications.

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**CEMENT TREATED RECONSTRUCTED BASE**

The pulverizing and mixing shall break up the existing roadbed to the extent that 98% to 100% by weight, exclusive of gravel or stone particles, passes a 2 inch sieve, a minimum of 95% passes a 1.5 inch sieve, and a range of 25%-55% passes a #4 sieve. The moisture content shall be maintained at a point that allows compaction to the required density.

Width of Treatment: Additional Class 7 base course will be used to extend the width of CTRB to the extents shown in typical cross sections. This aggregate shall be spread ahead of the pulverization equipment prior to mixing. The thickness of the additional material will vary as necessary to meet the lines and grades, compacted thickness, and typical cross section shown on the plans.

Only the equipment that is used in spreading and mixing will be allowed to pass over the spread cement before it is mixed into the existing materials. Cement that has been displaced shall be replaced before mixing is started. Care should be taken to prevent excessive dusting, displacement, or altering the uniform distribution of cement throughout the section from the time of cement placement until the cement is thoroughly mixed throughout the depth of stabilization.

Mixing Cement with Pulverized Materials: The contractor may perform initial dry mixing of the cement with the existing roadbed materials or may inject moisture into the mixing chamber of the mixing/pulverizing equipment during the first mixing. Water shall not be added by a spray bar from a water truck directly onto the unmixed cement spread. The cement shall be thoroughly mixed with the pulverized roadbed materials to provide a uniform distribution of the cement throughout the mixture. The temperature shall not be below 40 degree, and that the finished section should not be subjected to freezing temperatures for at least 7 days.

Mixing Water with Cement and Pulverized Materials: If the contractor does not inject moisture into the mixing chamber of the pulverizer/mixer during the first mixing, the pulverizer/mixer shall then be used to mix water into the mixture of cement and pulverized roadbed materials. The mixing shall be completed in one or more continuous pass(es) of the mixing unit. The mixture of the water, cement and pulverized roadbed materials shall be substantially that of optimum moisture content for that material and shall be in a condition suitable for immediate compaction without further mixing or grading.

When the mixer will handle only a part of the roadbed width, the successive increments shall be of such length that the full width of treated material may be promptly mixed, compacted and finished, with not more than 30 minutes between mixing adjacent lanes. The asphalt and cement mix shall not remain undisturbed after mixing and before compaction for more than 30 minutes.

When the uncompacted mixture is made too wet by the addition of too much water, or by rain, and the moisture content exceeds the specified tolerance for compaction, the entire affected section may be remixed at the Contractor's expense in an effort to dry the mixture through aeration.

Compaction and Finishing: The pulverizing, mixing and compaction shall be a continuous operation. During the initial test section, the Contractor shall establish an optimum rolling pattern. A sufficient number of coverages of the CTRB surface by the roller / rollers proposed to be used by the Contractor during production operations shall be made to achieve the maximum density possible. The Engineer will observe the Contractor's use of a nuclear density gauge to verify that the maximum densities of 96% are achieved. Finishing shall be completed within 4 hours of the start of mixing, or as determined by the Engineer.

The established rolling pattern shall be used for compacting all CTRB. If a change in the mixing depth or cement content occurs, or if unacceptable results are obtained, a new optimum rolling patter shall be established.

After the mixture has been compacted, the surface shall be shaped to the required lines, grades, and cross sections to within the required tolerances. During the shaping, light scarifying may be necessary to prevent the formation of compaction planes. Broom dragging or clipping of the surface may be required as a part of the process of shaping the surface during compaction. The surface material shall be maintained at the specified moisture content during finishing operations. The final compaction and finishing

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**CEMENT TREATED RECONSTRUCTED BASE**

operations may be varied, if necessary, to produce a smooth, dense surface free of surface compaction planes, cracks, ridges or loose material.

**Acceptance:** Will be in accordance with Section 306 of the latest edition of the AHTD Standard Specification for Highway Construction except as modified herein.

Testing, Tolerance, and Deficiency Correction: The thickness of the base will be checked by the Engineer at intervals not to exceed 500 feet. A tolerance of +/-1 inch point will be permitted. Adjustment from plan design thickness will be allowed where the existing pavement cross section is deficient.

Opening to Traffic: Traffic shall be placed on the roadway after the roadway is able to withstand traffic without damage to the surface, as directed by the Engineer. The contractor is to be responsible for maintaining the CTRB until all pavement layers have been constructed, and shall immediately repair any defects that may occur.

**METHOD OF MEASUREMENT:** CTRB will be measured in units of square yards. The length shall be measured along the surface of the pavement. The width shall be as specified on the plans or as directed by the Engineer. Portland Cement and Aggregate Base Course will be measured by the ton (metric ton).

**BASIS OF PAYMENT:** Portland Cement and Aggregate Base Course will be paid for at the contract unit price per ton (metric ton). CTRB will be paid for at the contract unit price per square yard. The prices shall be full compensation for all materials, equipment, tools, labor, and incidentals necessary to complete the work.

