Performance of Roller Compacted Concrete Pavement in Arkansas

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Abstract

In 2012, Roller Compacted Concrete (RCC) pavement was placed on a 2-mile section of a deteriorated roadway in Arkansas. Significant distresses in the area had been experienced as a result of the sharp increase in truck traffic associated with recent natural gas exploration efforts. RCC was chosen for the project because it afforded the ability to significantly increase the roadway's structural capacity while also minimizing construction time and cost. Although some challenges were met during construction, the final product was considered successful, and the pavement has performed well to date. While the surface has not proven to be as aesthetically pleasing as that of a traditional concrete pavement, the pavement has performed admirably and still exhibits good ride quality. After almost three years, IRI values have remained steady in spite of some surface defects. The primary distresses have been surface issues such as popouts and joint deterioration. The pavement has been subjected to relatively heavy traffic and significant seasonal temperature swings, and some cracking has been noted. This paper provides a detailed description of the project and a comprehensive performance summary to date, including a thorough discussion of the existing distresses.

Introduction

RCC is a zero-slump concrete mixture that is composed of the same constituent materials as traditional concrete mixtures, but has a much drier and stiffer consistency. When used for roadway paving, RCC is placed using an asphalt paver or high-density paver, then compacted using pneumatic and/or steel-wheeled vibratory rollers. RCC is an attractive paving alternative because it allows for a simplified construction process while also providing the substantial structural support of concrete. This work is significant for practitioners and researchers because it outlines many of the lessons learned, documents the performance to date, and establishes reasonable expectations for this type of pavement application. In many projects, RCC pavements may be initially topped with a wearing course, or an alternative surface may be placed as distresses begin to appear. In this project, the exposed RCC surface has continued to serve as the wearing course, allowing for a more comprehensive investigation of performance.

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Background

RCC pavements have been used for many years in a variety of heavy-duty applications such as lumber storage yards, heavy haul roads, loading docks, intermodal port facilities, and parking lots. More recently, RCC has received greater consideration for streets, highways, and airport paving. The state of South Carolina has successfully used RCC pavements as both structural and wearing courses on low and high volume highways (Zollinger and Johnson 2011). In Georgia, RCC was used to construct shoulders for Interstate 285, and was believed to provide a viable alternative to traditional asphalt shoulders (Kim 2007). RCC has also been used successfully in Colorado, Kansas, and Texas (Damrongwiriyanupap et al. 2012, Harris 2012, Moucka 2012). In Colorado, RCC pavements were examined to assess the relative performance of RCC, specifically assessing surfacing and jointing practices. To enhance surface condition and rideability, diamond grinding and jointing were recommended.

RCC Materials and Mix Design. In general, the materials used for RCC are the same as those used in conventional concrete mixtures – coarse aggregate, fine aggregate, cementitious materials, and water; however, there are major differences (ACI 2001). RCC has a lower water content, a lower paste content, and is generally not air entrained. For RCC pavements, aggregates should not exceed a nominal maximum aggregate size (NMAS) of 19.0 mm (¾ inch), and RCC requires more fine aggregate to achieve proper compaction.

Crushed or uncrushed aggregates may be used, although crushed aggregates are preferred because they are more likely to provide load transfer. Because of their decreased paste content, RCC mixes depend more heavily upon aggregate structure for their strength, and the greater angularity of crushed aggregates provides stability in the aggregate skeleton and higher flexural strength. Fine aggregates used in RCC pavements may be natural or manufactured, crushed or uncrushed, though crushed sands can also enhance aggregate interlock. 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 (Harrington et al. 2000). In addition, a small portion of natural sand helps to improve the workability of the RCC mixture, while also helping to maximize its density.

Mixture design for RCC pavement is most commonly performed using the soil compaction (modified proctor) test, as described in AASHTO T180 or ASTM D1557. In this method, an aggregate structure and trial 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. Cylinders are then prepared at the optimum moisture content and a range of cement contents to determine the minimum cement content that is capable of generating the desired level of compressive strength (PCA 2004, Amer et al. 2004).

