Construction of Interstate Concrete Shoulders using 100% Recycled Concrete Aggregate

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Abstract

In an effort to increase consideration of the use of recycled concrete aggregates (RCA) in concrete pavements, this paper describes the mix design and construction of 90 lane kilometers (56 lane miles) of Interstate concrete shoulder pavement using 100% of the coarse and fine portions of recycled concrete pavement, with only the addition of natural sand for workability. The project is located on Interstate 16 between Macon and Savannah, Georgia. The original project plans allowed the option of asphalt, concrete or roller compacted concrete shoulders. The Contractor proposed and Georgia DOT permitted the use of 100% recycled concrete pavement as an option for the shoulder construction. While Georgia DOT has allowed recycled concrete for use in graded aggregate base since the late 1990's, this is their first use of recycled concrete aggregates in pavement. The project also includes the replacement of the truck lane and rehabilitation of the existing inside lane. The project successfully incorporated 100% of the RCA in the new concrete shoulders while maintaining strength and workability, providing concrete shoulders as another viable option for RCA pavements.

Introduction

Recycling of concrete aggregates in new concrete pavements has recently become a focus area in the U.S. The Indiana Department of Transportation (DOT) released a study in 2013 that looked at different recycled concrete aggregate (RCA) replacement levels and included considering the cost benefits of using RCA (Verian et al. 2013). Missouri DOT studied the use of RCA in pavements and other infrastructure elements in 2014 and recommended limiting the replacement level to 50% (Volz et al. 2014). Washington State DOT presented the results of their RCA study at the 2015 Transportation Research Board meeting. The study reported that properties of mixes with up to the 45% RCA replacement were comparable to virgin concrete (Wen et al. 2015). Minnesota DOT has a current research project in progress to evaluate their RCA test sections (Reza, in progress). All of these State DOT projects focus on the use of RCA as a replacement for a portion of the coarse aggregate, as this is the more common use of RCA. FHWA has even developed a technology implementation plan for using RCA in new Portland cement concrete (PCC) projects (Garber et al. 2011). But the concrete industry, and perhaps more importantly the DOTs themselves have not truly embraced this form of recycling yet.

RCA in the United States is frequently used in unbound bases, but not as frequently in concrete pavements. A recent survey of RCA use by the State DOTs noted valid concerns with RCA that was composed of poor quality aggregate due to the original virgin aggregate material (i.e. alkali-silica reactive (ASR) or D-cracking problems). Concerns of consistency issues due to water demand fluctuations and quality of material, and the harshness of the mix were also seen as impediments to

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using RCA in new concrete mixes (Garber et al. 2011). In recent research reports it has been documented, for the States that have constructed new pavement with RCA, that the long-term performance can be comparable to pavements made with virgin aggregates (Gress et al. 2009). Constructability does seem to still be a concern, with quality and variability noted by the States.

This paper has been prepared to share a recent success in constructing concrete shoulders with 100% RCA to hopefully encourage alternate, even more productive uses of RCA in roadway construction in the future.

Georgia DOT's use of recycled pavement. The Georgia Department of Transportation's (Georgia DOT) first major contracted recycled asphalt pavement (RAP) project was located on Interstate 85 north of Atlanta in 1982 (Deaver 1983). The 6-lane roadway (3 lanes in each direction) was milled and a 5 cm. (2 in.) RAP binder mix with a 35% recycled to virgin aggregate ratio inlayed. Almost 45,500 Mg (50,000 tons) of recycled mix was placed. The surface mix was virgin material. From a research project prepared at the time it appeared that the project went well and no major problems were encountered, even though the site was a heavily traveled interstate. Of course, currently, the vast majority of the asphalt mixes (base, binder and surface) placed on all Georgia roads (Interstate to local roads) utilize RAP. In contrast, Georgia's first major recycled concrete pavement project is currently ongoing, in 2015, more than 30 years later.

Georgia DOT does have experience with using RCA as an unbound base material. Georgia DOT Standard Specification Section 815.03 (Crushed Concrete Base) was added to the Georgia Specifications in January 1997. The specification change allowed the use of concrete paving or structural concrete to be used for graded aggregate base as long as it met the quality and gradation requirement of the specifications and the source was approved by the Georgia DOT Office of Materials and Research like any other aggregate. Although it was allowed as early as 1997, there is no real record of its use until after 2004. This was also around the same time when the concept of concrete recycling was a focus of a presentation to the Contractors and DOT at the annual Georgia Partnership for Transportation Quality conference.