Payment will be made under:

| Pay Item | Pay Unit |
|---|---|
| Cement in Cement Treated Reconstructed Base | Ton (Metric Ton) |
| Aggregate in Cement Treated Reconstructed Base | Ton (Metric Ton) |
| Processing Cement Treated Reconstructed Base | Square Yard (Square Meter) |

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**ROLLER COMPACTED CONCRETE PAVEMENT**

**DESCRIPTION:** This item shall consist of constructing a Roller Compacted Concrete (RCC) Pavement on a Cement Treated Reconstructed Base (CTRB) or the existing asphalt pavement according to these specifications and conforming to the lines, grades, thicknesses, and typical cross sections shown on the plans or established by the Engineer.

**MATERIALS**

General: All materials to be used for RCC construction shall be approved by the Engineer based on laboratory tests or certifications of representative materials, which will be used in the actual construction. All materials shall conform to Section 501.02 of the latest edition of the *AHTD Standard Specifications for Highway Construction*, unless otherwise modified herein.

Aggregates: The design of the RCC pavement mixture approved for use in this project shall contain a nominal maximum aggregate size of ¾ inch, and shall conform to the following gradation requirements. The aggregate blend shall consist of both fine and coarse aggregate and will be a blend of 2 to 4 aggregates.

| Sieve Size, inch (mm) | Minimum % Passing | Maximum % Passing |
|---|---|---|
| 1" (25.0mm) | 100 | 100 |
| ¾" (19.0mm) | 90 | 100 |
| ½" (12.5mm) | 70 | 90 |
| 3/8" (9.5mm) | 60 | 85 |
| #4 (4.75mm) | 40 | 60 |
| #16 (1.18mm) | 20 | 40 |
| #100 (.150mm) | 6 | 18 |
| #200 (0.075mm) | 2 | 8 |

Table 1. Gradation Requirement for Roller Compacted Concrete Paving Mixture

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**ROLLER COMPACTED CONCRETE PAVEMENT**

Mix Design: The mix design will be done by the contractor in accordance with section 501.03 except as modified herein. The proportion used in the mix shall be determined by the proctor method according to AASHTO T180, Method D. The RCC pavement mixture shall have a minimum 28-day compressive strength of 5,000 psi. All specimen fabrication shall be performed in accordance with AASHTO R39 and ASTM C 1435. Designs shall include the blend gradation for the job mix formula, including cement content, water content, w/c ratio, 28-day strength. Trial batches are required as described in section 802.05.

Quality Control, Acceptance and Adjustment: Quality control and acceptance testing shall be performed by the contractor in accordance with section 501.04 except as modified herein. The Standard Lot size for acceptance will be 4000 square yards (square meters), with each standard lot divided into four sublots of 1000 square yards (square meters) each. No testing for slump or air content will be required. Three additional cores will be taken in each sublot and provided to the Engineer.

Lot and sublot compliance, rejection, and price reductions shall be determined based on the values in Table 2 in lieu of Table 501-1.

| **Property** | **Compliance Limits** | **Price Reduction Limits** | **Price Reduction** | **Rejection Limits** |
|---|---|---|---|---|
| Compressive strength | 5000 psi | 4999-4000psi | 10% | Less than 3500 psi |
| | | 3999-3500 psi | 20% | |

Table 2 - COMPLIANCE, PRICE REDUCTIONS, AND REJECTION LIMITS FOR ROLLER COMPACTED CONCRETE PAVEMENT

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**ROLLER COMPACTED CONCRETE PAVEMENT**

Tolerance in Pavement Thickness: Tolerance in the thickness shall be in accordance with section 501.10. Subsection 500.10 shall be modified to further include the following:

The equipment and methods employed in placing the roller compacted concrete material shall ensure accuracy and uniformity of depth and width. If conditions arise where such uniformity in the placing cannot be obtained, the Engineer may require additional equipment or modification in the placing procedure to obtain satisfactory results.

## EQUIPMENT

General: Roller compacted concrete shall be constructed with any combination of equipment that will produce a completed pavement meeting the requirements for mixing, transporting, placing, compacting, finishing, and curing as provided in this specification.

Mixing Plant: The RCC pavement mixture shall be produced in a pug mill plant or central batch plant, at a rate that is consistent with placement, and will allow for continuous movement of the paver. Concrete shall be delivered and discharged from the truck into the paver within one hour after the introduction of the mixing water to the cement. Close control of water content is required and thorough mixing is necessary to achieve a homogeneous mixture.

Haul Trucks: The mixture shall be delivered to the site in dump trucks, which are suited for depositing the mixture into the hopper of the paver. Each load transported to the site shall be covered to prevent contamination and evaporation. A suitable number of trucks must be available to ensure a constant supply of RCC pavement material in the hopper, allowing the paver to proceed at a consistent rate. Stopping and starting the paver should be kept to a minimum.

Paver: The paver should be capable of producing 85 percent of the laboratory-derived maximum density. A heavy-duty paver is preferred, especially for lift thicknesses of 8 inches or greater.

Safety Edge: When the RCC pavement will be used as the riding surface, the outside edges of the pavement shall be laid in such a manner as to form no steeper than a 1:1 slope or “safety edge”. The safety edge is a subsidiary to the paving and not paid for separately.

Compactors: Self-propelled steel drum vibratory rollers having a minimum static weight of 10 tons shall be used for primary compaction. For final compaction, either a steel drum roller, operated in a static mode, or a rubber-tired roller of equal or greater weight shall be utilized. Walk-behind vibratory rollers or plate tampers shall only be used for compacting areas inaccessible to large rollers.