RCC Pavement Production and Construction. RCC mixtures are typically batched in a continuous mixing pugmill or a rotary drum plant. The continuous mixing pugmill is used most frequently, and is preferred because it produces adequate mixing efficiency, is capable of providing homogeneous mixing, and provides a relatively large output capacity. Ideally, the plant is constructed in the proximity of the jobsite so that the concrete can be placed and compacted within 45 to 90 minutes of mixing.

RCC construction is simpler than that of conventional concrete pavement because it does not require forms, dowels, reinforcing, or finishing. Placement of RCC is much like that of an asphalt mat, in that the mix is delivered by a dump truck, transferred into a paver hopper, and placed by the paver. Best results are achieved when a high-density paver is utilized, and increased density may also be attained by adding a tamping bar to the screed. The mat is then further compacted by rollers that immediately follow the paver. A typical rolling process begins with a 10-ton dual-drum vibratory roller, used in static mode for two passes to 'set' the surface before primary compaction is then performed in the vibratory mode. Finish rolling is then accomplished by either a static steel-drum roller or a rubber-tire roller.

The formation of construction joints can be one of the more difficult aspects of RCC pavement construction. Though continuous paving in echelon would be optimal, this is rarely practical due to traffic considerations. Thus, longitudinal and transverse construction joints must be formed, and it is difficult to achieve the desired density at these locations. In order to properly form cold joints, the hardened lane should be sawed to produce a clean vertical face, and the fresh lane should be placed 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. Load transfer devices are not typically used in RCC, as load transfer is provided primarily by the aggregate interlock. When vertical faces are formed by sawing, no aggregate interlock is present; therefore, tightly constructed joints are a must.

Curing is also important for an RCC pavement 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. Curing compounds are often used as well. With proper early curing, RCC pavements can be opened to traffic as soon as desired strength levels are achieved, which is often within 24 to 48 hours of construction.

RCC Performance. Most references to RCC pavement performance are linked to properties of the surface of the pavement, including surface condition, skid resistance, smoothness, rideability, durability, and load transfer. Surface defects may include joint condition, weathering or raveling, joint sealant damage (if jointed), and patched areas. Due to the nature of the compaction process, an RCC surface is generally not as smooth as that of a conventional concrete surface; though with experience, smoothness may be improved. For low-speed, heavy-duty applications, some roughness is acceptable; but for pavements, surface quality is certainly a prime consideration. Thus, most RCC pavements are either diamond ground, or topped with an additional wearing course, such as dense-graded asphalt.

In the Colorado study, research was performed to investigate the performance of RCC pavements, specifically targeting the effects of jointing and diamond grinding (Damrongwiriyanupap et al. 2012). It was determined that diamond grinding was successful in reducing the level of raveling and chipping of the surface, and that jointing helped to significantly reduce both longitudinal and transverse cracking. Regarding non-surface characteristics such as compressive strength, splitting tensile strength, flexural strength, and drying shrinkage, RCC pavements were found to perform similarly to conventional concrete pavements. The RCC also performed well with respect to 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.

Project Description

In the fall of 2012, two sections of RCC pavement were placed on Arkansas Highway 213 in an effort to determine whether RCC could serve as a viable paving alternative for rural highways that were experiencing significant increases in traffic as a result of natural gas exploration activities in the area. The project location was a very rural area with relatively low traffic volumes, but had recently experienced more than 12 percent annual growth (as compared to the statewide average of 2 percent). The traffic stream was comprised of 18 percent trucks, resulting from gas well drilling, the local logging industry, and hauling from a nearby quarry.