Others experience using recycled pavement. Illinois DOT placed a CRCP Interstate pavement constructed with both coarse and fine RCA, with the addition of natural sand for workability, in 1986-87. The pavement was overlaid in 2010 after 23 years of use, which was the average life expectancy of Illinois CRCP's in a recent study (Roesler et al. 2011). Texas DOT recently reviewed a section of Interstate 10 in Houston that was placed in the 1990s using only coarse and fine RCA, with no virgin aggregates. After 18 years of service the 9 kilometer (5.8 mile) section was still performing satisfactorily (Choi et al. 2013).

The Recycled Materials Resource Center compared the performance of a number of pavements that had been constructed of recycled concrete aggregates in 7 States (Connecticut, Illinois, Iowa, Kansas, Minnesota, Wisconsin and Wyoming). Some of the RCA sections also had corresponding control sections. They did not find major differences in performance between the control and RCA sections except for one section in Minnesota, which they attributed potentially to very high mortar content in the RCA section. The overall conclusion was that RCA pavements can compare in performance to conventional virgin pavements (Gress et al. 2009).

A recent NCHRP synthesis on recycling, NCHRP 435, noted the use of RCA in the lower lift of two lift pavements, primarily in Europe, and confirmed the limited use of RCA in new PCC pavement in the U.S. as compared to unbound use. Potential use of RCA in shoulders was mentioned in the NCHRP report. The report noted that Michigan DOT allows RCA for valley gutter, sidewalk, concrete barriers, driveways, temporary pavement, interchange ramps, and shoulders" (Stroup-Gardiner and Wattenberg-Komas 2013). But, the Michigan DOT specification currently restricts RCA use to the coarse aggregate (Van Dam et al. 2013).

As a comparison of the overall use of recycled pavement, in a recent FHWA publication related to pavement sustainability it was noted that where 94.2% of RAP that was reused was used back in asphalt concrete, only 6.5% of RCA was reused in new concrete (Van Dam et al. 2015). Although the data did come from different sources and the concrete data was 10 years older than the asphalt data, more recent data for concrete based on a survey of the States supports the same low percentage of RCA use in new PCC (Garber et al. 2011). In an earlier FHWA 2004 review they noted a majority of the States had used crushed concrete as an unbound aggregate, but very few States had experience with using RCA in new PCC pavements (Gonzalez and Moo-Young 2004). In contrast, all 50 States now have experience with RAP in asphalt mixes, but there are only around 11 State DOTs, now 12 including Georgia DOT, that have experience with RCA in new PCC.

Coarse and Fine RCA. The FHWA Tech Brief on RCA notes that Coarse RCA is considered the material retained above the 4.75 mm (#4) sieve and fine RCA as that material passing the 4.75mm (#4) sieve. They recommend that only the coarse RCA be used in new pavements, but also recommend that if fine RCA is used that it be blended with a fine aggregate such that no more than 30% of the blend is RCA (FHWA 2007). Most RCA pavement projects have followed these restrictions. As described later, the Georgia DOT project used 100% RCA (coarse and fine) with a final blend of 81.1% RCA and 18.9% natural sand.

Georgia's RCA Construction Project

I-16 is the main interstate connecting Macon, GA to Savannah, GA. Along with a portion of I-75 it is the main link between the ports of Savannah and the capital city of Georgia, Atlanta. I-16 from Macon to Savannah was officially completed in September 1978, although portions of it were constructed as early as 1966, and opened in segments over time. The 48.3 km (30 mile) section that includes this project (~MP 39-68) was originally constructed under two separate projects with the same typical section. They were both completed in 1966. The current AADT on this section of I-16 is 18,000-20,000 with over 20% trucks. One of the original projects was designed for 18,050 AADT with 15% trucks for the forecasted year of 1975. The other was originally designed for an AADT of 21,650 and 12% trucks for the forecasted year of 1984. Nonetheless, the pavement designs were exactly the same.

Both projects consisted of 25.4 cm (10 in.) thick plain Portland cement concrete over a granular layer that was bituminous stabilized in the top 7.6 cm (three inches). As was common for the original interstates built in Georgia, these sections were not doweled. A previous Commissioner (Tom Moreland, GDOT Commissioner 1974-1987) shared that Georgia did dowel their concrete pavements prior to the Interstate Era. With the need for speed to complete the ambitious plan that was the Interstate system, and the industry's insistence that if you just add 2.5 cm (an inch) to the pavement you don't need dowels due to aggregate interlock; Georgia did not dowel concrete pavements from about 1960 to 1975.