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. Such equipment shall be equipped with a spreader pipe containing fog spray nozzles capable of evenly applying a fine spray of water to the surface of the RCC without damaging the final surface.

Inspection of Equipment: Before start-up, the Contractor’s equipment will be carefully inspected. Should any of the equipment fail to operate properly, no work will proceed until the deficiencies are corrected.

Access for Inspection and Calibration: The Engineer and his representatives shall have access at all times for any plant, equipment, or machinery to be used in order to check calibration, scales, controls, or operating adjustments

**PROFICIENCY REQUIREMENTS:** The Contractor placing the roller compacted concrete pavement for this project shall demonstrate proficiency with that material by providing documentation and/or reference letters from two (2) successful previously placed projects. If the contractor cannot demonstrate proficiency with RCC, then the contractor is required to have an individual with RCC expertise on site throughout the construction of the RCC pavement. The individual shall demonstrate proficiency with RCC by providing documentation and/or reference letters from two (2) successful previously placed projects.

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**ROLLER COMPACTED CONCRETE PAVEMENT**

## CONSTRUCTION REQUIREMENTS

Rolling and Density Requirements: At the beginning of placement of each mix design, the Contractor shall establish an optimum rolling pattern for the mix being placed. A sufficient number of coverages of the entire mat by the rollers proposed to be used by the Contractor during production paving operations shall be made to achieve the maximum density possible. The Engineer will observe the Contractor's use of a nuclear density gauge to verify that the maximum densities possible are obtained.

The established rolling pattern shall be used for compacting all mix placed. If a change in the accepted mix design occurs, or if the compaction method or equipment is changed, or if unacceptable results are obtained, a new optimum rolling pattern shall be established.

If for any reason a rolling pattern cannot be established to produce the specified density, a new mix design will be required. The Contractor shall establish an optimum rolling pattern that will produce the maximum density using the new mix design. Continuous production of the mix shall not begin until an optimum rolling pattern that produces the specified density within the allowable range has been established.

Rolling shall start longitudinally at the low edge and proceed toward the higher portion of the mat. When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first followed by the regular rolling procedure. Alternate passes of the roller shall be terminated at least 3' (1 m) from any preceding stop. Rolling on superelevated curves shall progress from the low side. Rollers shall not be stopped perpendicular to the centerline of the traveled way.

Compaction: Initial compaction shall begin immediately after paving, and shall be performed using a smooth steel drum vibratory roller. Finish rolling may be performed using a steel drum roller in static mode or a rubber-tired roller. Walk-behind tampers or rollers may be used for areas not accessible to large rollers. At no time shall the rolling operation cause movement of the mat or tearing of the surface. On the first pass, the roller shall maintain a distance of at least 6 inches

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**ROLLER COMPACTED CONCRETE PAVEMENT**

from the unconfined edge, then compacting the unconfined edge on subsequent passes. Compaction should be completed within 30 minutes of placement, or as directed by the Engineer.

The RCC pavement mat shall be compacted to a minimum of 98 percent of the maximum laboratory density obtained by AASHTO T180 Method D, based on wet density. A minimum of one density test shall be taken by the Contractor for every 1000 square yards of RCC pavement for the purpose of quality control.

Base/Subbase Preparation: Base/subbase should be uniformly compacted to at least 96 percent of maximum density, and shall not exhibit any instability, as determined by proof rolling. Immediately prior to the placement of RCC pavement, the subgrade or subbase shall be clean and free of debris, then uniformly moistened using a water truck with a spray bar. No standing water should be present.

Curing: After final compaction and density testing is complete; the RCC pavement surface shall be kept moist, using a fine mist of water, until a curing compound has been applied in accordance with Section 501.05 (l)(3) AHTD specifications. When the RCC pavement is to be covered with a bituminous wearing course, an approved emulsion product may be used for curing purposes.

Placement: The RCC pavement shall not be placed on a frozen or frost-covered surface, and should be placed when the air temperature is at least 40°F. The temperature of the RCC pavement surface should be protected such that its surface temperature does not drop below 40°F for at least 5 days. During hot weather paving, precautions should be taken to maintain appropriate moisture levels. Paving must be suspended during periods of rain, and may be suspended during periods of heavy mist if water ponds on the pavement surface. In such cases, the Engineer will determine whether paving is suspended.

If possible, RCC pavements should be constructed in one lift. Pavements greater than 10 inches in thickness should be constructed in two equal lifts. For multiple lift pavements, the second lift should be placed within 60 minutes of the first lift. No single lift should be less than 4 inches in thickness.

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**ROLLER COMPACTED CONCRETE PAVEMENT**

RCC pavement shall be placed continuously, and without segregation, such that a smooth surface results. Segregated coarse aggregate should be removed from the surface, though hand work shall be kept to an absolute minimum. If the paving process results in significant segregation or tearing of the mat, paving shall cease until the problem has been resolved.

