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The Use of Recycled Concrete Aggregate in a Dense Graded Aggregate Base Course

FINAL REPORT

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16. Abstract

The research project was broken up into 2 different parts. The first part involved evaluating the potential use of the Time Domain Reflectometry, TDR (ASTM D6780), as a non-nuclear means for determining the dry density and moisture content of granular base and subbase aggregates during quality control. Just prior to the study, Humboldt Equipment Company provided a device called the Electrical Density Gauge (EDG) that also claimed to be a non-nuclear means of determining dry density and moisture content. Both units were used on five separate field trials (5 sections for the TDR and 3 sections for the EDG) and compared against the NJDOT's nuclear density gauge. The field trials indicated that the TDR test method, as it currently stands according to ASTM D6780, does not compare well with the nuclear density gauge readings. This was mainly attributed to the TDR's soil constant calibration procedure. There also appeared to be a lack of sensitivity with the TDR method when compared to the nuclear gauge. The EDG showed a better correlation to the nuclear gauge, although this was expected since at the time of the study, the EDG device required field calibration. A newer version of the EDG now incorporates a laboratory calibration procedure that would eliminate the need for field calibration with a nuclear gauge.

The second part of the research study was to evaluate potential methods of increasing the permeability of recycled concrete aggregate (RCA), while attempting to maintain its structural integrity (i.e. – California Bearing Ratio, CBR). Before laboratory testing began, a survey was developed, sent to various state agencies, and tabulated to determine if other state agencies currently utilized RCA, and if so, what experience did they have regarding the drainage characteristics of the material. After the survey results were tabulated, laboratory testing was conducted on RCA blended with different aggregates; dense-graded aggregate (DGA), NJDOT I-3, and poorly graded sand. Work was also conducted on RCA material which was processed over a coarser sieve size (2 inches), as opposed to the finer 1.5 inches currently specified by NJDOT, in an attempt to include a larger, coarser fraction that could open up the internal structure of the RCA. This was in an attempt to meet some of the state agency specifications of the various states who responded to the survey saying they did not have any current issues with the permeability/drainage of their RCA materials. The results of the laboratory testing showed that the best performing modification to the RCA was when blended with 50% DGA. This increased the permeability to levels considered average, while still providing excellent bearing strength. The attempts of using the NJDOT I-3 and poorly graded sand did not dramatically increase the permeability, while a decrease in bearing strength was still reported. Increasing the top size of the processed/screened RCA from 1.5 inches to 2.0 inches helped to increase the permeability, while achieving the same bearing strength properties (CBR).

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ABSTRACT

The research project was broken up into 2 different parts. The first part involved evaluating the potential use of the Time Domain Reflectometry, TDR (ASTM D6780), as a non-nuclear means for determining the dry density and moisture content of granular base and subbase aggregates during quality control. Just prior to the study, Humboldt Equipment Company provided a device called the Electrical Density Gauge (EDG) that also claimed to be a non-nuclear means of determining dry density and moisture content. Both units were used on five separate field trials (5 sections for the TDR and 3 sections for the EDG) and compared against the NJDOT's nuclear density gauge. The field trials indicated that the TDR test method, as it currently stands according to ASTM D6780, does not compare well with the nuclear density gauge readings. This was mainly attributed to the TDR's soil constant calibration procedure. There also appeared to be a lack of sensitivity with the TDR method when compared to the nuclear gauge. The EDG showed a better correlation to the nuclear gauge, although this was expected since at the time of the study, the EDG device required field calibration. A newer version of the EDG now incorporates a laboratory calibration procedure that would eliminate the need for field calibration with a nuclear gauge.

The second part of the research study was to evaluate potential methods of increasing the permeability of recycled concrete aggregate (RCA), while attempting to maintain its structural integrity (i.e. – California Bearing Ratio, CBR). Before laboratory testing began, a survey was developed, sent to various state agencies, and tabulated to determine if other state agencies currently utilized RCA, and if so, what experience did they have regarding the drainage characteristics of the material. After the survey results were tabulated, laboratory testing was conducted on RCA blended with different aggregates; dense-graded aggregate (DGA), NJDOT I-3, and poorly graded sand. Work was also conducted on RCA material which was processed over a coarser sieve size (2 inches), as opposed to the finer 1.5 inches currently specified by NJDOT, in an attempt to include a larger, coarser fraction that could open up the internal structure of the RCA. This was in an attempt to meet some of the state agency specifications of the various states who responded to the survey saying they did not have any current issues with the permeability/drainage of their RCA materials. The results of the laboratory testing showed that the best performing modification to the RCA was when blended with 50% DGA. This increased the permeability to levels considered average, while still providing excellent bearing strength. The attempts of using the NJDOT I-3 and poorly graded sand did not dramatically increase the permeability, while a decrease in bearing strength was still reported. Increasing the top size of the processed/screened RCA from 1.5 inches to 2.0 inches helped to increase the permeability, while achieving the same bearing strength properties (CBR).

INTRODUCTION – PART 1 – Non-Nuclear Compaction Control

The objective of this study was to determine the suitability of using the Moisture Density Indication (MDI) in the construction quality control of compacted dense aggregate base layers. New Jersey Department of Transportation currently uses the nuclear density gauge to measure the dry density and moisture contents of compacted fills and base layers in its construction control program. Measurements from the MDI were therefore compared to those from the nuclear gauge.

The underlying principle of operation of the is Time Domain Reflectometry in which the apparent dielectric constant and bulk electrical conductivity are measured, and correlated to moisture content and density. The MDI used in the study was manufactured by Durham Geo Slope Indicator, and based on the University of Purdue TDR method. The test method is ASTM approved (ASTM D 6780).

Field testing was conducted on five sites that consisted of dense graded aggregates base layer as well as on some NJDOT designated I-9 porous fill materials. Limited testing was also done using an Electric Density Gauge (EDG) manufactured by EDG, LLC. The results on the field testing are presented in this report.

<u>Basic Theory of the Time Domain Reflectometry Method</u>

In general, TDR testing involves sending a fast-rising voltage pulse through a coaxial cable. The pulse passes through the sample and is reflected back through the coaxial cable. By measuring the electrical properties, moisture content and densities can be obtained.

The Purdue TDR setup is illustrated in Figure 1.

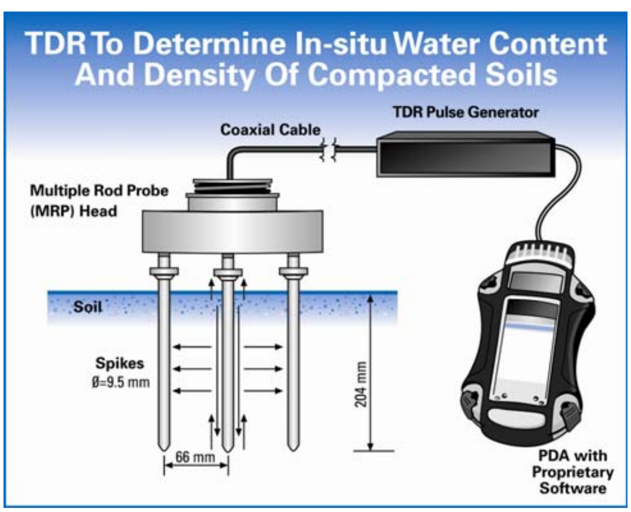


Figure 1 - Purdue TDR Setup (MDI Manual from Durham GeoSlope)

The voltage pulse travels through the sample at a rate or velocity that is proportional to the apparent dielectric contact K_a. The surface waves that are generated propagate along the buried spikes and are attenuated in proportion to the electrical conductivity EC_b along the travel path. In the Purdue method, Drnevich developed linear relationships between these two properties and the moisture content and dry density of the sample. The straight-line relationships are presented below. More details of the theory can be found in references.

$$\sqrt{K_a}*(*\rho_w/\rho_d) = a + bw \quad (1)$$

$$\sqrt{EC_b}*(*\rho_w/\rho_d) = c + dw \quad (2)$$

$$\sqrt{EC_b} = f + g\sqrt{K_a} \quad (3)$$

Where K_a is the apparent dielectric constant, EC_b is the electrical conductivity, ρ_w is the density of water ρ_d is the dry density and *w* the moisture content of the sample. *a, b, c, f* and *g* are constants.

Simultaneously solving these equations, yield:

$$\rho_d = (d\sqrt{K_a} - b\sqrt{EC_b})/(ad - cd) \quad (4)$$

$$w = (c\sqrt{K_a} - a\sqrt{EC_b})/(b\sqrt{EC_b} - d\sqrt{K_a}) \quad (5)$$

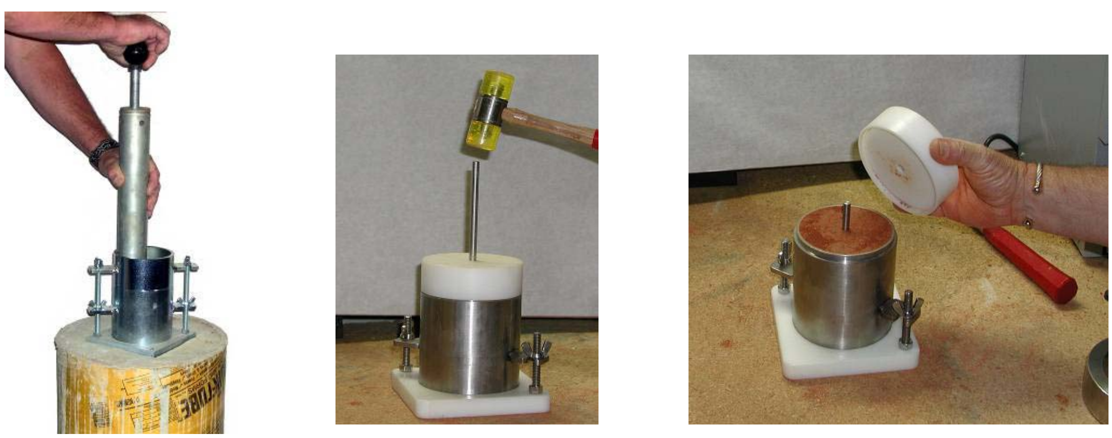
Equations 4 and 5 are the main equations used in the one- step method. It should be noted that a correction is required if the soil temperature is different from 68°F; details of which are presented in (Drnevich, 2003; Durham, 2004; Xiong and Drnevich, 2004). The soil constants are determined in the laboratory during the calibration procedure.

At the time of preparing this report, Rutgers did not receive any documentation on the equations and or the theory of operation from the manufacturer of the Electrical Density Gauge. However, it is understood that the EDG also operates under the TDR principle.

Laboratory Calibration-Determination of Soil Constants

In order to determine the calibration constants for the different samples, each sample was prepared as per ASTM D698. It should be noted that the maximum sizes of the DGA samples were greater than that allowed for Method A. However, the current set up for the calibration made available to Rutgers does not include a 6 inches compaction mold. The 4 inches mold provided was therefore used and sample prepared as per method A of ASTM D698. The calibration consisted of the following steps:

1. Air dry sample
2. Sieve sample through No. 4 sieve for ASTM D698 method A
3. Wet soil at different water contents to cover the range of moisture content expected in the field
4. Compact the soil in the 4-in mold mounted (Figure 2a) on a standard steel base as per ASTM D698 using standard compaction energy.
5. Weigh mold and soil and record as per ASTM D698.
6. Attach the mold to the non-conductive base and drive the center rod (rod must be clean) through the center of the non-conductive top template or guide (Figure 2b).
7. Remove guide, clean shoulder at the top of the mold, place mold collar and seat the Coaxial head on the adapter ring (Figures 2c). Be sure to rotate the ring and coaxial head to ensure good electrical contact.
8. Take TDR readings (Figure 3a and b) for each compaction test. A minimum of four tests is recommended.
9. After determination of the moisture content, the results of the compaction tests (dry density, TDR readings and moisture contents) can be input into the PDA software to determine the soil constants as per manufacturer's instructions. The soil constants can also be determined using the Excel template provided by the manufacturer (www.DurhamGeo.com/mdi).