Commissioner Moreland shared that restarting the use of dowels in concrete pavements in the 1970s was still one of his proudest accomplishments. (Tom Moreland, personal correspondence, March 18, 2015)

Project Information. The project that is the topic of this paper is designated M003956, I-16 in Laurens and Treutlen Counties. It consists of 90 kilometers (56 miles) of truck lane replacement and new inside and outside shoulders (See Figure 1). The truck lane had faulting up to 12.5 mm (0.5 in.) and was almost 50 years old. The existing concrete pavement did not display any material related distresses (i.e. ASR or D-cracking). The faulting and cracking it experienced was mainly due to the heavy truck loading and loss of support from the minimally stabilized base. The base was a bituminously stabilized granular soil. The inside shoulder was reconstructed so it could be used as a temporary lane during construction. The outside shoulder was also reconstructed. The new outside lane is 4 m. (13 ft) wide and replaced a 3.6 m. (12 ft) lane so it encroaches on the existing shoulder.

Figure 1-Showing new outside lane and new RCA PCC shoulders

The project was set up such that lane closures were only allowed for 3.2 km. (2 miles) with at least a 3.2 km (two mile) break in between. I-16 has a high volume of trucks, and a 112 km/hour (70 Mph) speed limit, and so the limit on lane closures was designed such that a car would be stuck behind a truck for less than 3.2 km (2 miles). The new outside lane is 28 cm (11 inches) thick, 4.6 m (15 ft.) jointed, doweled portland cement concrete. The inside lane was rehabilitated with isolated slab replacement and full width diamond grinding. The shoulders were let with three options: hot mix asphalt, RCC (roller compacted concrete) or PCC shoulders. The outside lane and the shoulders were all set up to have the existing base (granular soil) cement treated and then a special fabric placed between the cement treated soil and the new pavements.

The existing (25.4 cm) 10 inch thick concrete slab was to be removed, but with no graded aggregate base on the project there was no opportunity to reuse the material on site in the traditional way. The contractor, McCarthy Improvement Company, saw that the material was still valuable, and considered the environmental benefit of reuse, so they proposed to the DOT to build the shoulders using recycled aggregate in the PCC. Georgia DOT had extensive experience crushing old concrete into graded aggregate base, between 2005-2010 there was over 900,000 Mg (a million tons) used on Interstate projects in south Georgia. But there was no precedence using RCA into new concrete. The contractor performed numerous lab tests, meeting with and sharing the results with the DOT. They also performed a test section on one of their plant sites to show how the material would be placed. The test section also provided them an opportunity to identify slump loss for the material, and to test out their relatively new Topcon stringless system. They also had a requirement of placing a safety wedge on the outside of the shoulders on this project, and the test section gave them a chance to see how this would perform.

Crushing Operation. Georgia has two predominant geologies, the Piedmont in the northern half of the state, with its abundant granite supplies, and the Coastal Plains, which consists mainly of sands and some kaolin clays. Coarse aggregate supplies are mainly in the northern half of the state, while natural sands are found in the southern portion. Some coarse aggregate sources from Nova Scotia are even shipped into the Port of Savannah for use in the southern portion of the state.

While Georgia DOT has allowed crushed concrete to be used as graded aggregate base (GAB) since 1997, it has primarily been used in South Georgia, due to the abundance of aggregate in North Georgia. Over 1,360,000 Mg (1,500,000 tons) of recycled GAB was used in Georgia DOT projects from 2006-2014, which sounds like a lot of material, until you compare that to the approximately 27,215,500 Mg (30,000,000 tons) of GAB used statewide by Georgia DOT during that same time period.

Georgia DOT has over 70 qualified products lists (QPLs) that are maintained to preapprove materials and suppliers. QPLs 1 and 2, the first ones developed in the 1970s, are for fine and coarse aggregate sources, respectively. QPLs 1 and 2 consist of over 200 sources of aggregate materials. Contractors must get their sources preapproved if they are not already on the QPL. If the Contractor had chosen to do the crushing internally, they would have to get their aggregate locations and method approved by the Georgia DOT. The Contractor for this project chose to outsource the crushing operation on this project. They chose Remediation Resources out of Savannah, which already had a crushing site located near the project that was the result of a previous concrete rehabilitation project on I-16. The initial lab work and testing was performed using material from this adjacent project. As these projects were originally constructed in the 1960s around the same time it was anticipated that the material would be similar. Remediation Resources established two crushing sites adjacent to the two concrete plants that were erected by the Contractor on each end of the project. The crushing was accomplished using a Volvo EC 350 El loader which places the material into a KPL-JCI Fast Trax FT 2650, which then drops material into a KPI-JCI Fast Trax FT 4240. The crushers are run in tandem (Figures 2 and 3).