If possible, the adjacent lane should be placed within 60 minutes of the first lane, creating a fresh longitudinal joint. If this is not possible, then a vertical cut should be made along the exposed edge that will later form the longitudinal joint, removing approximately 4 inches and creating a vertical face. This cut should be made within 2 hours of placing the RCC pavement, and in a manner that maintains a smooth edge (i.e., no raveling). Clean and moisten the face of the joint prior to placing the adjacent lane. Ensure that a sufficient quantity of material is present at the joint to create a densely compacted joint at the appropriate mat height.

Traffic: The RCC pavement mat may be opened to light traffic after 24 hours, provided a compressive strength of at least 1800 psi has been obtained. Unrestricted traffic may be allowed on the pavement after the compressive strength has reached 2500 psi. These strengths will be determined based on the Contractor's compressive strength testing of cores obtained by the Contractor. The Contractor will be responsible for appropriate traffic control during lane closures.

Smoothness: When the RCC Pavement will be used as the final roadway surface as indicated by the typical section, the surface shall be ground in accordance with Section 510, Grinding Portland Cement Concrete Pavement except that the entire surface shall be ground to a minimum depth of 1/16", and an IRI of 48" per mile. This grinding will be paid for at the unit price for "Grinding Portland Cement Concrete Pavement". When the RCC Pavement will have an ACHM layer placed over it as indicated by the typical section, grinding of the RCC Pavement may be necessary in order to achieve the smoothness requirements of the ACHM Surface Layer. Grinding for this purpose shall be at no cost to the Department.

**ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT**

**SPECIAL PROVISION**

**JOB FS8031**

**ROLLER COMPACTED CONCRETE PAVEMENT**

**METHOD OF MEASUREMENT:** Roller Compacted Concrete will be measured by the square yard (square meter). The width for measurement will be the width as constructed according to the plans and typical cross sections or as directed by the Engineer.

**BASIS OF PAYMENT:** Work completed and accepted and measured as provided above will be paid for at the contract unit price bid per square yard (square meter) for Roller Compacted Concrete Pavement, of the thickness and type specified, which price shall be full compensation for preparing the subgrade or base and shaping the shoulders unless otherwise specified; for furnishing, transporting, and placing materials, and all other joint materials; for the preparation and processing of materials; for mixing, spreading, vibrating, compacting, finishing, and curing; for performing mix designs and quality control and acceptance sampling and testing; for sawing, cleaning, filling, and sealing joints; for half width construction; for furnishing the profilograph; taking all required profiles, performing all necessary computations; and for all labor, equipment, tools, and incidentals necessary to complete the work; provided, that for such area as is deficient in thickness, only the adjusted price will be paid as specified in Subsection 501.10. No payment will be made for pavement deficient in thickness in excess of ½" (12 mm), even though the deficient pavement may be allowed to remain in place, nor for repair as specified in Subsection 501.09.

Payment will be made under:

| Pay Item | Pay Unit |
|---|---|
| Roller Compacted Concrete (5") | Square Yards |
| Roller Compacted Concrete (6") | Square Yards |
| Roller Compacted Concrete (7") | Square Yards |
| Roller Compacted Concrete (8") | Square Yards |

# APPENDIX B

# PROPOSED SPECIAL PROVISIONS

# PROPOSED SPECIAL PROVISION

## JOB XXXXXX

## CEMENT TREATED RECONSTRUCTED BASE

**DESCRIPTION:** Cement Treated Reconstructed Base (CTRB) shall meet the requirements of Section 305 of the latest edition of the AHTD Standard Specification for Highway Construction except as modified herein. This item shall consist of pulverizing and mixing the existing asphalt pavement and base with additional base, Portland cement, and water to produce a uniform mixture meeting the requirements specified herein and in substantial conformity with the lines, grades, compacted thickness, and typical cross section shown on the plans.

**MATERIALS:** Additional aggregate shall meet Section 303 of the latest edition of the *AHTD Standard Specifications for Highway Construction* for Class 7 aggregate base course. Water and cement shall meet the materials requirement of Section 307.03.

**EQUIPMENT:** The pulverizing and mixing shall be done with one or more machines that produce the required degree of pulverization and uniformity. The pulverization equipment shall be capable of cutting and pulverizing uniformly to the proper depth with cutters that will plane to a uniform surface over the entire width of the cut and uniformly mix the materials. Other pieces of equipment that may be required are a motorized grader, cement spreading unit, water truck, and compaction equipment. The Engineer will not approve specific equipment for this work prior to its use on the project but will require the Contractor to use equipment that will produce a base course mixture meeting the requirements of these specifications.

**CONSTRUCTION REQUIREMENTS:** Sufficient equipment shall be available so that the work may proceed in proper sequence to completion without unnecessary delay. Equipment, tools, and machinery used shall be maintained in a satisfactory working condition. The pulverizing mixing and compaction shall be a continuous operation. The rate of application shall be determined by trial mixing and shall be approved by the Engineer. The specified quantity of cement shall be applied on the material to be pulverized, mixed and compacted and shall not exceed that which cannot be processed in the same working day. Spreading of cement will be allowed after scarification of the existing asphalt pavement and prior to the pulverization and mixing for the entire thickness of the stabilized course. When bulk cement is used the equipment shall be capable of handling and spreading the cement in the required amount. The moisture content of the material to be processed shall be sufficiently low to permit a uniform and intimate mixture of the aggregate material and cement. The compaction of the mixture of water, cement and roadbed materials shall begin within 30 minutes after the final mixing. Any procedure that results in excessive loss of material or that does not achieve the desired results shall be immediately discontinued.

