Project Objectives:

The purpose of this research study is the determination of whether concrete produced with RCA can meet the quality needs of NJDOT. If it can, then best practices need to be reflected in recommended quality control plans and guide specifications. This determination is clearly the objective of the work however there are additional objectives that must be accomplished first which will influence any specifications produced. The research objectives are identified and briefly described below.

**Objective 1 – Identify the challenges, barriers, and other issues related to the use of RCA in PCC.** This objective will be accomplished through literature reviews, consultation with industry experts, and consultation with other STAs (including those that allow use of RCA in PCC and those that have elected not to).
**Objective 2 - Identify and quantify regional RCA sources.** While NJDOT does not have a direct economic mandate related to RCA, its use could have impact on the economics of state funded projects. It is important to know what the regional sources are for RCA, what the current processing capacity is, and what the potential for growth is should a specification be adopted. These factors can influence the size and types of applications of RCA in PCC.

**Objective 3 - Experimental characterization and validation of RCA available in region.** There have been a tremendous number of experimental studies exploring various issues related to use of RCA in PCC. The results of these studies will be invaluable in identifying and potentially overcoming any barriers to implementation. However, the results from previous studies will be of most benefit if it can be shown that the work was performed using materials comparable to those used in the earlier studies so that the work is directly applicable. In addition, characterization and control of variability within RCA stockpiles must be an important part of the quality control plans and guide specifications.

**Objective 4 - Development of recommended best practices and specifications.** The information collected in the literature review, through discussions with other STAs, and the experimental characterization of locally available RCA will be coalesced to document recommended best practices and guide specifications for the use of RCA in PCC or a recommendation not to use the material in PCC.

**Objective 5 - Field installations.** Based on results of the studies, appropriate applications for RC in PCC will be identified and trial installations will be made to evaluate field performance.

**Objective 6 – Implementation and training plan.** An implementation and training plan must be completed to assure a technology transfer from the project participants to NJDOT personnel.

**Project Abstract:**

As noted in the RFP for NJDOT project 2009-05, diminishing virgin aggregate supplies make it in the best interest of both NJDOT and the concrete industry to consider the use of recycled concrete as aggregate for new PCC. For a number of years now sources of local aggregates in Southern New Jersey have been scarce leading to increased costs from the longer distances required to transport aggregates. The use of recycled concrete could provide an additional source of aggregates, conserve the resources that are available, reduce the costs associated with disposal of construction materials, and conserve the limited landfill space in the region. Other states have found that RCA provides engineering, economic and environmental benefits. However, recycled concrete aggregates (RCA) must meet the quality needs of NJDOT if they are to be used in PCC.

RCA is produced through the crushing of concrete pavements or other waste concrete after removal of any reinforcing steel. Required gradations are produced through crushing and screening in much the same way aggregates are produced from virgin materials. To be used as aggregate, RCA requires most of the same tests performed on virgin aggregates. However, important distinctions between RCA and virgin aggregates have led state transportation officials in New Jersey and much of the rest of the country to be cautious in the adopting RCA as an acceptable aggregate for PCC. The presence of cement paste or
mortar adhering to the recycled aggregates reduces density, increases porosity, and increases drying shrinkage of PCC. Additional concerns include problems with the quality of the original concrete being recycled, and the presence of contaminants. The two primary sources of stockpiled RCA for use in PCC are Class B recyclers who accept and crush concrete waste and precasters who have an interest in crushing and reusing surplus material from the end of a production run and from damaged cast pieces. These varied sources suggest there will be a greater variety in properties both within a given a stockpile source and between the various sources. These are some of the issues that must be addressed before RCA is implemented in NJDOT projects.