Two sections were designed and constructed using RCC as the wearing course. Each section was 1.38 km (0.86 mi) in length. The 1993 AASHTO Pavement Design method was used to determine thickness. The first section included a 17.8 cm (7 in) section of RCC pavement placed on a Cement Treated Reconstructed Base (CTRB). The second section was a 20.3 cm (8 in) section of RCC placed as an overlay of the existing asphalt surface. In each section, the lane width was increased from 3 m (10 ft) to 3.4 m (11 ft), and 0.9 m (3 ft) shoulders were added.

The RCC mix design, summarized in Table 1, contained a combination of coarse aggregate, fine aggregate, and intermediate screenings in order to meet the gradation requirements, and the design was performed using the modified proctor method (AASHTO T180). Specifications required a minimum compressive strength of 34.47 MPa (5000 psi) at 28 days and a minimum in-place compacted density of 98 percent of maximum wet density.

Table 1. 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	

Section 1. Construction of Section 1 seemed to be plagued with a number of difficulties. Most of the problems were related to minor malfunctions or maintenance issues within the plant, such as blown gaskets, broken belts, and material clogs. The down time for repairs at the plant translated to delays at the paver, and resulted in limited paving time available each day. Rain delays, cool temperatures, and the shorter daylight hours of fall further complicated construction.

The westbound lane of Section 1 was paved first, and progress was slow, achieving less than 305 m (1000 feet) of paving per day for the first three days. Although project specifications required a heavy-duty paver capable of achieving at least 85 percent density behind the screed, densities averaged 83 to 84 percent. Adjustments were made to the paver, and densities improved. After rolling, compacted densities only ranged from 90 to 95 percent, and so a larger steel-wheel vibratory roller was obtained, successfully meeting the required 98 percent minimum requirement. After final compaction was completed, in-place densities were measured according to ASTM C1040. Then curing compound was sprayed onto the mat, and joints were sawn at 15-foot spacings using an early-entry saw. Cores were cut to determine compressive strength and to confirm mat thickness. Cylinders were also prepared according to ASTM C1435 and used for strength determinations.

Compressive strengths of 17.24 MPa (2500 psi) were required for the pavement to be opened to traffic, which included construction traffic. The first section of the westbound lane was opened to traffic after 4 days, due to slower than anticipated strength gain. Paving in the eastbound lane progressed more smoothly, but still not as quickly as desired. Early indications of compressive strength were also disappointing, with some 24-hour strengths as low as 3.17 MPa (460 psi).

Section 2. Due to the difficulties experienced on Section 1, several changes were made before the construction of Section 2 began. Fly ash was removed from the mix design and replaced with Type 1 cement, a new pug mill plant system designed specifically for use with RCC was brought in, and a heavier paver with a more aggressive vibrating screed was acquired. Mat densities on Section 2 were as high as 97 percent behind the screed (prior to rolling), and easily met the 98 percent minimum requirement after rolling. Overall, the project progressed much more smoothly and compressive strengths were greatly improved. The increase in compressive strength was believed to be at least partially due to the removal of fly ash from the mix design, allowing for greater early strength gain. Temperature was also believed to play a major role in early strength gain. During the project, nighttime low temperatures averaged 1.7 °C (35 °F) and ranged from -7.2 to 15.6 °C (19 to 60 °F). Lower 24-hr compressive core strengths corresponded with lower temperatures, while higher strengths coincided with higher temperatures. While paving was not allowed at temperatures below 4.4 °C (40 °F), it was believed that the nighttime low temperature also played a major role. Thus, it was recommended that the minimum placement temperature be increased to 10 °C (50 °F), with a forecasted overnight low temperature of not less than 4.4 °C (40 °F).