(a) (b) (c)

Figure 2 - Compaction of Sample (a), Insertion of Center Rod (b) and Removal of non-conductive top template (c)

(a) (b)

Figure 3 - Placing of MRP Head (a) and Taking TDR Reading (b)

Calibration Results

A total of five samples from three DOT construction sites were tested. Samples were obtained from the following projects:

1. Route 206 expansion-Dense graded aggregate (DGA) samples (Southern Region)
2. Route 30 and Delilah road-NJDOT I-9 porous fill (Southern Region)
3. I-78 rehabilitation/expansion-Recycled concrete DGA sample (Northern Region)
4. I-78 rehabilitation/expansion-NJDOT I-9 porous fill (Northern Region)
5. Route 46 rehabilitation-DGA samples (Northern Region)

Photos of the samples used for the laboratory tests are shown in Figures 4 to 7.

(a) (b)

Figure 4- Route 206 DGA Sample (a) Passing Sieve No.4 and (b) Retained on Sieve No.4

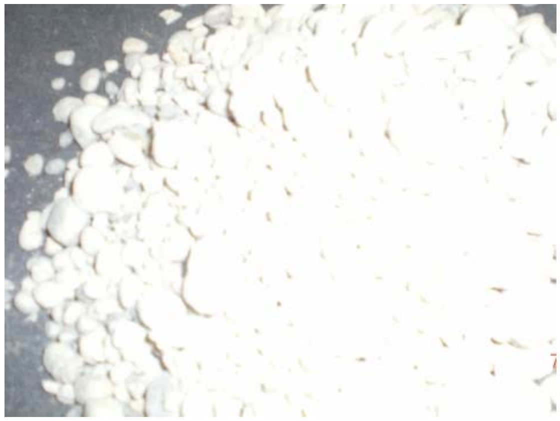


Figure 5 - Route 30 and Delilah Road Porous I-9 Sample

(a) (b)

Figure 6 - I-78 Samples (a) Recycled Concrete DGA and (b) Porous I-9 Fill

Figure 7 - Route 46 DGA Sample

As previously mentioned, the purpose of the laboratory calibration is to determine the soil constants a, b, c, d, f and g required for the One-step method. These constants were determined based on the straight-line relationships discussed in section 1.1. Very good fits were obtained with R^2 ranging from 0.92 to 0.99. Table 1 is a summary of the soil constants. Sample plots for Route 206 are presented in Figures 8 to 10.

Table 1 - Summary of Soil Constants

Sample	a	b	c	d	f	g
Rt. 206 DGA	0.9135	9.397	0.0156	0.3351	-0.0324	0.0347
Rt. 30/Delilah Road	0.8924	9.1568	0.0254	0.1417	0.0208	0.0155
I-78 DGA	0.1779	15.542	-0.0061	0.7543	0.0163	0.0466
I-78 I-9 Porous Fill	1.0817	8.9411	0.0786	0.9067	-0.05	0.0997
Rt. 46 DGA	0.7415	10.636	0.0032	0.0989	-0.0669	0.0623

The PDA software has the capability to automatically determine these constants and the user has to link them to the appropriate calibration file for field testing.

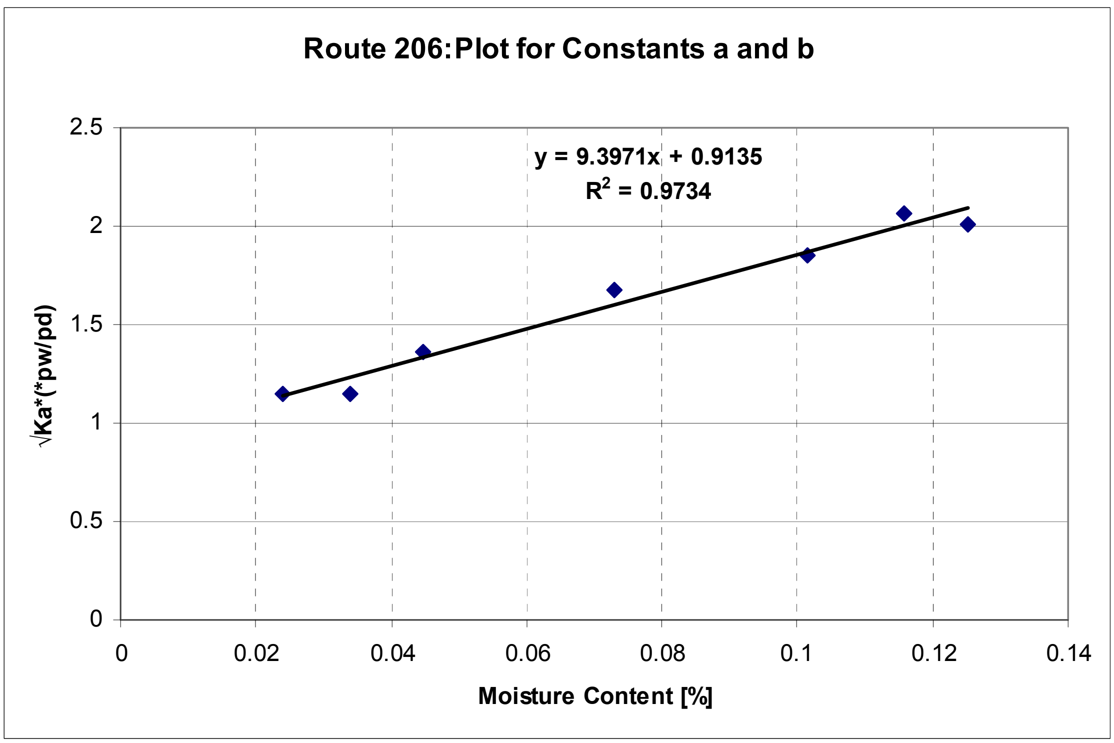


Figure 8 - Route 206 Determination for constants a and b

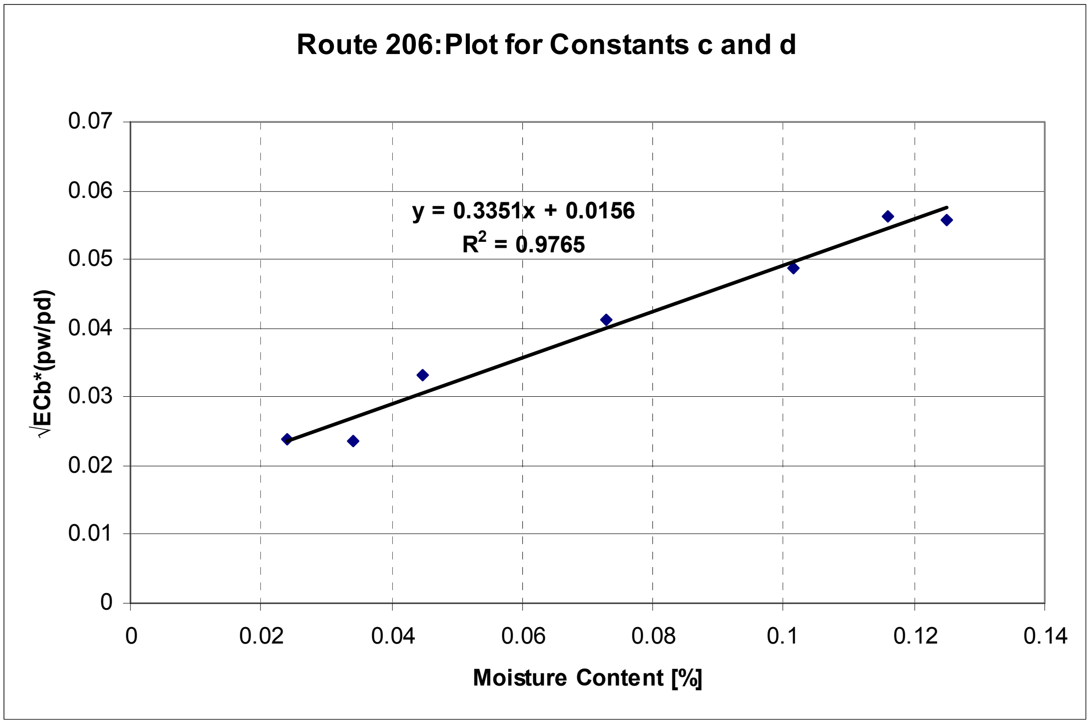


Figure 9 - Route 206 Determination for constants c and d

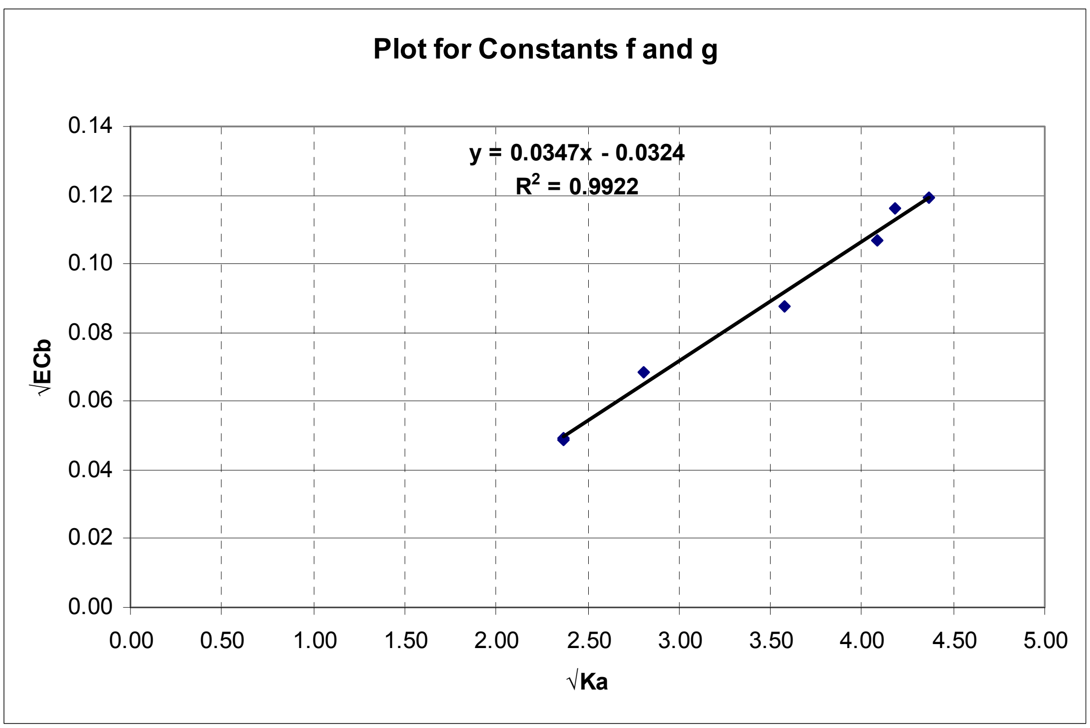


Figure 10 - Route 206 Determination for constants f and g

Field Testing

After the calibration constants were determined configuration files were setup for the various projects. Field testing was conducted using the One-Step method because of the ease in the field. The field operations included testing using a Nuclear Density Gauge, Geo Slope MDI-2000 and the Humboldt Electrical Density Gauge (EDG). Photos of the setup for each device are shown in Figures 10 to 12.

Figure 11 – Nuclear Gauge Setup

Only limited testing was done using the EDG because the current setup does not include a procedure to determine the soil models in the laboratory. A simple field calibration procedure was used for the EDG in which sections of the field were soaked with different amounts of water and the calibration done using the nuclear gauge. Due to the fact that the purpose of this study is to compare the results of the non-nuclear devices with the nuclear gauge, it was felt that this calibration procedure produced biased results. Hence much confidence should not be placed in the results. This is not to imply that the EDG is not a viable method for compaction quality control, but that the current setup needs to be improved to ease its application. The results are therefore not discussed further.