A radial telescoping stacker was used to construct the stockpiles of crushed concrete to limit segregation (Figure 4). The concrete was crushed into a GAB blend (Table 1). Each site was given a source code for the QPL and was inspected and the material tested before use on the construction project.

Concrete Plant. Two concrete plants were used, one near each end of the project. The concrete plants were both Rex central mix plants. The first one at Exit 49 was a single drum plant. The second, located at Exit 67, was a double drum plant. Two bins were used to supply the plant with the RCA and the natural sand. The RCA material was fed into the concrete plant similar to a blended 57 stone.

Figure 2- First Crusher

Figure 3 – Second Crusher

Figure 4 - Radial Stacker

RCA Shoulder Mix Design. The concrete mix itself consists of a 81.1% crushed concrete (RCA) and 18.9% natural sand. The sand was added to make the mix workable and it also added to the strength. The contractor did try a 100% RCA mix in the lab, but it was too sticky to be useable, so they experimented with adding natural sand to the mix. The RCA gradation and the gradation of the final blend are shown in Table 1. The final blend meets the requirements of Georgia DOT GAB.

Table 1 also shows the gradation bands for Georgia DOT 457, 67 and 57 stone and the gradation for GAB. Georgia DOT specifications allow the use of any of these types of gradations, (along with Number 10 fine sand) in concrete pavement mixes. GAB can be used for concrete shoulders, with the modification that the 2 mm (No 10) sieve range is 30 to 45 percent. The gradation shown under the heading "PCC Shoulder Spec for this project" was the agreed upon gradation range for the RCA shoulders. The RCA mix gradation is similar to the GAB gradation, but allows a little more variability on the 2 mm (No 10) sieve. The PCC shoulder specification was modified to allow this gradation. Although the GDOT PCC shoulder specification only has a 13.8 MPa (2000 psi) compressive strength requirement, the contractor amended the specification by stipulating 24.1 MPa (3500 psi), to match the RCC requirements and making it more amenable to the DOT to accept the change.

Table 1- M003956 RCA and Typical GDOT Gradations

	Ave RCA	**RCA blend w/ natural sand**	PCC Shoulder Spec for this project	GDOT 467	GDOT 57	GDOT 67	GDOT GAB
50 mm (2 in)	100	100	100	100			100
37.5 mm (1.5 in.)	99.7	99.2	97-100	95-100	100		95-100
25 mm (1 in.)	89	83		_	95-100	100	_
19 mm (3/4 in.)	80.4	70.8	60-95	35-70	_	90-100	60-95
12.5 mm (½ in.)	62.4	56.2		_	25-60	_	_
9.5mm (3/8 in.)	54.4	49.7		10-30	_	20-55	_
4.75 mm (#4)	39.9	39.8		0-5	0-10	0-10	_
2.36 mm (#8)	_	_			0-5	0-5	_
2 mm (#10)	11.2	33.3	25-50				10-35
75µm (#200)	4.0	2.5	1-8				7-15

The mix design proportions used in the PCC Shoulder mix design with and without flyash are shown in Table 2.

Table 2-PCC Shoulder Mix Design

	PCC Shoulder Mix with Flyash	PCC Shoulder Mix without Flyash
Cement, Type 1	226 kg (499 lbs)	245 kg (541 lbs)
Flyash, Type F	50 kg (110 lbs)	
Natural Sand	249 kg (550lbs)	215 kg (475lbs)
RCA	971 kg (2141lbs)	1036 kg (2286lbs)
Water	137 liters (36.3 gal)	137 liters (36.3 gal)
Air Entraining	5%	
Design Slump	37.5mm (1.5 in.)	
Admixtures	BASF Pozzolith 80 BASF MB AE90	

The design criteria for the GDOT specifications and for the mainline and shoulder pavements used on this project are shown in Table 3 and 4. As shown, the minimum cement content for the mainline and shoulder design was the same, although the typical specification requirements for shoulder PCC strength is lower.