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**CEMENT TREATED RECONSTRUCTED BASE**

Prior to joining a previous day's work, or work more than two hours old, a vertical construction joint, normal to the center-line of the roadway shall be made in the old work. The joint shall be moistened if dry. Additional processing shall not be started until the construction joint has been approved by the Engineer.

All longitudinal joints shall be constructed parallel to the centerline by cutting into the existing edge for a sufficient distance to provide a vertical face for the depth of the course. The material cut away may be disposed of by spreading in a thin layer on the adjacent lane to be constructed, or otherwise disposed of in a satisfactory manner. If dry, cut joints shall be moistened immediately in advance of placing fresh mixture adjacent to them.

The first section of each cement treated course constructed will serve as a test section. The length of the test section (not less than three hundred fifty (350) linear feet, not more than five hundred (500) linear feet for the designated width) will be determined by the capability of the equipment provided to perform the work. The Engineer will test and evaluate the performance of the test section. The test section must be determined to be acceptable by the Engineer before work can proceed.

In case the Engineer determines the work is not satisfactory, the Contractor shall revise his procedures and augment or replace equipment as necessary to assure work completion in accordance with the contract, and shall correct all deficient work at no additional cost to the Department.

**CONSTRUCTION METHODS:** Pulverizing and Mixing: The width and depth of the required pulverizing and mixing will be shown on plans. The depth of pulverizing shall be controlled to ensure that only the existing base and surface are pulverized. Care should be taken to avoid pulverizing and mixing existing subgrade soil during construction. This may require thickness adjustment at the direction of the Engineer. Pulverizing and mixing may be accomplished in one or more passes subject to meeting the pulverization and uniformity requirements of these specifications.

The pulverizing and mixing shall break up the existing roadbed to the extent that 98% to 100% by weight, exclusive of gravel or stone particles, passes a 2 inch sieve, a minimum of 95% passes a 1.5 inch sieve, and a range of 25%-55% passes a #4 sieve.

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**CEMENT TREATED RECONSTRUCTED BASE**

The moisture content shall be maintained at a point that allows compaction to the required density.

Width of Treatment: Additional Class 7 base course will be used to extend the width of CTRB to the extents shown in typical cross sections. This aggregate shall be spread ahead of the pulverization equipment prior to mixing. The thickness of the additional material will vary as necessary to meet the lines and grades, compacted thickness, and typical cross section shown on the plans.

Only the equipment that is used in spreading and mixing will be allowed to pass over the spread cement before it is mixed into the existing materials. Cement that has been displaced shall be replaced before mixing is started. Care should be taken to prevent excessive dusting, displacement, or altering the uniform distribution of cement throughout the section from the time of cement placement until the cement is thoroughly mixed throughout the depth of stabilization.

Mixing Cement with Pulverized Materials: The contractor may perform initial dry mixing of the cement with the existing roadbed materials or may inject moisture into the mixing chamber of the mixing/pulverizing equipment during the first mixing. Water shall not be added by a spray bar from a water truck directly onto the unmixed cement spread. The cement shall be thoroughly mixed with the pulverized roadbed materials to provide a uniform distribution of the cement throughout the mixture. The temperature shall not be below 40 degree, and that the finished section should not be subjected to freezing temperatures for at least 7 days.

Mixing Water with Cement and Pulverized Materials: If the contractor does not inject moisture into the mixing chamber of the pulverizer/mixer during the first mixing, the pulverizer/mixer shall then be used to mix water into the mixture of cement and pulverized roadbed materials. The mixing shall be completed in one or more continuous pass(es) of the mixing unit. The mixture of the water, cement and pulverized roadbed materials shall be substantially that of optimum moisture content for that material and shall be in a condition suitable for immediate compaction without further mixing or grading.

When the mixer will handle only a part of the roadbed width, the successive increments shall be of such length that the full width of treated material may be promptly mixed, compacted and finished, with not more than 30 minutes between mixing adjacent lanes.

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**CEMENT TREATED RECONSTRUCTED BASE**

The asphalt and cement mix shall not remain undisturbed after mixing and before compaction for more than 30 minutes.

When the uncompacted mixture is made too wet by the addition of too much water, or by rain, and the moisture content exceeds the specified tolerance for compaction, the entire affected section may be remixed at the Contractor's expense in an effort to dry the mixture through aeration.

Compaction and Finishing: The pulverizing, mixing and compaction shall be a continuous operation. During the initial test section, the Contractor shall establish an optimum rolling pattern. A sufficient number of coverages of the CTRB surface by the roller / rollers proposed to be used by the Contractor during production operations shall be made to achieve the maximum density possible. The Engineer will observe the Contractor's use of a nuclear density gauge to verify that the maximum densities of 96% are achieved. Finishing shall be completed within 4 hours of the start of mixing, or as determined by the Engineer.

The established rolling pattern shall be used for compacting all CTRB. If a change in the mixing depth or cement content occurs, or if unacceptable results are obtained, a new optimum rolling patter shall be established.