Figure 12 - Moisture Density Indicator-MDI 2000 (TDR) Setup

Figure 13 - Electrical Density Gauge (EDG) Setup

The one-step method was conducted at project site as per manufacturer's procedure and the results from the nuclear gauge at the same locations recorded for comparison. Nuclear gauge readings were taken at a depth of approximately 9 inches equal to the length of the field spikes. The one-step field testing with the MDI included the following steps:

- Prepare soil surface
- Place template and drive in spikes
- Remove template
- Position the multiple rod probe (MRP) head on top of spikes
- Connect MRP to MDI and PDA
- Open configuration file and take TDR reading. Record temperature and apply correction
- Observe waveform to ensure good signal and save file

Field Results and Comparison

The results of the field tests (dry density and moisture content) are summarized in Table 2. The difference between the results of the nuclear gauge and the MDI are shown in Table 3 and Figure 13. In general, the moisture content results of the MDI and the nuclear gauge are close but average differences in the dry density results varies from 1.98 to 14.77 pcf or 1.3% to 12.53%. Results from Route 30/Delilah road show the closest agreement in the dry density and Route 206 the closest agreement in moisture content. The MDI seems to be insensitive to the changes in the dry density measured at different locations along the site compared to those recorded by the nuclear gauge. In order words, the MDI records consistent (or the same) dry density throughout the site while those for the nuke gauge show a wider spread or more variation.

The aggregate gradations for the I-9 porous fill samples are within the range application of the MDI. The results for Delilah road show better agreement with the nuclear gauge than those from I-78. These samples were very porous and some problems were encounter in the lab during the compaction tests. The aggregate particles seem to absorb the water and release them into the mold during compaction. There were instances in which water oozed out of the sample after compaction and a drop in the weight was difficult to achieve ever after repeated attempts.

As previously mentioned, the 4" mold used in the lab to determine the constants and the constants were developed with samples finer than the No.4 sieve (4.75mm). The differences may be related to the (passing # No.4) samples not being representative of the true electrical conductivity and dielectric properties of the insitu compacted DGA aggregate base layers. The continuity and quality of the electrical response would also be affected by the amount of void within the aggregate layer (s) due to the larger size of the particles. Although the method seems to be applicable to some aggregate samples, the maximum aggregate size should be limited to ¾'' as indicated by Drnevich (1) to allow use of the 4" compaction mold.

Table 2 - Field Dry Densities and Moisture Contents from Various Devices

	Test	Nuclear Gauge		MDI		EDG	
		Dry Density [pcf]	**Moisture content [%]**	**Dry Density [pcf]**	**Moisture content [%]**	**Dry Density [pcf]**	**Moisture content [%]**
Route 206 (DGA)	1	130.0	2.1	126.8	2.3	Not tested	Not tested
	2	138.0	3.0	127.6	3.4	Not tested	Not tested
	3	131.1	2.4	127.1	2.6	Not tested	Not tested
	4	140.0	3.2	127.4	3.1	Not tested	Not tested
Rt.30/Delilah Road (I-9 Porous Fill)	1	114.3	3.8	111.9	2.5	111.5	3.7
	2	114.2	3.5	111.9	3.2	111.0	3.6
	3	115.9	3.3	111.9	3.1	110.9	3.6
	4	110.8	4.0	111.9	3.3	111.4	3.6
	5	111.8	4.1	111.9	2.8	111.2	4.2
I-78 (DGA)	1	117.8	9.8	105.9	9.9	Not tested	Not tested
	2	116.1	9.3	105.9	9.8	Not tested	Not tested
	3	120.2	9.9	106.1	10.1	Not tested	Not tested
I-78 (I-9 Porous Fill)	1	131.9	3.8	109.3	4.8	137.3	4.3
	2	137.0	3.8	109.7	5.4	137.8	4.4
	3	133.0	3.7	108.5	3.4	134.0	4.3
Rt. 46 (DGA)	1	117.5	7.9	104.0	7.9	123.4	8.5
	2	116.5	8.7	103.3	7.1	123.4	9.0
	3	119.2	6.1	101.6	5.1	123.4	9.1

Table 3 - Summary Percent Differences between Nuclear Gauge and MDI

	Test	Nuke –MDI Difference Dry Density [pcf]	Nuke –MDI Difference Moisture content [%]	Nuke-MDI Percent Difference Dry Density [%]	Nuke-MDI Percent Moisture content [%]
Route 206 (DGA)	1	3.2	-0.2	2.5	-9.5
	2	10.4	-0.4	7.5	-13.3
	3	4.0	-0.2	3.1	-8.3
	4	12.6	0.1	9.0	3.1
	AVG	7.6	-0.2	5.5	-7.0
Rt.30/Delilah Road (I-9 Porous Fill)	1	2.4	1.30	2.10	34.21
	2	2.3	0.30	2.01	8.57
	3	4	0.20	3.45	6.06
	4	1.1	0.70	-0.99	17.50
	5	0.1	1.30	-0.09	31.71
	AVG	1.98	0.76	1.30	19.61
I-78 (DGA)	1	11.90	-0.10	10.10	-1.02
	2	10.20	-0.50	8.79	-5.38
	3	14.10	-0.20	11.73	-2.02
	AVG	12.07	-0.27	10.21	-2.81
I-78 (I-9 Porous Fill)	1	22.60	-1.00	17.13	-26.32
	2	27.30	-1.60	19.93	-42.11
	3	24.50	0.30	18.42	8.11
	AVG	24.80	-0.77	18.49	-20.10
Rt. 46 (DGA)	1	13.50	0.00	11.49	0.00
	2	13.20	1.60	11.33	18.39
	3	17.60	1.00	14.77	16.39
	AVG	14.77	0.87	12.53	11.59

Additionally, especially for Route I-78 and Route 46 DGA, it was observed that the samples tested in the laboratory were much cleaner than the compacted in-situ materials. It would be expected that the overall electric response/properties would be much different especially if the “dirt” is of a different composition compared to that of the aggregates particles.

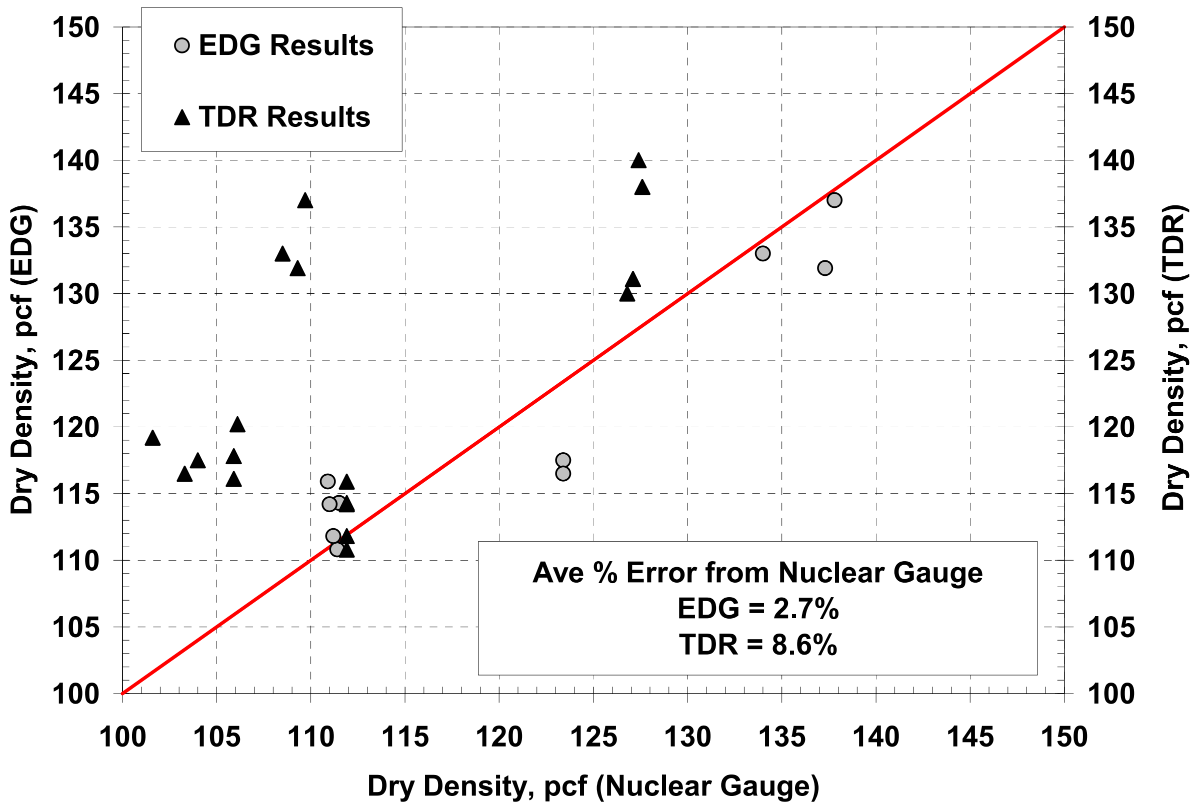


Figure 14 – Comparison of TDR and EDG Devices to the Nuclear Gauge

In reference 1 (Yu and Drnevich, 2004), it is stated that: "The TDR method can be used with coarse-textured soils where ***30%*** by weight of the material ***has particle sizes exceeding the No. 4 sieve (4.75 mm) and the maximum particle size passes the ¾-inch sieve (19 mm).*** Most of the research and beta testing performed to date has been conducted on soils with limited gravel permitting the use of 4-inch diameter compaction molds and probe placement diameter. Equipment and procedures have not been fully developed for 6-inch diameter molds and probe placement. Nor do we have experience with problems that might be associated with driving the four probes in heavily compacted aggregates common to base course used in pavements.". These statements indicate some limitations of the current MDI setup. Due to these limitations, the results for the dense graded aggregate (DGA) samples with more than 30% retained on sieve No. 4 maybe not be reliable.

The following problems were encountered during field testing on the DGA base layers and during the laboratory calibration:

- Difficulty in driving the spikes into the aggregate base. A much larger hammer was required and it took more than 15 minutes per test to drive the spikes. Some of the spikes got slightly crooked or bent in the process.
- The size (diameter) of the spikes is too small for use in testing DGA pavement base layers. Larger spikes of a least 1" diameter would be more suitable as this would

enhance driving into compacted aggregate base.

- Difficulty in removing the template after driving spikes. Release pin was hard to remove. Even after the pin was removed, getting template off was a problem due to the large aggregate sizes. Had to dig around the edges to remove.
- On several occasions, there was a problem getting a suitable signal even though the MRP head had perfect contact with the rods.
- The equipment froze on several occasions during lab and field testing and the PDA had to reset/rebooted to overcome the problem.

CONCLUSIONS – PART 1 – NON-NUCLEAR COMPACTION CONTROL

An evaluation of the MDI developed by the University of Purdue and manufactured by Durham GeoSlope was conducted for the NJDOT to determine its suitability for use in the construction control of mostly dense graded aggregate base layers. The one-step method because of is ease and expediency in the field was favored over the two-step method.

Field evaluation involved the collection of density and moisture contents from five different project sites that consisted of either compacted dense graded aggregate base layers and or compacted porous fills. Dry densities and moisture contents measured with the MDI were compared with those from nuclear density gauges. In general, both the nuclear gauges and the MDI recorded very similar moisture contents. However, differences of up to 12.53% were observed in the dry density measurements. For the most part, the dry densities recorded by the MDI were less than those from the nuclear gauges. Better agreements were obtained for the moisture content.

The required calibration constants were determined using a 4-in mold after sieving through the No.4 sieve (similar to AASHTO T99, Method C). Due to the large size of the DGA, a 6-in mold as per ASTM, would have been more suitable for the sample sizes. However, the 6-in mold laboratory calibration setup is not available when the study was conducted. The differences in the dry densities may be due to the calibration constants were not being representative of the insitu materials as the lab tests were conducted on the finer fractions that made up a small fraction of the gradation. Furthermore, Drnevich stated that the current method is limited to samples with more than 30% passing sieve number 4 and particle size not greater than ¾ inch.

Measurements from the EDG were not discussed further because of the bias introduced by using the nuclear gauge for the field calibration. The results from the EDG could therefore not be compared those from the nuclear gauge. However, recommendations were provided to the manufacturer (Humboldt Manufacturing Company) on improving the device and incorporating a laboratory calibration component.