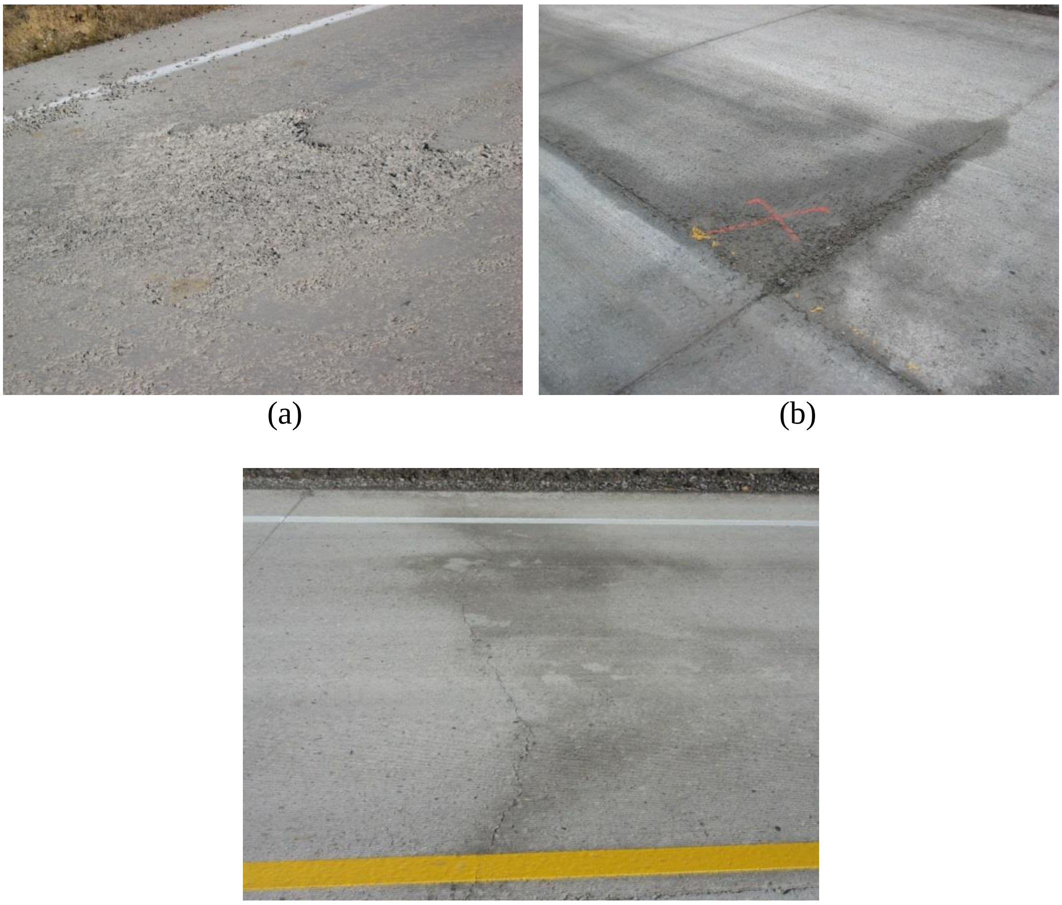
Section 1 Reconstruction. Compressive strengths in Section 1 were lower than anticipated after 24 hours, and strengths after 3, 7, and 14 days were also less than desired. Due to the poor strength levels and the success of improvements implemented in Section 2, the contractor elected to remove and replace the majority of Section 1. Compressive strengths were much improved, again confirming the successes resulting from the changes made to the process. A portion of the westbound lane of Section 1 was left in its original condition, allowing for performance comparisons. Diamond grinding was performed on both sections after all paving was completed. The finished product is shown in Figure 1.

Figure 1. Arkansas Highway 213 RCC Pavement Project

Maintenance of Traffic. This project site was a two-lane highway with a number of driveway access points and no viable detour alternative. During construction, two-way traffic was reduced to one lane and a pilot car was used to direct traffic 24 hours per day until the RCC was opened to traffic. Due to slower than anticipated strength gain in portions of the RCC, the pilot car was used for a longer timeframe than desired, but delays were minimal. The pilot car was advantageous in that it limited the speed of drivers through the construction zone, enhancing work zone safety. A video camera was also installed to provide live video feed of a portion of Section 1, which could be accessed remotely to monitor construction progress, frequency of trucks, and pilot car activities.