After the mixture has been compacted, the surface shall be shaped to the required lines, grades, and cross sections to within the required tolerances. During the shaping, light scarifying may be necessary to prevent the formation of compaction planes. Broom dragging or clipping of the surface may be required as a part of the process of shaping the surface during compaction. The surface material shall be maintained at the specified moisture content during finishing operations. The final compaction and finishing operations may be varied, if necessary, to produce a smooth, dense surface free of surface compaction planes, cracks, ridges or loose material.

**Acceptance:** Will be in accordance with Section 306 of the latest edition of the AHTD Standard Specification for Highway Construction except as modified herein.

Testing, Tolerance, and Deficiency Correction: The thickness of the base will be checked by the Engineer at intervals not to exceed 500 feet. A tolerance of +/-1 inch point will be permitted. Adjustment from plan design thickness will be allowed where the existing pavement cross section is deficient.

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**CEMENT TREATED RECONSTRUCTED BASE**

Opening to Traffic: Traffic shall be placed on the roadway after the roadway is able to withstand traffic without damage to the surface, as directed by the Engineer. The contractor is to be responsible for maintaining the CTRB until all pavement layers have been constructed, and shall immediately repair any defects that may occur.

**METHOD OF MEASUREMENT:** CTRB will be measured in units of square yards. The length shall be measured along the surface of the pavement. The width shall be as specified on the plans or as directed by the Engineer. Portland Cement and Aggregate Base Course will be measured by the ton (metric ton).

**BASIS OF PAYMENT:** Portland Cement and Aggregate Base Course will be paid for at the contract unit price per ton (metric ton). CTRB will be paid for at the contract unit price per square yard. The prices shall be full compensation for all materials, equipment, tools, labor, and incidentals necessary to complete the work.

Payment will be made under:

| Pay Item | Pay Unit |
|---|---|
| Cement in Cement Treated Reconstructed Base | Ton (Metric Ton) |
| Aggregate in Cement Treated Reconstructed Base | Ton (Metric Ton) |
| Processing Cement Treated Reconstructed Base | Square Yard (Square Meter) |

# PROPOSED SPECIAL PROVISION

## JOB XXXXXX

## ROLLER COMPACTED CONCRETE PAVEMENT

**DESCRIPTION:** This item shall consist of constructing a Roller Compacted Concrete (RCC) Pavement on a Cement Treated Reconstructed Base (CTRB) or the existing asphalt pavement according to these specifications and conforming to the lines, grades, thicknesses, and typical cross sections shown on the plans or established by the Engineer.

**MATERIALS**

General: All materials to be used for RCC construction shall be approved by the Engineer based on laboratory tests or certifications of representative materials, which will be used in the actual construction. All materials shall conform to Section 501.02 of the latest edition of the *AHTD Standard Specifications for Highway Construction*, unless otherwise modified herein.

Aggregates: The design of the RCC pavement mixture approved for use in this project shall contain a nominal maximum aggregate size of ¾ inch, and shall conform to the following gradation requirements. The aggregate blend shall consist of both fine and coarse aggregate and will be a blend of 2 to 4 aggregates.

| Sieve Size, inch (mm) | Minimum % Passing | Maximum % Passing |
|---|---|---|
| 1” (25.0mm) | 100 | 100 |
| ¾” (19.0mm) | 90 | 100 |
| ½” (12.5mm) | 70 | 90 |
| 3/8” (9.5mm) | 60 | 85 |
| #4 (4.75mm) | 40 | 60 |
| #16 (1.18mm) | 20 | 40 |
| #100 (.150mm) | 6 | 18 |
| #200 (0.075mm) | 2 | 8 |

Table 1. Gradation Requirement for Roller Compacted Concrete Paving Mixture

Mix Design: The mix design will be done by the contractor in accordance with section 501.03 except as modified herein. The proportion used in the mix shall

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**ROLLER COMPACTED CONCRETE PAVEMENT**

be determined by the proctor method according to AASHTO T180, Method D. The RCC pavement mixture shall have a minimum 28-day compressive strength of 5,000 psi. Supplemental cementitious materials should not be used. All specimen fabrication shall be performed in accordance with AASHTO R39 and ASTM C 1435. Designs shall include the blend gradation for the job mix formula, including cement content, water content, w/c ratio, 28-day strength. Trial batches are required as described in section 802.05.

Quality Control, Acceptance and Adjustment: Quality control and acceptance testing shall be performed by the contractor in accordance with section 501.04 except as modified herein. The Standard Lot size for acceptance will be 4000 square yards (square meters), with each standard lot divided into four sublots of 1000 square yards (square meters) each. No testing for slump or air content will be required. (removed requirement for three additional cores)

Lot and sublot compliance, rejection, and price reductions shall be determined based on the values in Table 2 in lieu of Table 501-1.

| Property | Compliance Limits | Price Reduction Limits | Price Reduction | Rejection Limits |
|---|---|---|---|---|
| Compressive strength | 4000 psi (min) (28.0 MPa) | 3999-3800 psi (27.9 – 26.2 MPa)<br><br>3799-3600 psi (26.1 – 24.8 MPa)<br><br>3599 – 3400 psi (24.7 – 23.4 MPa) | 10%<br><br>20%<br><br>30% | Lot rejection: < 3400 psi (23.4 MPa)<br><br>Sublot rejection: <3200 psi (22.1 MPa) |

Table 2 - COMPLIANCE, PRICE REDUCTIONS, AND REJECTION LIMITS FOR ROLLER COMPACTED CONCRETE PAVEMENT

Tolerance in Pavement Thickness: Tolerance in the thickness shall be in accordance with section 501.10. Subsection 500.10 shall be modified to further include the following:

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**ROLLER COMPACTED CONCRETE PAVEMENT**

The equipment and methods employed in placing the roller compacted concrete material shall ensure accuracy and uniformity of depth and width. If conditions arise where such uniformity in the placing cannot be obtained, the Engineer may require additional equipment or modification in the placing procedure to obtain satisfactory results.