RECOMMENDATIONS – PART 1 – NON-NUCLEAR COMPACTION CONTROL

The following are recommendations are proposed for the application of the MDI to compaction control:

- The manufacturer should develop a 6-in mold setup for the laboratory determination of the calibration constants. Constants from the 6-in and 4-in molds should be compared to identify any differences and to develop modification to the test if necessary.
- Manufacture spikes with larger diameter (at least 1-inch) to facilitate driving into DGA layers.
- Spikes should be of varying lengths so that measurements can be made in layers of different depths. In practice, some base layers can be as thick as 18 or more inches. The MDI should be setup such that density and moisture content can be obtained at different depth. This would imply that the software should be setup so that the user can input different length of spike.
- Additional testing to develop a database of calibration constants. This would provide the NJDOT with a range of possible calibration constants that can be used a default values depending on the source of the aggregates.
- At this time, the results from this study concludes that the current ASTM D6780 test method is not recommended for compaction quality control of base course aggregate materials.

INTRODUCTION – PART 2 – RECYCLED CONCRETE AGGREGATE

The New Jersey Department of Transportation (NJDOT) has a responsibility to be environmentally friendly and promotes the use of recycling on many of their transportation infrastructure projects. One example of NJDOT's recycling effort has been in the use of recycled concrete aggregate (RCA) as a base course aggregate. The NJDOT has been using RCA for dense graded aggregate base course (DGABC) in New Jersey since the mid 1980's. To date, RCA has provided an excellent foundation for New Jersey's pavements. However, recent laboratory research by Rutgers University has shown that when compacted to typical pavement construction density levels, RCA has permeability levels on the order of 0.0 to 0.3 ft/day (Bennert and Maher, 2005). According to the AASHTO Guide for Design of Pavement Structures, the quality of pavement drainage for the RCA would be classified as poor to very poor (Table 4).

Table 4 – Quality of Drainage (AASHTO Guide for Design of Pavement Structures, 1993)

Quality of Drainage	Minimum Permeability	Time for Pavement to Drain	Drainage Coefficient
Excellent	1000 ft/day	2 hours	1.2
Good	85 ft/day	1 day	1.0
Fair	11 ft/day	1 week	0.8
Poor	0.5 ft/day	1 month	0.6
Very Poor	0.02 ft/day	Water will not drain	0.4

Meanwhile, the permeability values of New Jersey's virgin DGABC were found to range between 123 and 170 ft/day. Testing was conducted for DGABC sources located in North and Central NJ. Using Table 1 as a guide, the NJ's DGABC permeabilities would be classified as Good. Therefore, this raises the following question: Is there a way to increase the permeability of RCA by blending it with other aggregate materials to achieve permeability levels on the order of virgin DGABC? And if so, how will this effect the structural properties of the new aggregate blend (i.e. – will it decrease the structural properties below that of virgin DGABC)?

The research conducted by Bennert and Maher (2005) further looked into blending RCA with other aggregate materials in an effort to increase its permeability. When RCA was blended with virgin DGABC, the permeability values quickly increased to 60 to 80 ft/day. However, with percentages of DGABC as high as 75% (25% RCA), the permeability of the blended aggregate was still only able to achieve 75 to 80 ft/day, approximately one half of the virgin DGABC. Based on Table 1, the RCA:DGABC blended aggregates would classify as having Fair drainage. Using the California Bearing Ratio (CBR) test to gauge the structural capacity of the RCA blends showed that the addition of DGABC causes the CBR value to initially decrease and then increase to levels comparable to virgin DGABC. The research clearly showed that RCA:DGABC blends on the order of 50:50 to 75:25 can achieve Fair permeability (60 to 70 ft/day) while maintaining high CBR values (160 to 180). Resilient modulus testing conducted on the identical blends verified the CBR test results. NJDOT recently modified their specification to allow a 50:50 blend of RCA:DGABC for use as a base course aggregate, however, there are some questions as to whether it is possible to increase the permeability to that of virgin DGABC.

Further blending of RCA was also conducted using recycled asphalt pavement (RAP). Once again, RAP and RCA was blended at varying percentages and tested for permeability. Testing showed that regardless of the blended percentages, the permeability of the RCA/RAP blends could not achieve rates higher than 6 ft/day (Table 2). CBR testing conducted on the RCA:RAP blends indicated a severe adverse affect when RAP was blended with RCA. The initial CBR value of the RCA was approximately 200 and decreased steadily for every increase in RAP percentage (Figure 2). Therefore, it is evident that the RCA:RAP blends not only creates a “clogged” pavement system, but also one having a poor bearing capacity when compared to virgin DGABC.

The initial research conducted by Rutgers University (Bennert and Maher, 2005) raises some interesting questions:

1. Are there materials, other than DGABC, that can be blended with RCA and increase the permeability of the aggregate blend, while not sacrificing its structural performance?
2. Does a base aggregate permeability classified as Fair to Poor have a severe adverse affect on pavement performance? And if so, is there a permeability criteria that NJDOT pavement designers should desire from the base aggregate materials?

NATIONAL SURVEY REGARDING USE OF RCA FOR PAVEMENT DESIGN

As part of the Literature and background review, the Rutgers University research team conducted a National survey of the use of RCA as a granular material in pavement base and subbase layers. The survey instrument (Appendix A) was distributed through the **American Association of State Highway and Transportation Officials** (AASHTO) Materials Committee Listserv. A total of 25 States and 1 Canadian Province responded to the survey. The state agencies who responded are shown in Figure 14.

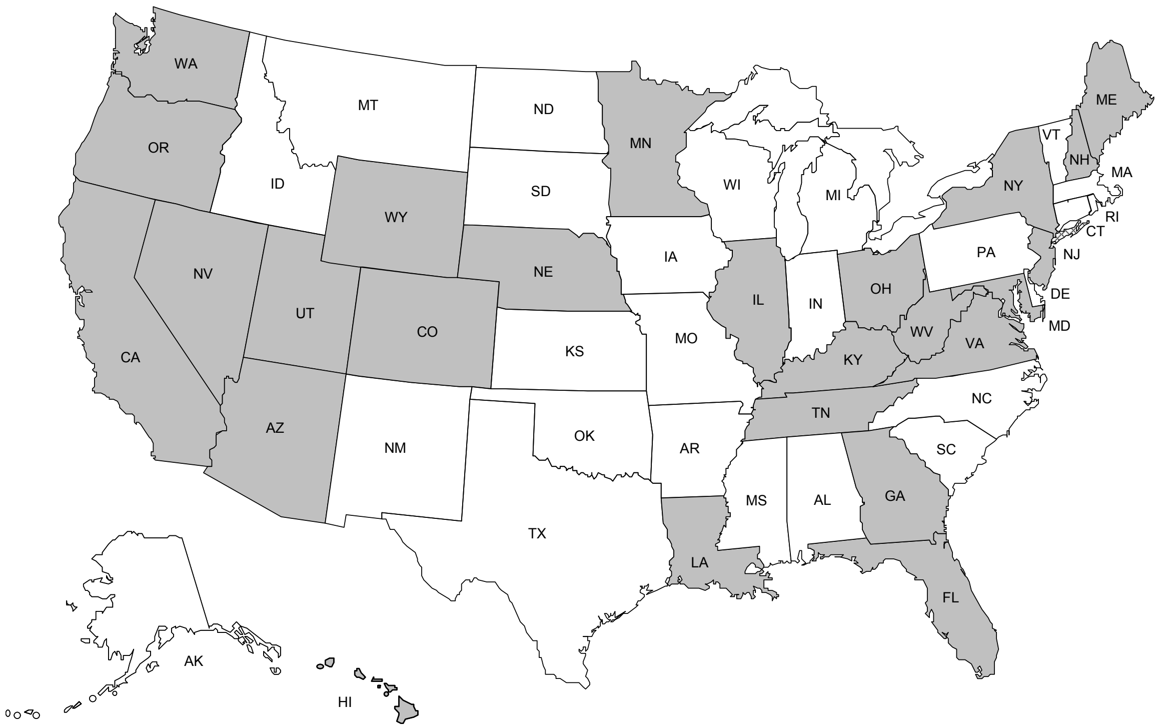


Figure 15 – State Agencies that Responded to RCA Survey

The survey was developed to determine which organizations use RCA as a pavement material, and to examine their specifications or practices for levels of permeability, material blending practices, possible use of filter fabric, problems associated with either use of RCA or permeability, and issues associated with Alkali Silica Reactivity (ASR) aggregates.

<u>Use and Source of RCA</u>

Based on the survey responses, 18 of the 26 organizations (69%) use RCA for pavement base courses, 12 of the 26 organizations (46%) use RCA for pavement subbase base courses, while 8 of the 26 organizations (31%) use RCA for a variety of material purposes including pipe bedding, surface course aggregate, and subgrade stabilizer. Twelve of the organizations use RCA for pavement base and subbase courses and several indicated that they only use it for a base course while others only use it as a subbase material. Five of the organizations indicated that they do not use RCA.

Based on the survey responses, 15 of the 21 responses (71%) use RCA alone as a pavement layer material, while 6 of the 21 responses (29%) use a blend of RCA with other materials. Two organizations allow it to be blended or used alone as long as it meets the virgin material property requirements.

Of the responses that indicated that they use the RCA <u>alone</u>, 9 of the 18 responses (50%) use gradation to specify the material properties, while 9 of the 18 responses (50%) use other criteria (some in combination with gradation) to specify the material properties. These include sand equivalent, freeze thaw stability, composition, and durability (sulfate soundness, LA abrasion).

Of the responses that indicated that they use the RCA <u>blended with other materials</u>, 2 of the 13 responses (15%) specify a percentage of RCA to virgin material by weight, 6 of the 13 responses (46%) use gradation to specify the material properties, while 5 of the 13 responses (38%) use other criteria (some in combination with gradation) to specify the material properties. These include sand equivalent, freeze thaw stability, composition, Atterberg limits, AASHTO A-1a, NP classification, and durability (sulfate soundness, LA abrasion).

For those organizations that specify blending by weight, one allows up to 100% of the blend to be RCA based on gradation requirement, one allow a maximum of 50% of the blend to be RCA, one requires a minimum of 20% of the blend be RCA, and one allows the contractor to select the blend proportions as long at it meets the AASHTO A-1a, NP classification.

The source of RCA material for use in pavement base and subbase layers varies widely. The majority of the responses indicate that the sources are recycled concrete pavement and structures. Some organizations are very specific (e.g., pcc pavements that are removed and replaced on the same project), and some accept material from plants or contractors (as long as it meets their specification).

<u>**Use of Filter Fabric**</u>

Of the responses that answered the questions on the use of filter fabric, 17 of the 22 (77%) indicated that they <u>do not</u> use filter fabric, and 2 of the 22 (9%) use it below the RCA material. One of the two states indicated that they use it below the RCA when it is used over an untreated or lime treated soil, and the other state comments that the dust from the RCA forms an impervious cake on the filter fabric.

<u>**DGA vs RCA – Is it specified the same?**</u>

Based on the responses, 16 of the 22 responses (73%) indicated that they specify a "dense graded aggregate" material and allow the contractor to choose the

material that is used and only one state specifies that RCA will be used. Of the organizations that chose the "other" option, one approves the material based on meeting the layer material properties, one specifies a free draining material or DGABC, but does not give the contractor the option, one will consider RCA if requested by the contractor as long as the material comes from a Department project, and one will consider it on a project by project basis.

Performance of RCA vs. Virgin Aggregates

Based on the responses, 20 of the 25 responses (80%) indicated that they do not monitor the performance of pavement with RCA vs. those with virgin materials, while 5 of the 25 responses (20%) indicated that they have monitored the performance.

Of the organizations that indicated that they have monitored the performance of pavements with RCA vs. those with virgin materials:

- Louisiana found that "performance is dictated by material specification compliance and good construction methods rather than choice of aggregate",
- Illinois and Virginia found "no difference";
- Ohio found "high amounts of tufa and clogging of the drainage".

Of the organizations that indicated a difference;

- Washington DC DOT indicated that "works good in areas with no groundwater problems";
- Nebraska indicated that RCA had overall good performance, but more expensive so not used as often as recycled materials" and "great stability, but had poor permeability". They changed gradation of RCA to coarser gradation.

Therefore, of the four state agencies that have measured or recorded field performance of RCA and compared it to other virgin aggregates, permeability seemed to have been the biggest concern.

Permeability of Pavement Materials

Based on the responses, no organization has a permeability requirement for base or subbase material and no organization monitors the permeability of these materials. Louisiana is working on a permeability requirement for their specification.