Performance

Immediately after the completion of paving, distresses began to appear in the original portion of Section 1, as shown in Figure 2. The most notable were localized areas of segregation and raveling. Minor raveling was later removed during diamond grinding, but deeper areas of raveling still visible after grinding were patched with an epoxy resin. Distresses were also evident at longitudinal and transverse construction joints, where roughness extended beyond the grinding depth. One crack, shown in the figure, formed almost immediately after construction. This crack was a transverse crack in the westbound lane that extended across the entire lane width. With the exception of roughness at the longitudinal joints and some low areas that were not removed during diamond grinding, no significant distresses were immediately evident in Section 2 or the reconstructed portion of Section 1. Smoothness was excellent after diamond grinding, with the pavement having an average International Roughness Index (IRI) of 70 inches/mile.



(a) (b) (c)

Figure 2. Early distresses in the original portion of Section 1: raveling (a), joint deterioration (b), and transverse crack (c).

Six months after construction, a distress survey was performed to identify the early appearance of additional distresses. Cracking was extremely limited, with the worst being the original transverse crack 3 mm (1/8 in) in width that extended across the entire lane (present since construction). The most common distresses were popouts, generally ranging from 2 to 10 cm (1 to 4 in) in diameter, and spalling at the longitudinal and transverse joints.

Additional distress surveys were performed at 9, 12 and 33 months of age. During the first year, Section 1 primarily experienced transverse joint spalls, some cracking, and longitudinal joint deterioration. Section 2 also had deterioration at the longitudinal joint, as well as popouts and some raveling, but had minimal cracking. Popouts were more frequently noted in Section 2 and the reconstructed portions of Section 1.

After almost 3 years, a few popouts and areas of segregation had further deteriorated into small areas of raveling, and cracking, however many had retained their original shape. Longitudinal joint deterioration and transverse joint spalling had only slightly worsened, while cracking had increased significantly in some areas.

Despite these distresses ride quality was still excellent, having an average IRI of 1.20 m/km (76 in/mi). A summary of distresses throughout the monitoring period is provided in Table 2, and discussion relating to each distress follows.

Table 2. Distress Summary

Cracking (number of cracks)				
Age (months)	Section 1 Original	Section 1 Reconstructed	Section 2 Westbound	Section 2 Eastbound
6	4	1	1	0
9	6	1	1	0
12	9	1	1	0
33	16	6	3	0

Transverse Joint Deterioration (percent defective)				
Age (months)	Section 1 Original	Section 1 Reconstructed	Section 2 Westbound	Section 2 Eastbound
6	5.3	2.7	1.0	0.7
9	7.0	2.7	1.0	0.7
12	7.5	3.4	1.3	2.0
33	7.5	3.6	2.0	2.3

Longitudinal Joint Deterioration (percent defective)			
Age (months)	Section 1 Original	Section 1 Reconstructed	Section 2
6	9.6	2.4	5.3
9	20.0	5.3	7.1
12	21.4	9.4	10.0
33	22.1	11.2	11.1

Popouts (number of popouts)				
Age (months)	Section 1 Original	Section 1 Reconstructed	Section 2 Westbound	Section 2 Eastbound
6	2	35	50	22
9	3	42	50	22
12	3	44	50	23
33	6	44	50	23

Raveling (percent length affected)				
Age (months)	Section 1 Original	Section 1 Reconstructed	Section 2 Westbound	Section 2 Eastbound
6	1.1	0.6	0.4	1.1
9	2.5	0.6	0.9	1.3
12	2.9	1.3	1.3	1.3
33	5.7	1.3	1.3	1.6

Smoothness (IRI)		
Age (months)	Average IRI (m/km)	Average IRI (in/mi)
1	1.10	69.5
3	1.20	76.0
6	1.13	71.6
9	1.12	70.8
33	1.21	76.4

Cracking. While RCC (as with traditional concrete) is expected to crack, the cracks in RCC should remain tight enough for the aggregate particles to provide the necessary load transfer. For this reason, jointing is not generally necessary for RCC. However, jointing was performed at 4.6-m (15-foot) spacings in an attempt to control cracking and maintain the best possible surface condition.