## EQUIPMENT

General: Roller compacted concrete shall be constructed with any combination of equipment that will produce a completed pavement meeting the requirements for mixing, transporting, placing, compacting, finishing, and curing as provided in this specification.

Mixing Plant: The RCC pavement mixture shall be produced in a twin-shaft pug mill plant or central batch plant, at a rate that is consistent with placement, and will allow for continuous movement of the paver. Concrete shall be delivered and discharged from the truck into the paver within one hour after the introduction of the mixing water to the cement. Close control of water content is required and thorough mixing is necessary to achieve a homogeneous mixture.

Haul Trucks: The mixture shall be delivered to the site in dump trucks, which are suited for depositing the mixture into the hopper of the paver. Each load transported to the site shall be covered to prevent contamination and evaporation. A suitable number of trucks must be available to ensure a constant supply of RCC pavement material in the hopper, allowing the paver to proceed at a consistent rate. Stopping and starting the paver should be kept to a minimum.

Paver: The paver shall be a high-density paver and should be capable of producing 85 percent of the laboratory-derived maximum density. Lift thicknesses should be limited to 8 inches.

Safety Edge: When the RCC pavement will be used as the riding surface, the outside edges of the pavement shall be laid in such a manner as to form no steeper than a 1:1 slope or "safety edge".

Compactors: Self-propelled steel drum vibratory rollers having a minimum static weight of 10 tons shall be used for primary compaction. For final compaction, either a steel drum roller, operated in a static mode, or a rubber-tired roller of

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**ROLLER COMPACTED CONCRETE PAVEMENT**

equal or greater weight shall be utilized. Walk-behind vibratory rollers or plate tampers shall only be used for compacting areas inaccessible to large rollers.

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. Such equipment shall be equipped with a spreader pipe containing fog spray nozzles capable of evenly applying a fine spray of water to the surface of the RCC without damaging the final surface.

Inspection of Equipment: Before start-up, the Contractor's equipment will be carefully inspected. Should any of the equipment fail to operate properly, no work will proceed until the deficiencies are corrected.

Access for Inspection and Calibration: The Engineer and his representatives shall have access at all times for any plant, equipment, or machinery to be used in order to check calibration, scales, controls, or operating adjustments

**PROFICIENCY REQUIREMENTS:** The Contractor placing the roller compacted concrete pavement for this project shall demonstrate proficiency with that material by providing documentation and/or reference letters from two (2) successful previously placed projects. If the contractor cannot demonstrate proficiency with RCC, then the contractor is required to have an individual with RCC expertise on site throughout the construction of the RCC pavement. The individual shall demonstrate proficiency with RCC by providing documentation and/or reference letters from two (2) successful previously placed projects.

**CONSTRUCTION REQUIREMENTS**

Rolling and Density Requirements: At the beginning of placement of each mix design, the Contractor shall establish an optimum rolling pattern for the mix being placed. A sufficient number of coverages of the entire mat by the rollers proposed to be used by the Contractor during production paving operations shall be made to achieve the maximum density possible. The Engineer will observe the Contractor's use of a nuclear density gauge to verify that the maximum densities possible are obtained.

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**ROLLER COMPACTED CONCRETE PAVEMENT**

The established rolling pattern shall be used for compacting all mix placed. If a change in the accepted mix design occurs, or if the compaction method or equipment is changed, or if unacceptable results are obtained, a new optimum rolling pattern shall be established.

If for any reason a rolling pattern cannot be established to produce the specified density, a new mix design will be required. The Contractor shall establish an optimum rolling pattern that will produce the maximum density using the new mix design. Continuous production of the mix shall not begin until an optimum rolling pattern that produces the specified density within the allowable range has been established.

Rolling shall start longitudinally at the low edge and proceed toward the higher portion of the mat. When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first followed by the regular rolling procedure. Alternate passes of the roller shall be terminated at least 3’ (1 m) from any preceding stop. Rolling on superelevated curves shall progress from the low side. Rollers shall not be stopped perpendicular to the centerline of the traveled way.

Compaction: Initial compaction shall begin immediately after paving, and shall be performed using a smooth steel drum vibratory roller. Finish rolling may be performed using a steel drum roller in static mode or a rubber-tired roller. Walk-behind tampers or rollers may be used for areas not accessible to large rollers. At no time shall the rolling operation cause movement of the mat or tearing of the surface. On the first pass, the roller shall maintain a distance of at least 6 inches from the unconfined edge, then compacting the unconfined edge on subsequent passes. Compaction should be completed within 30 minutes of placement, or as directed by the Engineer.