In a related question, 15 of the 24 organizations (62%) indicated that they have had pavement failures due to poor drainage of the base or subbase layer, while 9 of the 24 organizations (37%) indicated that they have had no pavement failures attributed to poor drainage of the base or subbase layer materials.

Use of RCA with Alkali Silica Reactivity (ASR)

Based on the responses, 12 of the 22 responses (54%) indicated that they do use RCA with ASR in their base or subbase materials, while 10 of the 22 responses (45%) indicated that they do not use RCA with ASR. All organizations that accept RCA with ASR indicated that they do not treat any material with ASR prior to use as a base or subbase materials.

No organization responding to the survey tests RCA for ASR reactivity.

Analysis of Survey Results

In reviewing the survey results, an important piece of information that was immediately evident was that there were some state agencies that used RCA that had mixed final results; some states had pavement drainage issues while others did not. These states are further identified below:

- State agencies using RCA with no drainage-related pavement failures
    - Florida, Minnesota, and Washington
- State agencies using RCA with drainage-related pavement failures
    - California, Georgia, Illinois, Louisiana, and Nebraska

The aggregate specifications for the base aggregate use of RCA was obtained and compared to determine how the “Good vs Poor” states compared. Table 5 shows this comparison. Immediately, one can see that states that use the 2 inch sieve as the top sieve (i.e. – all RCA screened over the two inch sieve) reported to have no drainage-related pavement failures. Meanwhile, the state agencies who reported pavement failures related to poor drainage all had top sieve sizes of 1 ½ inches, except for Georgia DOT. Georgia DOT, along with Illinois DOT who also reported drainage issues, allow eleven (11) and twelve (12) percent fines in their RCA aggregate base course, respectively. The research conducted by Bennert and Maher (2005) clearly illustrated the “clogging” that occurs when the aggregate base course material has a fines content around 10%.

Therefore, based on the preliminary findings of the survey, the following two items should be investigated to increase the permeability (drainage) of RCA:

1. Utilize the blending of different aggregate materials to help increase the drainage performance of the RCA; and
2. Increase the processing size (top size) of the RCA to 2 inches from its current 1.5 inch top size.

Table 5 – State Agency Specifications with Good and Poor Draining Base Aggregates

Particle Size	Good Drainage (No Reported Failures)			Poor Drainage (Reported Failures)				New Jersey DOT (DGABC)
	Florida DOT	Minnesota DOT	Washington State DOT	Georgia DOT	Illinois DOT	Louisiana DOT	Nevada DOT	
3"	--	--	--	--	--	--	--	--
2 1/2"	--	--	--	--	--	--	--	--
2"	100	100	75-100	100	--	--	--	
1½"	--	95-100	--	97-100	100	100	--	100
1"	--	65-95	--	--	90-100	90-100	--	--
¾"	65-90	45-85	--	60-90	--	70-100	--	55 - 90
1/2"	--	--	--	--	60-80	--	100	--
3/8"	40-83	35-70	--	--	--	--	96-100	--
No. 4	27-63	15-45	22-100	--	40-56	35-65	89-97	25 - 50
No. 8	--	--	--	--	--	--		--
No. 10	20-49	10-30	--	25-45	--	--	45-65	--
No. 16	--	--	--	--	10-40	--	--	--
No. 30	--	--	--	--	--	--	--	--
No. 40	--	5-25	--	--	--	12-32	16-44	--
No. 50	8-24	--	--	--	--	--	--	5 – 20
No. 60	--	--	--	5-30	--	--	--	--
No. 100	--	--	--	--	--	--	--	--
No. 200	0-7.5	<12	0-10	4-11	4-12	0-8	0-6	3-10

Note: Georgia indicated poor performance with 100% passing the 2-inch sieve

LABORATORY EVALUATION OF RCA MATERIALS

The laboratory evaluation of RCA materials was conducted in three phases to assess the overall performance of the material, as well as to determine it is was possible, keeping in consideration the practicality of the methodology, to increase the drainage performance of the RCA. The laboratory evaluation consisted of:

1. Evaluate the permeability and stability consistency of RCA sampled from three different suppliers/regions. This would show that the permeability issues were not solely related to the lone supplier's RCA from the original study conducted by Bennert and Maher (2005);
2. Utilize the blending of different aggregate materials to attempt to increase the drainage performance of the RCA materials.
3. Evaluate the potential of increasing the top size of the RCA gradation band to 2 inches, instead of the 1.5 inches currently specified by NJDOT. As shown in the survey results, the three states responding that drainage was not an issue with their RCA materials specify a top size of 2 inches.

Laboratory Consistency of RCA

An important aspect of the original study (Bennert and Maher, 2005) was that the data generated and reported was only for a Central Region source of RCA (Trap Rock Industries in Kingston, NJ). Therefore, two additional sources were also sampled and tested; 1) AE Stone (South Region) and 2) Tilcon Industries (Mt. Hope). Since the two additional sources are already NJDOT approved, only the permeability and CBR values were recorded. A minimum of three tests for each samples and test was conducted and averaged. The permeability and CBR results are shown in Figure 15 and 16, respectively.

The results for the different regions show that slight, but expected; variability exists among the three different regional sources of RCA. However, for each parameter evaluated (permeability and CBR), the results consistently indicate that RCA has excellent stability, yet poor drainage characteristics.

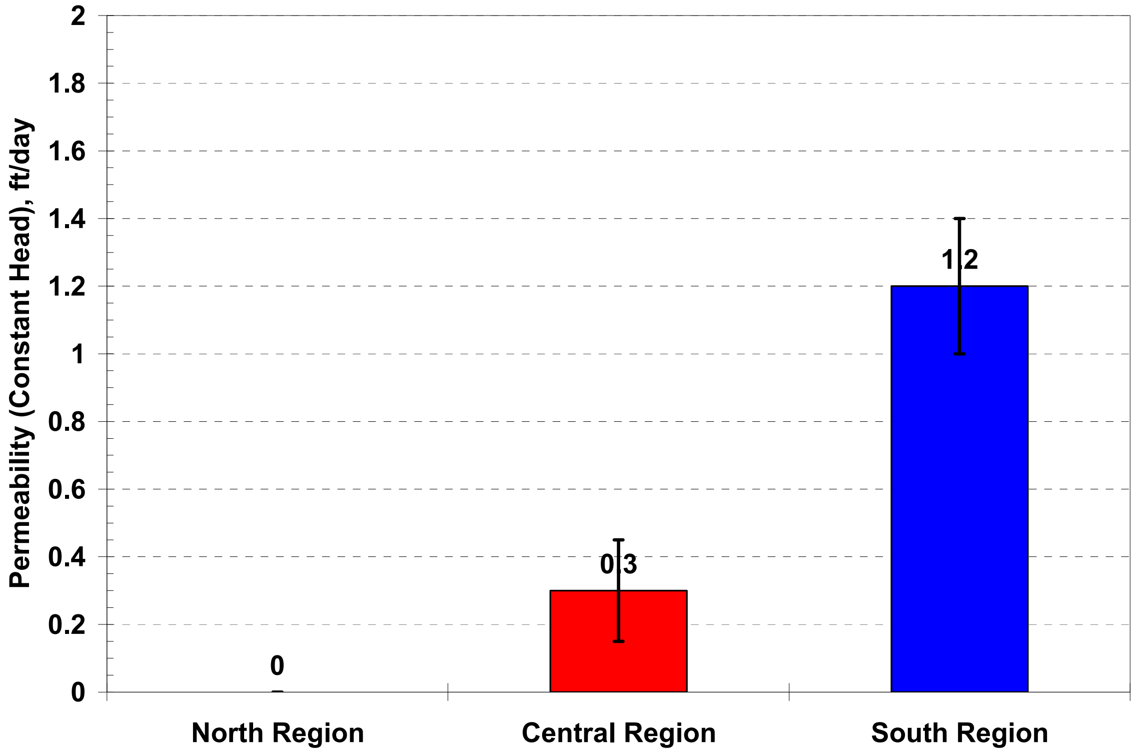


Figure 16 – Permeability Results of RCA from Different NJDOT Regions

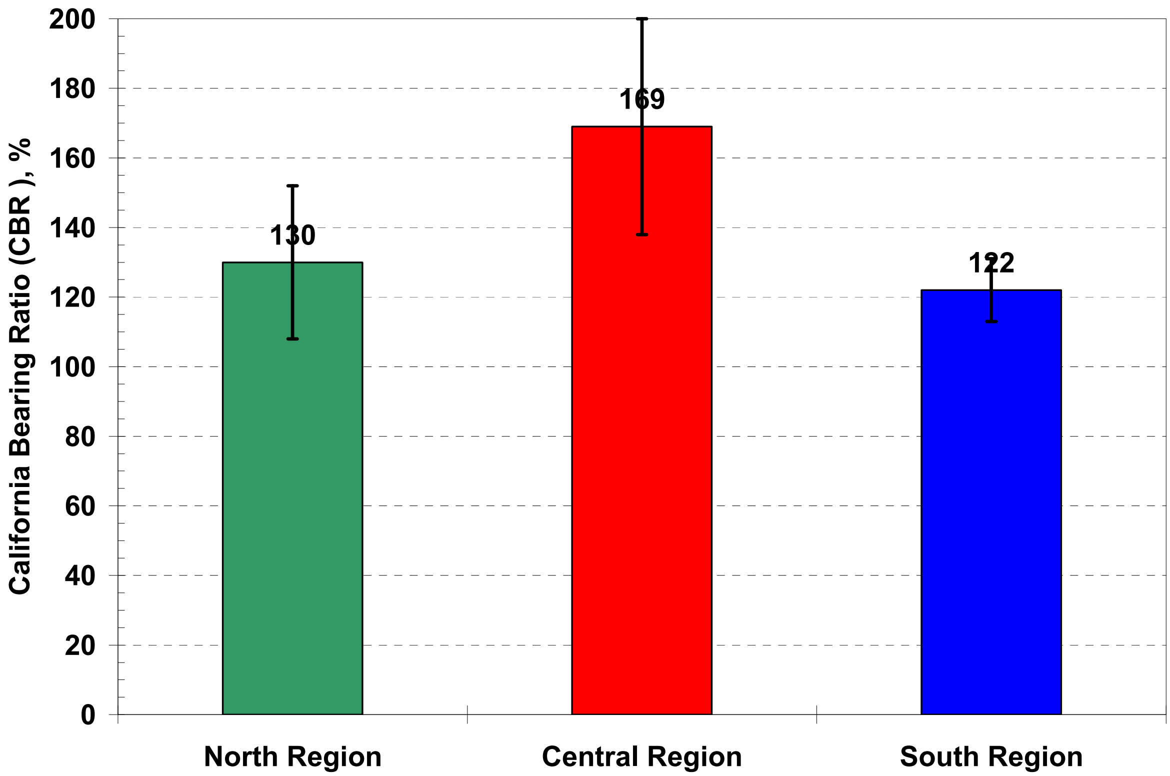


Figure 17 – CBR Results of RCA from Different NJDOT Regions

RCA and Aggregate Blending

The modification of RCA to increase its permeability must be done in a practical manner and one that will not produce additional expenses to suppliers, and therefore, back onto NJDOT. For example, most of the time when there exists a permeability issue with an aggregate/sand material, the first thing most consider is reducing or eliminating the fines (i.e. – material finer than the No. 200 sieve). However, this action would cause to serious issues;

1. The washed material from the RCA would most likely create some type of issue with the NJDEP due to the alkaline nature of the RCA. Therefore, it this was to take place, the washed material (fines and water) would need to be collected and not allowed as any type of runoff.
2. The physical action of washing the aggregate would increase the cost of the final product, especially when taking into account the collection and disposal of the wash. This cost would be transferred to the contractor, which in turn would be transferred to NJDOT.

Again, looking at the practical options while trying to not increase cost or processing time for the suppliers, the two best options were; 1) to evaluate the blending of RCA with different aggregate materials to artificial increase the drainage and/or 2) look at increasing the top size of the RCA to try and "coarser up" the aggregate structure. This section discusses the work regarding the blending of aggregate materials in RCA.