As previously stated, one full-width crack was immediately evident in the original westbound lane of Section 1. No specific cause was determined for this crack; however, this crack was in the same general location that areas of lower densities had previously been identified. After 6 months, a total of 4 cracks were identified in the original portion of Section 1, and that number grew to 9 cracks within 12 months. During the first year, only two cracks formed in Section 2 and the reconstructed portion of Section 1, and these cracks were corner breaks that were very small in width.

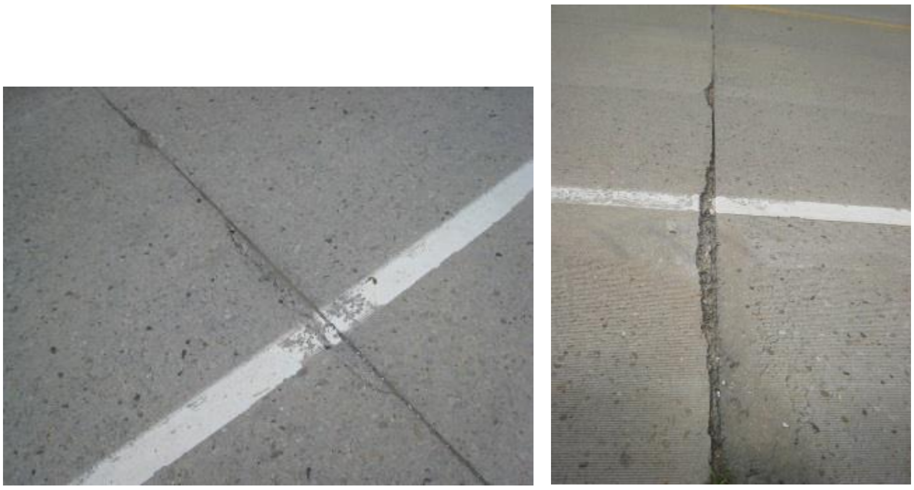
At 33 months, several more small cracks had formed. These cracks were mostly located in the original portion of Section 1, and were primarily corner breaks or minor surface cracking that had connected in areas of segregation (see Figure 3). One major longitudinal crack was identified in Section 2. This crack was near the middle of the lane and approximately 53 m (175 ft) in length (shown in Figure 4). Prior to placement of the RCC, this section had been a significantly rutted asphalt pavement. Although an asphalt leveling course was placed prior to the RCC, it was suspected that the prior distresses provided uneven support, allowing the underlying distresses to reflect through to the RCC layer. No cracks were noted in the eastbound lane of Section 2.

(a) (b)

Figure 3. Corner break (a) and transverse crack (b) in Section 1.

Figure 4. Longitudinal crack in Section 2.

Transverse Joint Deterioration. Transverse joints were cut as soon as was practical after paving using an early entry saw, and the joints were sealed. Transverse joint deterioration was noted in several locations shortly after construction, and the distress increased throughout the first year. In most cases, this distress was observed as a small crack along the edge of the joint, approximately 8 to 15 cm (3 to 6 in.) in length. Over time, the spalled appearance worsened, as shown in Figure 5. The original portion of Section 1 suffered the greatest percentage of these distresses, with some deterioration in all sections of the project. Although the percentage of affected joints increased slightly between the 12-month and the 33-month survey, the rate of deterioration appeared to have slowed.



(a) (b)

Figure 5. Transverse joint deterioration after 6 months (a) and 33 months (b).