Table 3 – Mainline Mix Design Criteria
GDOT Specifications and M003956 Project design

	GDOT PCC Specifications Section 430	M003956 Mainline PCC
Minimum Cement Content kg/m (ctw/cy)	320 (5.41)	326 (5.51)
Max W-C ratio	0.53	0.47-0.52
Design Air (%)	4-5.5	4.5
T 126 & T 97 Flexural strength	4.1 MPa (600 psi) +.67s*	4.1 MPa (600 psi) minimum
T 126 & T 22 Compressive strength (28 day)	20 MPa (3,000 psi) + .18R*	20 MPa (3,000 psi) minimum
Coarse aggregate	467, 67 or 57	869 kg (1916 lb)
Fine Aggregate	Size 10	552 kg (1218 lb)

*s is standard deviation and R is range from at least 12 tests

Table 4 – Shoulder Mix Design Criteria
GDOT Specifications and M003956 Project

	GDOT PCC Shoulder Specification Section 440	M003956 Shoulder PCC
Minimum Cement Content kg/m (ctw/cy)	250 (4.25)	326 (5.51)
Max W-C ratio	0.75	0.73
Design Air (%)	5-7	5
T 126 & T 97 Flexural strength	2.8 MPa (400 psi) +.67s*	4.1 MPa (607 psi) (design)
T 126 & T 22 Compressive strength (28 day)	13.8 MPa (2,000 psi) + .18R*	31.9 MPa (4625 psi) (design) 24 MPa (3500 psi) (acceptance)
Coarse aggregate**	467,67 or 57mod***	971 kg (2141 lb) RCA
Fine Aggregate	Size 10	249 kg (550 lb) sand

*s is standard deviation and R is range from at least 12 tests
**RCA consisted of coarse and fine aggregate
***57mod is 57 gradation with 30-45% passing the #10 (2mm)

RCA Material. As noted earlier, the existing concrete showed no signs of materials related distress. The RCA from the original 1970s concrete that was used for the shoulders measured a specific gravity near 2.5, 6.1% absorption, an LA abrasion of 28 and a soundness loss near 0. The absorption was measured separately for the coarse and fine portions of the RCA and the results were 4.75% for the coarse fraction and 8.6% for the fine fraction. As a comparison, the virgin coarse aggregate used in the mainline paving was a mylonitic gneiss/ amphibolite from near Macon, Georgia and it has a specific gravity around 2.7, 0.49% absorption, an LA Abrasion of 19 and a Magnesium sulfate soundness loss of 0.6.

Construction Quality Assurance. As is noted in the literature, moisture and stockpile management is very important for RCA mixes. The FHWA 2004 report notes that States that have used RCA have noted that they have had to keep good control on the moisture of the stockpiles, even wetting the stockpiles (Gonzalez and Moo-Young 2006). Since the material for this project was crushed into GAB form, there was a concern that wetting the stockpiles could cause segregation in the stockpiles. The contractor chose to monitor the water content and perform stockpile control through proper loading and unloading of the stockpile. It was also noted that the center of the stockpile always held water well, even though the outside appeared dry. The QC technician noted that the typical moisture content test that he ran first thing everyday was a challenge, as the material would look dry but still be losing moisture for over an hour. He eventually found that a propane stove worked much better than a hotplate in getting the moisture out quicker (Figure 4). The PCC shoulder has met all acceptance criteria, and consistently exceeds the minimum strength requirements, with the majority of the test results for compressive strength over 27.6 MPa (4,000 psi). The slump consistently met the requirements of 0 mm to 75 mm (0 to 3 inches), with values varying from 6 to 64 mm (0.25 inch to 2.50 inch).

Figure 5- Propane stove used by QC

Paving, curing and joint sawing/sealing. The placement of the RCA PCC shoulder was similar to the mainline regular concrete mix paving. The only changes were in the extra consideration of temperature and haul distance. In this area of I-16 some Exits are 8 or more kilometers (5 or more miles) apart and this needed to be considered in the paving operation. Occasionally the mix would be a little dry due to temperature and/or haul distance, but in most cases the finishers felt that the RCA was just as easy to finish as the mainline regular paving. The sawing operation could typically begin sooner than on the mainline, and the sawing operation sometimes was not too far behind the paver.

Conclusion

The construction project is scheduled to be complete in 2016, so complications may still arise, but the concrete placement of the shoulder mix has gone extremely well with no major concerns. Additional attention to quality control is necessary to maintain consistency in RCA mixes, especially when using fine RCA. The Contractor must consider moisture control and considerations for the effect of different hauling distances, especially as related to slump loss. But, the Georgia DOT is pleased with the consistency and apparent quality of the shoulder paving and the environment was spared the disposal of good reusable recycled concrete. An additional positive story can be told about RCA use in concrete pavements, and it is possible the percentage of RCA use in new concrete pavements could reach the percentage of use of RAP in asphalt pavements, someday in the future.

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