The main premise behind blending other aggregates with recycled concrete aggregate (RCA) is to potential "open up" the internal void structure of the RCA to allow more water to flow through the final blended material. Table 6 shows laboratory results of RCA blended with two different materials; NJDOT DGABC and RAP. Both the DGABC and RAP aggregate are considered "coarser" type aggregates and should have "opened up" the internal void structure of the RCA. As the results show, the addition of DGABC did increase the permeability to a condition considered by the AASHTO Guide for Design of Pavement Structures (1993) as Fair to Good. However, the addition of RAP did not provide any additional benefit, as the RAP itself did not have very good drainage characteristics.

Table 6 – Initial Permeability and CBR Information Regarding RCA Blends

Region of NJ	Soil Gradation Type	Permeability from Constant Head Test (ft/day)	California Bearing Ratio at 0.1"
DGABC + RCA	100% RCA	0.0	169
	75% RCA	65.3	151
	50% RCA	66.0	123
	25% RCA	76.5	126
	0% RCA (100% DGABC)	76.5	182
RAP + RCA	100% RCA	0.0	169
	75% RCA	1.0	106
	50% RCA	5.4	68
	25% RCA	0.7	29
	0% RCA (100% RAP)	16.9	18

- DGABC indicates Virgin Aggregate (Dense Graded Aggregate Base Course)

Laboratory Results – RCA Blends

In evaluating the potential use of blending aggregates with RCA to increase the permeability, two important factors must be considered:

1. The aggregate material to be blended with RCA should be readily available and not cost more than the use of RCA solely; and
2. The final blend should still maintain an appropriate stability (CBR value) for pavement design applications.

Based on the previous results shown in Table 6, it was apparent that a coarse-graded aggregate or a very, poorly graded sand material was needed to help open up the internal void structure of the RCA material. Taking into account the factors listed above, three new materials were selected for blending and laboratory evaluation; 1) NJDOT I-3, NJDOT I-9, and 3) poorly graded dredge sand. Both the NJDOT I-3 and I-9 are readily available for future implementation. Rutgers University had previously evaluated the NJDOT I-3 aggregate in the study by Bennert and Maher (2005) and found the average permeability to be between 55 and 60 ft/day. However, because the evaluation of the RCA was solely for base course application, the addition of an I-3 was not considered.

The NJDOT I-9 aggregate was evaluated because of its use as a porous fill material. The I-9 that was sampled and used for testing was being utilized as a porous fill for the Rt 30/Delilah Road construction project. This is the same project that was used during the TDR field evaluation.

The poorly graded dredge sand was considered because of its current abundance in the Delaware River (lower Cape May area) dredging program. With an immediate and long-term need to disposal, it was thought that the poorly graded nature may increase the interconnected voids within the RCA aggregate structure.

The results of the blending evaluation are shown below as Table 7. The results show that each of the aggregate materials blended with the RCA did increase the permeability when compared to RCA. However, the magnitude of the increase in most cases did not dramatically improve the drainage. In the case of the NJDOT I-9 blend, although the increase in permeability was more substantial than the remaining materials, it was found to be very difficult to compact, which is most likely the reason for the lower CBR values. This may also have been attributed to the rounded nature of the I-9 Porous Fill aggregates that were used. This may also be the reason for the lower CBR values in the I-3 aggregate blend.

Table 7 – Permeability and CBR Values for RCA Blends

Region of NJ	Soil Gradation Type	Permeability from Constant Head Test (ft/day)	California Bearing Ratio at 0.1"
RCA + NJDOT I-3	100% RCA	0.3	169
	75% RCA, 25% I-3	1.9	129
	50% RCA, 50% I-3	8.5	80
	25% RCA, 75% I-3	13.0	67
RCA + NJDOT I-9	75% RCA, 25% I-9	27.3	87
	50% RCA, 50% I-9	66.8	43
RCA + Dredge Sand (D.S.)	75% RCA, 25% D.S.	0.1	107
	50% RCA, 50% D.S.	1.9	69

Laboratory Comparison of Different Top Sizes

One of the major findings of the survey responses was that the states that responded no drainage issues with RCA, based on field monitoring, indicated that their state specifications utilized RCA with a top size of 2 inches. Meanwhile, states that responded having drainage issues on monitored RCA sections had top sizes equal to or less than 1.5 inches. NJDOT currently specifies a top size of 1.5 inches.

To evaluate whether or not increasing the top size of the RCA would also increase the overall permeability, two RCA suppliers were asked to produce/crush RCA and screen it over a 2 inch sieve. Unfortunately, one of the suppliers, Tilcon Industries, had some issues with their crushing/screening equipment that is designed for RCA. Therefore, only AE Stone provided both a 2 inch and 1.5 inch top size RCA material. In fact, AE Stone arranged it so that both materials (2 inch and 1.5 inch) were produced from the same general area of the RCA pile on site.

The first thing of interest was how the modification in crushing/screening process changed the overall gradation of the RCA. Figure 17 shows the gradation of the two different top size RCA materials. The results show screening the RCA over the 2 inch sieve did not change the percent passing on the 37.5mm sieve (1.5 inch), as both processes resulted in 100% passing. However, screening the RCA over the 2 inch sieve did decrease the percent passing on the 25mm sieve from 95% to 90%, when compared to the 1.5 inch top size RCA.

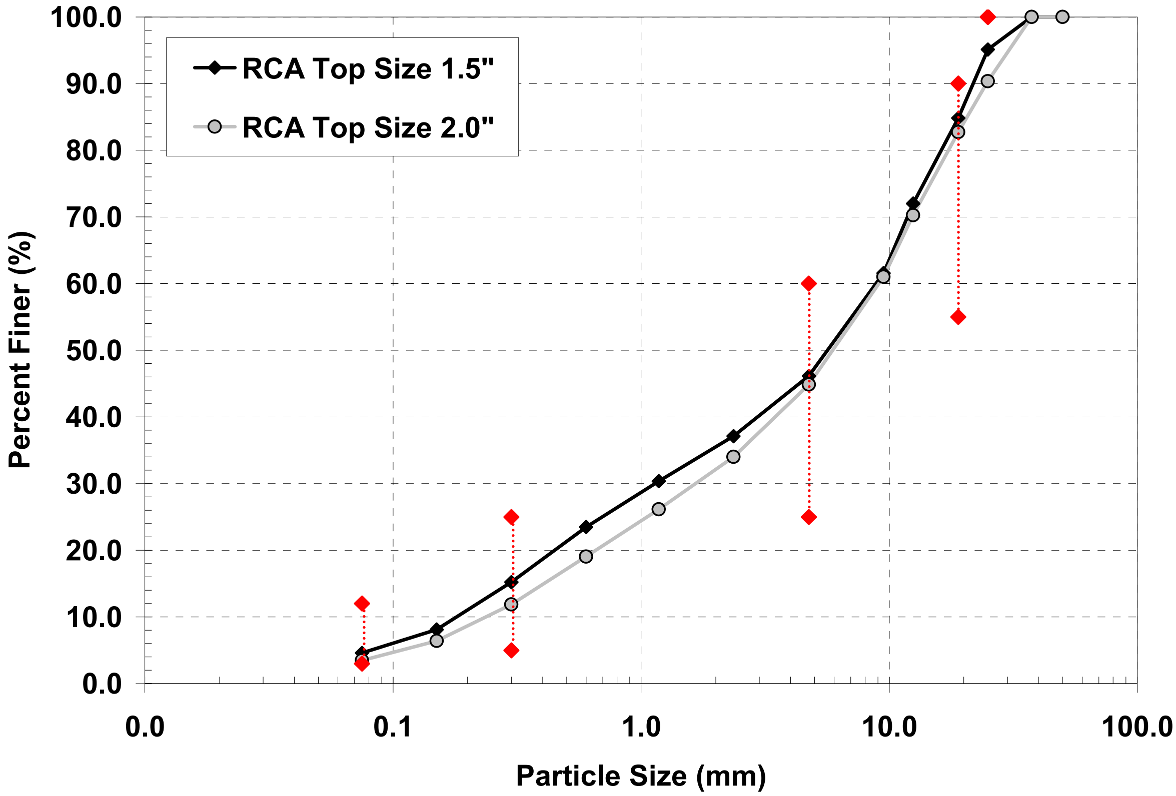


Figure 18 – Aggregate Gradations of 2 Inch and 1.5 Inch Top Size RCA Materials Produced by AE Stone

Processing the RCA over the 2 inch sieve also decreased the percent passing for material finer than the No. 8 sieve (i.e. – 2.36 mm and less) by approximately 3 to 4%. The percent fines decreased from 4.6% to 3.5% when the RCA was processed/screened over the 2 inch sieve.

Permeability and CBR testing was conducted using the two differently processed RCA materials. The laboratory results show that increasing the top size to 2 inches from 1.5 inches increased the permeability to almost 6 ft/day while also increasing the CBR value to 133%. Although the permeability would still be classified by the AASHTO Pavement Design Guide (1993) as Poor to Fair, it is still five times greater than when the RCA is processed/screened over the 1.5 inch sieve, without sacrificing the stability of the aggregate base layer.

Table 8 – Influence of RCA Processing on Permeability and CBR Values

Soil Gradation Type	Permeability from Constant Head Test (ft/day)	California Bearing Ratio at 0.1"
1.5" Top Size RCA	1.2	122
2.0" Top Size RCA	5.9	133

CONCLUSIONS – PART 2 – DRAINAGE EVALUATION OF RCA

A laboratory study was conducted to determine the permeability characteristics of recycled concrete aggregate (RCA) regarding;

1. General performance (permeability and CBR) consistency between different producers;
2. Effect of blending different aggregate sources to help increase the permeability of the RCA while not sacrificing the stability; and
3. Evaluate if changing the processing/screening of RCA from a 1.5 inch sieve to a 2 inch sieve could potentially increase the permeability of the RCA.

Based on the laboratory study, the following conclusions were drawn:

1. The overall performance of the RCA among the three different suppliers sampled for the study showed that RCA can be classified as having a low permeability and high stability/bearing strength for pavement design applications. The permeability of the three different sources ranged from 0 to 1.2 ft/day, while the CBR ranged from 112% to 169%.
2. It appears that the best material to blend with RCA to increase the permeability, while not decreasing the overall stability/bearing strength is DGABC. The use of RAP, NJDOT I-3, and poorly graded sand all slightly increased the permeability of the RCA. The NJDOT I-9, sampled from the Rt 30/Delilah project was able to increase the permeability to over 60 ft/day at a 50:50 blend with RCA. Unfortunately, at this ratio, the final blend was very difficult to compact in the laboratory mold and the final CBR results were much lower than expected.
3. Although based on limited testing at one Regional source (South Region – A.E. Stone), changing the processing/screening of RCA from a 1.5 inch to a 2 inch top size sieve, the permeability of the RCA increased from 1.2 ft/day to 5.9 ft/day, while also increasing the CBR value from 122% to 133%.

RECOMMENDATIONS – PART 2 – DRAINAGE EVALAUTION OF RCA

To help increase the permeability of the RCA while not sacrificing the bearing strength of the material, the following are recommended:

1. It is recommended to blend RCA with DGABC up to a ratio of 50:50. At this ratio, a permeability of approximately 60 ft/day can be expected with good CBR values for bearing strength of the pavement base layer.

2. It is also recommended to allow suppliers to start producing RCA over a 2 inch top size, instead of the currently specified 1.5 inch. Although it only increased the permeability from 1.2 ft/day to 5.9 ft/day, it did helps to start opening up the internal structure of the RCA, while maintaining the bearing strength of the material.
3. Based on the literature review and survey conducted during this study, the researchers could not find any evidence of pavement failures due to poor drainage properties of RCA in New Jersey. Therefore, even though the permeability values of RCA would be classified as Poor according to the 1993 AASHTO Design Guide for Pavement Structures, it may not be necessary to recommend changes to RCA simply to improve permeability properties until evidence of pavement failures due to poor drainage of RCA layers are discovered.

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APPENDIX A – Survey Questions

RCA Survey

The New Jersey Department of Transportation is conducting a research study on the use of recycled concrete aggregates for pavement granular base and subbase layers. Please provide this survey to the Department's Materials Engineer or Pavement Designer.

State:
Point of Contact:
Return Mailing Address:
Phone Number:
E-mail Address:

1. Does your State use Recycled Concrete Aggregate (RCA) for pavement base or subbase layer material?

- Base Course - yes
- Base Course - no
- Subbase Course - yes
- Subbase Course - no

Other (Please Specify):

2. If yes to any part of question 1 above, does your State use RCA alone or blended with other virgin aggregate materials?