The RCC pavement mat shall be compacted to a minimum of 98 percent of the maximum laboratory density obtained by AASHTO T180 Method D, based on wet density. A minimum of one density test shall be taken by the Contractor for every 1000 square yards of RCC pavement for the purpose of quality control.

Base/Subbase Preparation: Base/subbase should be uniformly compacted to at least 96 percent of maximum density, and shall not exhibit any instability, as determined by proof rolling. Immediately prior to the placement of RCC pavement, the subgrade or subbase shall be clean and free of debris, then

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**ROLLER COMPACTED CONCRETE PAVEMENT**

uniformly moistened using a water truck with a spray bar. No standing water should be present.

Curing: After final compaction and density testing is complete; the RCC pavement surface shall be kept moist, using a fine mist of water, until a curing compound has been applied in accordance with Section 501.05 (l)(3) AHTD specifications. When the RCC pavement is to be covered with a bituminous wearing course, an approved emulsion product may be used for curing purposes.

Placement: Placement of RCC shall be limited to the months of April through September. The RCC pavement shall not be placed on a frozen or frost-covered surface, and should be placed when the air temperature is at least 50°F. The temperature of the RCC pavement surface should be protected such that its surface temperature does not drop below 40°F for at least 5 days. During hot weather paving, precautions should be taken to maintain appropriate moisture levels. Paving must be suspended during periods of rain, and may be suspended during periods of heavy mist if water ponds on the pavement surface. In such cases, the Engineer will determine whether paving is suspended.

If possible, RCC pavements should be constructed in one lift. Pavements greater than 10 inches in thickness should be constructed in two equal lifts. For multiple lift pavements, the second lift should be placed within 60 minutes of the first lift. No single lift should be less than 4 inches in thickness.

RCC pavement shall be placed continuously, and without segregation, such that a smooth surface results. Segregated coarse aggregate should be removed from the surface, though hand work shall be kept to an absolute minimum. If the paving process results in significant segregation or tearing of the mat, paving shall cease until the problem has been resolved.

If possible, the adjacent lane should be placed within 60 minutes of the first lane, creating a fresh longitudinal joint. If this is not possible, then a vertical cut should be made along the exposed edge that will later form the longitudinal joint, removing approximately 4 inches and creating a vertical face. This cut should be made within 2 hours of placing the RCC pavement, and in a manner that maintains a smooth edge (i.e., no raveling). Clean and moisten the face of the joint prior to placing the adjacent lane. Ensure that a sufficient quantity of

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**ROLLER COMPACTED CONCRETE PAVEMENT**

material is present at the joint to create a densely compacted joint at the appropriate mat height.

Traffic: The RCC pavement mat may be opened to unrestricted traffic after 24 hours, provided a compressive strength of at least 2500 psi has been obtained. These strengths will be determined based on the Contractor's compressive strength testing of cores obtained by the Contractor. The Contractor will be responsible for appropriate traffic control during lane closures.

Smoothness: When the RCC Pavement will be used as the final roadway surface as indicated by the typical section, the surface shall be ground in accordance with Section 510, Grinding Portland Cement Concrete Pavement except that the entire surface shall be ground to a minimum depth of 1/16", and an IRI of 100 inches per mile. This grinding will be paid for at the unit price for "Grinding Portland Cement Concrete Pavement". When the RCC Pavement will have an ACHM layer placed over it as indicated by the typical section, grinding of the RCC Pavement may be necessary in order to achieve the smoothness requirements of the ACHM Surface Layer. Grinding for this purpose shall be at no cost to the Department.

**METHOD OF MEASUREMENT:** Roller Compacted Concrete will be measured by the square yard (square meter). The width for measurement will be the width as constructed according to the plans and typical cross sections or as directed by the Engineer.

**BASIS OF PAYMENT:** Work completed and accepted and measured as provided above will be paid for at the contract unit price bid per square yard (square meter) for Roller Compacted Concrete Pavement, of the thickness and type specified, which price shall be full compensation for preparing the subgrade or base and shaping the shoulders unless otherwise specified; for furnishing, transporting, and placing materials, and all other joint materials; for the preparation and processing of materials; for mixing, spreading, vibrating, compacting, finishing, and curing; for performing mix designs and quality control and acceptance sampling and testing; for sawing, cleaning, filling, and sealing joints; for half width construction; for furnishing the profilograph; taking all required profiles, performing all necessary computations; and for all labor, equipment, tools, and incidentals necessary to complete the work; provided, that for such area as is

**PROPOSED SPECIAL PROVISION**

**JOB XXXXXX**

**ROLLER COMPACTED CONCRETE PAVEMENT**

deficient in thickness, only the adjusted price will be paid as specified in Subsection 501.10. No payment will be made for pavement deficient in thickness in excess of ½" (12 mm), even though the deficient pavement may be allowed to remain in place, nor for repair as specified in Subsection 501.09.

Payment will be made under:

| **Pay Item** | **Pay Unit** |
|---|---|
| Roller Compacted Concrete (5") | Square Yard (Square Meter) |
| Roller Compacted Concrete (6") | Square Yard (Square Meter) |
| Roller Compacted Concrete (7") | Square Yard (Square Meter) |
| Roller Compacted Concrete (8") | Square Yard (Square Meter) |