Longitudinal Joint Deterioration. Longitudinal joint deterioration was also a prevalent distress. Because two adjacent lanes of RCC could not be placed at the same time, the first paved lane hardened before the second lane was placed. This edge was unconfined, resulting in an area of low density. Thus, a minimum of 10 cm (4 in.) was sawed from the centerline area in order to form a solid vertical surface against which to compact the second lane. Forming a dense, smooth centerline joint proved to be 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. In some of the more severely distressed locations, an epoxy sealant was placed, though the seal material did not perform consistently (see Figure 6). The original portion of Section 1 exhibited the greatest level of deterioration. In this section, most of the deterioration appeared within the first 9 months of service, with deterioration slowing after that. In the other sections, longitudinal joint distresses appeared more slowly, but have continued to increase throughout the 33-month period.

(a) (b)

Figure 6. Longitudinal joint deterioration with (a) and without (b) sealant.

Popouts. Popouts were believed to be a function of the aggregate type and surface density, and did not significantly affect the structural integrity of the pavement. Popouts ranged from 25 mm (1 in.) in diameter to almost 150 mm (6 in.) after the first year of service. For the distress survey, only popouts having a diameter of 75 mm (3 in.) and greater were included in the distress count. While Section 2 and the reconstructed portion of Section 1 performed better than the original portion of Section 1 with regard to overall distress, this portion of Section 1 was a much better performer with respect to popouts. The majority of popouts appeared within the first 6 months of service, and while the size of some popouts increased after the first year, many generally retained their original shape, as shown in Figure 7. The appearance of popouts did not increase significantly after the first year.

(a)

(b)

(c)

(d)

Figure 7. Popout after 6 months (a, c) and 33 months (b, d).

Raveling. Raveling was another surface distress noted in 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. Two of the more severe areas of raveling are shown in Figure 8. In Section 2 and the reconstructed portion of Section 1, the percent length affected by raveling was limited to approximately 2 percent, and has not changed significantly after the first year of service. The original portion of Section 1, however, had approximately 3 percent of length affected by raveling at 12 months of service, and two-fold increase after 33 months.

Figure 8. Examples of raveling.

Smoothness. Smoothness was another performance concern, and the Ames Lightweight Profiler was used to determine the IRI during and after construction. Before diamond grinding, IRI values ranged from 3.46 to 5.68 m/km (219 to 360 in/mi), which was certainly not considered to be adequate for a driving surface. After diamond grinding the average IRI value was 1.10 m/km (69.5 in/mi), which was similar to that of a newly constructed traditional concrete pavement. Although diamond grinding was employed as a means for creating a smooth driving surface, the surface distresses were expected to adversely affect ride quality over time. During the first year, IRI values ranged from 1.10 to 1.20 m/km (70 to 76 in/mi), but ride quality has not worsened since that time. Despite the existence of surface distresses, ride quality has remained good with a 33-month IRI value of 1.21 m/km (76.4 in/mi).

Conclusion

Overall, the RCC pavement on Arkansas Highway 213 has performed admirably, and has been able to withstand intermittent heavy loads resulting from heavy truck traffic at nearby gas well drilling sites, an aggregate quarry, and logging industry. Structurally, distresses have been minimal during the first 33 months of service, and ride quality has remained excellent with almost no change throughout the monitoring period. Some surface distresses have appeared, primarily joint deterioration, raveling, and popouts. Some issues were noted during the construction process of the original portion of Section 1, and distresses have been more prevalent in that segment. In a number of cases, the observed distresses presented very shortly after construction, but have not significantly worsened since that time. Longitudinal joint deterioration at the centerline was the only distress to affect more than 5 percent of the total project length. Cracking has been noted, though most appeared to be small surface cracks that formed as a result of segregation or raveling at the surface.

The RCC has been successful in providing the additional structural capacity needed for this project location. It is important to understand that the aesthetic expectations for RCC should not be the same as that of traditional concrete, but that the structural support can be just as substantial. The success of this pavement in serving its purpose confirms that RCC is certainly capable of providing adequate support and ride quality, and should be considered for other projects of this type.

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