- Alone
- Blended

3. If alone, how does your State specify the material properties?

- Gradation
- Permeability
- Composition
- Other
- Other (Please Specify):

4. If blended with virgin aggregates, how does your State specify the material properties?

- [ ] Percentage of RCA to virgin material by weight
- [ ] Gradation
- [ ] Permeability
- [ ] Composition
- [ ] Other (Please Specify):

If blended by percentage of RCA to virgin material by weight, what is the percentage of each?

RCA

Virgin Aggregate

5. Does your State use filter fabric above, below or above and below the Recycled Concrete Aggregate (RCA) material?

- [ ] Above
- [ ] Below
- [ ] Above and Below
- [ ] do not use filter fabric
- [ ] Other (Please Specify):

6. Does your State specify "RCA" as the layer material or specify a "dense graded aggregate" and allow the contractor to choose to use virgin aggregate or RCA as the layer material?

- [ ] Specify RCA
- [ ] Specify DGABC and allow Contractor to choose
- [ ] Other (Please Specify):

7. Has your State monitored the performance of pavements with RCA vs. those with virgin aggregates?

- [ ] Yes
- [ ] No

If your State has monitored the performance of pavements with RCA vs. those with virgin aggregates, Did you find that:

RCA was better	
Virgin Aggregate was better	
No difference	

8. Has your State observed any pavement failures attributed to poor permeability in the base or subbase layer

- [ ] Yes
- [ ] No

9. Does your State have a specification for RCA when used as a Pavement base or subbase layer material?

- [ ] Yes (Please provide a copy of the specification)
- [ ] No

10. Where does your State obtain its RCA materials? (e.g., demolition debris, Pcc pavement, etc.)

11. Does your State accept concrete material with **ASR** for RCA when used as a Pavement base or subbase layer material?

☐ Yes

☐ No

If your State accepts concrete material with ASR for RCA, do you treat it before use as a base or subbase material?

☐ Yes

☐ No

If your State treats concrete material with ASR before use as a base or subbase material, how is it treated?

12. Does your State test for ASR when accepting concrete material for RCA for use as a Pavement base or subbase layer material?

☐ Yes

☐ No

IF your State tests for ASR when accepting concrete material for RCA for use as a Pavement base or subbase layer material, how is it tested?

13. Does your State have a permeability specification for <u>virgin</u> granular base and subbase materials?

- [x] Yes
- [ ] No

If yes, what is the Minimum Permeability Level for base and subbase material?

Base

Subbase

Are permeability levels verified?

- [ ] Yes
- [ ] No

26) Comments:

APPENDIX B – Survey Responses by State Agencies

State	1. Does your State use Recycled Concrete Aggregate (RCA) for pavement base or subbase layer material?				
	Base Course		Subbase Course		Other
	yes	no	yes	no	
New Jersey	**Base Course - yes**				
Arizona					See Question #26
California	Base Course - yes		Subbase Course - yes		
Colorado	Base Course - yes		Subbase Course - yes		
DC DOT	Base Course - yes			Subbase Course - no	use in areas with no groundwater problem
Florida	Base Course - yes				Also as stabilizer in 12" lift directly beneath base that we identify as Subgrade. Cannot answer next question with radio buttons because we do both.
Georgia	Base Course - yes				
Georgia	Base Course - yes				
Hawaii		Base Course - no		Subbase Course - no	
Illinois	Base Course - yes		Subbase Course - yes		
Kentucky	Base Course - yes		Subbase Course - yes		
Louisiana	Base Course - yes		Subbase Course - yes		surface course, coarse aggr. for HMAC, Bedding Material, and subgrade layer

Maine		Base Course - no		Subbase Course - no	
Maryland					project by project approval
Minnesota	Base Course - yes				
Nebraska	Base Course - yes				
Nevada		Base Course - no		Subbase Course - no	We may consider if requested by a contractor
Ohio Department of Transportation		Base Course - no		Subbase Course - no	We looked at the material performance using freeze thaw testing and found high break down of the graded materials as compared to native materials
Oregon		Base Course - no	Subbase Course - yes		project basis only
Tennessee	Base Course - yes		Subbase Course - yes		
Utah	Base Course - yes		Subbase Course - yes		
Virginia	Base Course - yes		Subbase Course - yes		
Washington	Base Course - yes		Subbase Course - yes		
West Virginia		Base Course - no		Subbase Course - no	
Wyoming	Base Course - yes		Subbase Course - yes		
Ontario	Base Course - yes		Subbase Course - yes		

State	2. If yes to any part of question 1 above, does your State use RCA alone or blended with other virgin aggregate materials?	3. If alone, how does your State specify the material properties?
	Alone/Blended	Gradation Permeability Composition Other(Please Specify):
New Jersey	**Alone**	**gradation & composition**
Arizona	Blended	
California	Blended	
Colorado	Alone	Gradation
DC DOT	Alone	Gradation
Florida	Alone	Gradation, Composition, Durability (Sulfate Soundness, LA Abrasion)
Georgia	Alone	Gradation and Sand Equivalent (GDT-63)
Georgia	Alone	Gradation
Hawaii		
Illinois	Alone	Gradation
Kentucky	Alone	Gradation
Louisiana	Blended	We specify gradation in all uses, and some uses allow blending, some don't. we also require LA abrasion and Sulfate Soundess testing
Maine		
Maryland	Alone	gradation, LA, modified proctor, pH
Minnesota	Blended	
Nebraska	Alone	Gradation
Nevada		
Ohio Department of Transportation		Freeze thaw stability
Oregon	Alone	Gradation
Tennessee	Alone	Gradation

Utah	Alone	We require it to meet the same requirements of virgin aggregate. A-1a, NP with wear and soundness requirements.
Virginia	Blended	VDOT allows crushed concrete alone or blended
Washington	Alone	The final product must meet all the specifications for the specified use. For example, if used as Gravel Base, it must meet all of the applicable Gravel Base specs.
West Virginia		
Wyoming	Blended	
Ontario	Alone	Gradation

State	4. If blended with virgin aggregates, how does your State specify the material properties?	If blended by percentage of RCA to virgin material by weight, what is the percentage of each?	
	Percentage of RCA to virgin material by weight Gradation Permeability Composition Other (Please Specify):	RCA	Virgin Aggregate
New Jersey			
Arizona	Percentage of RCA to virgin material by weight	50% Maximum	50% Minimum
California	Gradation	up to 100 %	
Colorado	Gradation		
DC DOT			
Florida	Atterberg limits. The contractor is required to stabilze the subgrade to a minimum Limerock Bearing Ratio value of 40.		
Georgia			
Georgia			
Hawaii			
Illinois	Generally by gradation and composition		
Kentucky	Gradation		
Louisiana	same as above. Proportion of blends are not specified		
Maine			
Maryland			

Minnesota	Gradation		
Nebraska			
Nevada			
Ohio Department of Transportation			
Oregon	Gradation		
Tennessee			
Utah	We require it to meet the same requirements of virgin aggregate. A-1a, NP with wear and soundness requirements.	Varies based on contractor desires	
Virginia	Gradation	at least 20%	
Washington	We allow blends, but the specifications for the type of material must still be met.		
West Virginia			
Wyoming	Percentage of RCA to virgin material by weight	Varies due to available material- 50% would be a rough estimate	50%
Ontario			

State	5. Does your State use filter fabric above, below or above and below the Recycled Concrete Aggregate (RCA) material?	6. Does your State specify "RCA" as the layer material or specify a "dense graded aggregate" and allow the contractor to choose to use virgin aggregate or RCA as the layer material?

Above	Specify RCA
Below	Specify DGABC and allow Contractor to choose
Above and Below	Other (Please Specify):
do not use filter fabric	
Other (Please Specify):	

New Jersey	do not use filter fabric	Specify DGABC and allow Contractor to choose
Arizona	do not use filter fabric	Specify DGABC and allow Contractor to choose
California	do not specify the use of filter fabric	Specify DGABC and allow Contractor to choose
Colorado	do not use filter fabric	Specify DGABC and allow Contractor to choose
DC DOT	Below	Allows if specified in special provision
Florida	do not use filter fabric	RCA is one of many options we will permit. Currently the RCA must come from a Department project, and the Contractor must request its use.
Georgia	do not use filter fabric	Specify DGABC and allow Contractor to choose
Georgia	do not use filter fabric	Specify DGABC and allow Contractor to choose
Hawaii		
Illinois	do not use filter fabric	Specify DGABC and allow Contractor to choose
Kentucky	do not use filter fabric	Specify DGABC and allow Contractor to choose
Louisiana	Below when placed on untreated or lime treated soils	Specify DGABC and allow Contractor to choose
Maine		
Maryland	do not use filter fabric	Specify DGABC and allow Contractor to choose
Minnesota	do not use filter fabric	Specify DGABC and allow Contractor to choose
Nebraska	do not use filter fabric	Specify DGABC and allow Contractor to choose
Nevada		
Ohio Department of	do not use filter fabric	

Transportation		
Oregon	Below	On a project basis, allow Contractor choice of using RCA in subbase, alone or blended 0-100%
Tennessee	do not use filter fabric	Specify DGABC and allow Contractor to choose
Utah	do not use filter fabric	Specify DGABC and allow Contractor to choose
Virginia	dust forms impervious cake, blinding fabric	Specify DGABC and allow Contractor to choose
Washington	do not use filter fabric	We allow for a wide variety of materials, but the specifications for the type of material must still be met.
West Virginia		Typically either a free draining base or DGABC is specified. The Contractor doesn't have the option to choose.
Wyoming	do not use filter fabric	Specify RCA
Ontario	do not use filter fabric	Specify DGABC and allow Contractor to choose

State	7. Has your State monitored the performance of pavements with RCA vs. those with virgin aggregates?	If your State has monitored the performance of pavements with RCA vs. those with virgin aggregates, Did you find that:		
	Yes/No	RCA was better	Virgin Aggregate was better	No difference
New Jersey	**No**			
Arizona	No			
California	Yes			studies at U C Pavement

			Research Center
Colorado	No		
DC DOT	Yes	works good in areas with no groundwater problems	
Florida	No		
Georgia	No		
Georgia	No		
Hawaii	No		
Illinois	Yes		No difference seen
Kentucky	No		
Louisiana	Yes		Performance is dictated by material specification compliance and good construction methods rather than choice of aggregate
Maine			
Maryland	No		

Minnesota	No				
Nebraska	No		great stability, but had poor perm. changed gradation of RCA to coarser	overall good performance, but more expensive so not used as often as recycled materials	
Nevada	No				
Ohio Department of Transportation	Yes			yes. While the monitoring was more toward drainage issues we found high amounts of tufa and clogging of the drainage.	
Oregon	No				
Tennessee	No				
Utah	No				
Virginia	No				Where used, we have seen no difference
Washington	No				
West Virginia	No				

Wyoming	No
Ontario	No

State	8. Has your State observed any pavement failures attributed to poor permeability in the base or subbase layer?
	Yes/No
New Jersey	**No**
Arizona	No
California	Yes
Colorado	No
DC DOT	Yes
Florida	No
Georgia	No
Georgia	Yes
Hawaii	No

Illinois	Yes
Kentucky	No
Louisiana	Yes
Maine	
Maryland	No
Minnesota	No
Nebraska	Yes
Nevada	No
Ohio Department of Transportation	No
Oregon	Yes
Tennessee	Yes
Utah	No
Virginia	Yes
Washington	No
West Virginia	
Wyoming	No
Ontario	No

State	9. Does your State have a specification for RCA when used as a Pavement base or subbase layer material? Yes/No
New Jersey	**Yes (Please provide a copy of the specification)**
Arizona	Yes (Please provide a copy of the specification)
California	Yes (Please provide a copy of the specification)
Colorado	No
DC DOT	Yes (Please provide a copy of the specification)
Florida	Yes (Please provide a copy of the specification)
Georgia	Yes (Please provide a copy of the specification)
Georgia	Yes (Please provide a copy of the specification)
Hawaii	No
Illinois	Yes (Please provide a copy of the specification)

Kentucky	No
Louisiana	Yes (Please provide a copy of the specification)
Maine	
Maryland	No
Minnesota	Yes (Please provide a copy of the specification)
Nebraska	Yes (Please provide a copy of the specification)
Nevada	No
Ohio Department of Transportation	No
Oregon	No
Tennessee	Yes (Please provide a copy of the specification)
Utah	No
Virginia	Yes (Please provide a copy of the specification)
Washington	Yes (Please provide a copy of the specification)
West Virginia	No
Wyoming	No
Ontario	Yes (Please provide a copy of the specification)

State	10. Where does your State obtain its RCA materials? (e.g., demolition debris, pcc pavement, etc.)
New Jersey	**From recyclers who get their material from pavements, bridges and demolition. Also allow contractor produced material which is primarily pavements or bridges.**
Arizona	Typically, we would obtain RCA from salvaged Portland Cement Concrete Pavement.
California	processed ashpalt concrete, portland cement concrete, lean concrete base, or cement treated base
Colorado	Contractor Provided
DC DOT	Pavement and other structures and supplied by local plants
Florida	Currenty pcc pavement, but we plan to open up to demolition debris.
Georgia	PCC pavement or structural concrete

Georgia	Mostly from recycled concrete slabs - Interstate Reconstruction Projects
Hawaii	demolition, pcc pavement
Illinois	Material comes from everywhere. Each 5,000T stockpile is tested for deleterious materials prior to use. See attached Spec.
Kentucky	Concrete pavement removed from Department projects.
Louisiana	Largest single source is old PCC pavement. some demo debris (kept separate if possible) is used, but quantity varies
Maine	
Maryland	varies, wille evaluate a source/stockpile based on contractor's submittal
Minnesota	PCC Pavement
Nebraska	State PCC pavements
Nevada	
Ohio Department of Transportation	If we had spec we would only accept from our own projects because of the lack of control of material.
Oregon	PCC pavement to be removed and replaced on a specific job.
Tennessee	Any RCA that meet the specifications
Utah	Demo mostly
Virginia	Mostly demolition debris
Washington	Mostly PCC pavement
West Virginia	N/A
Wyoming	pcc pavements from the project that it will be used on.
Ontario	mostly from demolition debris, e..g., bridge replacement, but may be obtained from municipal sources

State	11. Does your State accept concrete material with **ASR** for RCA when used as a Pavement base or subbase layer material?	If your State accepts concrete material with ASR for RCA, do you treat it before use as a base or subbase material?	If your State treats concrete material with ASR before use as a base or subbase material, how is it treated?	12. Does your State test for ASR when accepting concrete material for RCA for use as a Pavement base or subbase layer material?	IF your State tests for ASR when accepting concrete material for RCA for use as a Pavement base or subbase layer material, how is it tested?
	Yes/No	Yes/No		Yes/No	
New Jersey	**Yes**	**No**		**No**	
Arizona	Yes	No		No	
California	Yes	No	Does Not Apply	No	Does not apply
Colorado	Yes	No		No	
DC DOT	No	No		No	
Florida			For ASR issues - we don't know of any ASR aggregate issues with our aggregates.	No	
Georgia	No			No	
Georgia	No	No	ASR issues should have be addressed when the concrete was produced.	No	
Hawaii	No				
Illinois	Yes	No		No	
Kentucky	No			No	
Louisiana	Yes		We have not encountered this (yet).	No	
Maine					
Maryland	Yes	No		No	
Minnesota	Yes	No	WE don't have ASR so question 18 and 19 don't apply.	No	
Nebraska	Yes	No		No	

Nevada				No	
Ohio Department of Transportation	No				
Oregon	No			No	
Tennessee	No			No	
Utah	Yes	No		No	
Virginia	Yes	No	Do not treat for base or subase applications	No	
Washington	No			No	
West Virginia			N/A		N/A
Wyoming	Yes	No		No	
Ontario	No				

State	13. Does your State have a permeability specification for virgin granular base and subbase materials?	If yes, what is the Minimum Permeability Level for base and subbase material?		Are permeability levels verified?
	Yes/No	Base	Subbase	Yes/No
New Jersey	**No**			**No**
Arizona	No			
California	No			
Colorado	No			No
DC DOT	No			No
Florida	No			No
Georgia	No			
Georgia	No			No
Hawaii	No			No
Illinois	No			
Kentucky	No			No
Louisiana	No	working on it!!		
Maine				
Maryland	No			
Minnesota	No			
Nebraska	No			
Nevada	No			No
Ohio Department of Transportation	No			
Oregon	No			
Tennessee	No			No
Utah	No			
Virginia	No			
Washington	No			
West Virginia	No			
Wyoming	No			

Ontario	No
State	Comments:

New Jersey	
Arizona	Our specifications allow for the use of RCA in base or subbase courses, but to date RCA has rarely been used if at all.
California	
Colorado	
DC DOT	RCA that break up under alternate freezinf and thawing or wetting and drying shall not be used. Material shall be free from organic matter, asphalt, bricks, lumps or balls of clay.
Florida	We think the permeability we want is maintained by keeping the minus 200 to less than 10%.
Georgia	We have tested our normal graded aggregate base and it is mainly impermeable, our pavements are designed to keep the water out, not to free drain.
Georgia	The State doesn't use permeabile base or subbase (of any level)courses in roadway construction.
Hawaii	We are more concerned about the RCA clogging the permeable base that we use below the AC. We also found from county roads that when there is too much rebars in the RCA,volcano-like dimples form due to the corrosion of the rebars below the AC.
Illinois	
Kentucky	There is evidence RCM may present problems when utilized in drainage applications due to the potential to degrade and, when applicable, blend fabric and rodent screens. Therefore, do not use RCM in drainage applications or in conjunction with drainage systems.
Louisiana	Our research arm is the Louisiana Transportation Research Center, LTRC, which is located on the Baton Rouge campus of LSU. They, along with the Materials & Testing Section and the Pavement Design Section, have been looking at increasing permeability of all unbound aggregate bases. We do not have a minimum permeability specification ready to implement as of now.
Maine	
Maryland	
Minnesota	
Nebraska	
Nevada	RCA has not been used on many projects.

Ohio Department of Transportation	Seems like you are chasing the wrong issue. Your permeability is likely being screwed because the material tends to have continued breakdown in placement (compaction) and freeze durability. This resizes the material and along with the cementatious properties binds the material similar to re concreting. Additionally you probably have a stiffer base somewhat similar to cement treated aggregate base which now becomes more rigid than you want under a portland concrete pavement helping contribute to mid slab cracking.
Oregon	Oregon DOT Pavement Services Unit is just beginning to explore the use of Recycled Concrete Aggregate. Currently there are no projects to perform monitoring of performance.
Tennessee	903.05-Aggregate for Mineral Aggregate Base and Surface Courses. Aggregates for Mineral Aggregate Base and Surface Courses shall be crushed stone, crushed slag, crushed or uncrushed gravel, crushed or 903 722 uncrushed chert, crushed recycled concrete, or screened reclaimed asphalt pavement(RAP) together with such material as manufactured sand or other fine materials naturally contained, or added thereto as needed to conform with these Specifications. The aggregate shall be of 2 Types: Type A and Type B. (a) Type A aggregate for mineral aggregate base and surface courses shall consist of hard durable particles or fragments of stone, slag, gravel, or chert, and other finely divided mineral matter. Recycled concrete aggregate or reclaimed asphalt pavement, at a maximum rate of 25%, by weight, may be used for Type A aggregate, provided the combined aggregate blend meets all the requirements specified below. The recycled concrete and asphalt shall be crushed and screened to produce a uniform stockpile before being blended with the virgin material. The recycled stockpiles shall be free of bricks, steel, wood, and all other deleterious materials. Individual, or blended materials shall meet the requirements specified below: 1. Crushed stone shall be free of silt and clay. The coarse aggregate portion (retained on the No. 4(4.75 mm) sieve) of the stone shall have a percentage of wear of not greater than 50, and when subjected to five alternations of the sodium sulfate soundness test, the weighted percentage of loss shall not exceed 15. 2. Crushed slag shall be free of silt and clay and shall meet the quality requirements of crushed stone. It shall be reasonably uniform in density and shall have a dry-rodded weight of at least 70 lbs/c.f.(112 kgs/0.1 m3). 3. Gravel and chert shall be screened and all oversize material may be crushed and fed uniformly back over the screen. The coarse aggregate portion shall have a percentage of wear of not greater than 50, and when subjected to 5 alternations of the sodium sulfate soundness test, the weighted percentage of loss shall not exceed 15. The portion of the material passing the No. 40(425 μm) sieve shall be non-plastic, or shall have a liquid limit of not greater than 30 and a plasticity index of not more than eight. If fine aggregate, coarse aggregate or binder, in addition to that present in the base material, is

necessary in order to meet the gradation or density requirements or for satisfactory bonding of the material, it shall be uniformly blended with the base course material at the mixing plant by a mechanical feeder to maintain a uniform flow on the belt to the mixer. Blending of materials on the stockpiles or in the pits by bulldozer, clamshell, dragline or similar equipment will not be permitted. The composite gradation of Type A aggregate shall be the grading specified.

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(b) Type B aggregate for mineral aggregate base shall consist of crushed or uncrushed gravel, crushed or uncrushed chert, crushed stone or crushed slag, and other finely divided particles. Recycled concrete aggregate or reclaimed asphalt pavement, at a maximum rate of 30%, by weight, may be used for Type B aggregate, provided the combined aggregate blend meets all the requirements specified below. The recycled concrete and asphalt shall be crushed and screened to produce a uniform stockpile before being blended with the virgin material. The recylced stockpiles shall be free of bricks, steel, wood, and all other deleterious materials. The quality of Type B aggregate shall be the same as the quality requirements for Type A aggregate with the following exceptions: The Sodium Sulfate Soundness shall not exceed 20. Type B aggregate shall be screened and the oversize materials may be wasted or crushed and returned over the screen and uniformly blended with the other material. Material having a clay content greater than 12%, as determined by hydrometer analysis (AASHTO T 88), will not be permitted. Material having a clay content not exceeding 12 per cent will be acceptable provided a plasticity index-fines product does not exceed 3 when calculated by the following formula: % Passing No. 40(425 µm) x P.I. of - No. 40(425 µm) Material 100 If an excess of binder occurs, crushed stone, crushed slag, gravel, chert, sand, or other approved granular materials shall be uniformly incorporated in such proportions, not to exceed twenty per cent of the total mix, as the Engineer directs. If the quantity of binder is insufficient to bond the base or surface course properly, additional binder of approved quality, in an amount not to exceed 15% of the total mix, shall be uniformly incorporated as directed by the Engineer. The use of material requiring the addition of coarse aggregate or binder in excess of the above limits will not be permitted, unless otherwise specified on the Plans or in the Contract. Blending of additional material, if required, may be performed either at the screening or mixing plant or on the road. If blending is done at the plant, mechanical feeders that will maintain a uniform flow of the materials on the conveyor belt to the mixer or screening plant shall be employed. If blending is done on the road, the two or more materials shall be spread in uniform layers and blended by means of a mechanical mixer. Blending of materials on the stockpile or in the pit by means of a bulldozer, clamshell, or similar equipment will not be permitted. When combinations of materials for Type B aggregate for mineral aggregate base and surface courses such as creek gravel and chert, bank gravel and chert, crushed stone and chert, crushed slag and chert, are permitted, they will be designated on the Plans or in the Contract, and the pertinent requirements of this

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Specification for quality, blending of materials, and gradings shall apply. The composite gradation of Type B aggregate shall be the grading specified on the Plans or in the Contract.

Utah	
Virginia	We ran experimental permeability tests on virgin base stone and got results of about 2 x 10-4 cm/sec. We have not conducted tests on RCA. Our specifications allow contractors to use RCA (alone or blended, their choice). If they use RCA, the blend or RCA product must meet VDOT specifications for gradation.
Washington	Our Standard Specs are available online at: http://www.wsdot.wa.gov/publications/manuals/fulltext/M41-10/SS2006.pdf Recycled Materials specs are in Division 9-03.21
West Virginia	We allow recycled concrete pavement to be used as coarse aggregate in concrete pavement, but it's rarely (if ever)used in this application. We haven't used RCA as a base or subbase material and don't have any specifications that address its use.
Wyoming	
Ontario	