The research will identify benefits and barriers to the use of recycled concrete as aggregate in PCC through literature reviews and discussions with state transportation agencies currently using this material. Because there is an extensive body of literature already available, laboratory experimentation will be limited. The purpose of any experimental laboratory work is to validate the RCA product available in the region is comparable to that used in previous studies so that these prior results may be extrapolated with confidence. Laboratory work will also be used to determine the consistency of RCA stockpiles throughout the region, looking at both variability between sources and variability within a stockpile. The outcome of the research project will be documentation of best practices and an implementable guide specification and quality control procedures for the use of RCA in concrete or a recommendation not to use the material.

The field installations included as part of this work are limited to lower risk applications that allow the specifications and recommendations to be tested in a controlled manner. The results of these initial field installations will be used to inform future research efforts if needed under new contracts to either expand the types of applications or address issues that arise in the initial field trials.

The research program will be directed by Dr. Douglas Cleary at Rowan University. Dr. Cleary will perform the work assisted by a team consisting of a graduate student, paid undergraduate students, unpaid undergraduate students working in the Rowan engineering clinics and the civil engineering department laboratory technician. The research plan consists of a literature review, consultation with state transportation agencies outside New Jersey and other industry experts, experimental characterization of regional RCA sources, and field demonstration projects. This work will form the basis for the final project report and implementation and training plan.

In this research study, the emphasis will be placed on building from the previous work already done elsewhere in the evaluation of RCA in PCC. These previous studies will be supplemented with limited laboratory and field testing. There is a very large body of literature available in technical journals and conference proceedings related to RCA. This previous work has fairly thoroughly identified how use of RCA affects proportioning, installation, and durability of PCC and the considerations that must be made when using the material. The advance to be made in this study is to evaluate the relevance of the previous work, consider and resolve discrepancies that may be found, and put this work into context with the specific needs and conditions faced by NJDOT and the contractors in the state. As noted previously there are a handful of states that have allowed the use of RCA in PCC for several years now. Additional contacts will be made with industry experts in organizations such as ACI and PCA. The experiences in other states and the results of the literature studies will be used, while considering any unique conditions in New Jersey, to help inform any
recommendations and specifications developed. Given the availability of a large number of previous studies and the experiences of a number of states, including northern states, already allowing the use of RCA in PCC, the most efficient and cost effective way to approach this research project is through consideration of the lessons already learned rather than through an extensive experimental program involving development, testing, and modification of numerous mixes.

However, it is important to know regionally what the source material being used to produce RCA is, what the current processing capacity is, and what the potential for growth is should a specification be adopted. These factors will have some influence on the size and types of applications for which RCA PCC ultimately is used. For this reason the research plan includes the need to identify current regional RCA producers and evaluate current and future processing capabilities.

Evaluation of the regional RCA sources includes a sampling program to characterize the locally available RCA. Testing will include chloride content, absorption, specific gravity, and gradation as well as documentation of amount of foreign inclusions such as asphalt or steel in the recycled aggregate. No testing for ASR, freeze-thaw, and abrasion resistance will be conducted. Samples from each source will be collected at least twice to evaluate the consistency of the material.

Results of the literature review, contacts with other STAs, and evaluation of the regional recycled aggregate capacity and characteristics of the aggregates will result in recommendations for the use of RCA in PCC. Should these be positive, guide specifications will be developed to address the application and limitations of the use of RCA including quality control recommendations. In consultation with the NJDOT Project Manager and research panel, industry representatives and other personnel deemed appropriate, plans for field trials will be developed including installation and monitoring plans. Ultimately the work will be documented in the final report and presentation and disseminated through the implementation and training plan.

1. Progress this quarter by task: (italicized material from the original proposal)

**Task 1.1 Literature review** - A survey of the extensive body of work identified in the project proposal and including additional review of material contained within the reference lists of those documents will performed. Additional effort will be expended to identify other relevant work. The purpose of the task is to identify the issues and recommendations available regarding use of RCA in Portland cement concrete applications.

There have been no changes since the previous progress report.

**Task 1.2 Contacts with STAs, trade groups and professional societies** – Several states including Virginia, W. Virginia, S. Carolina, Illinois, Michigan, Minnesota, North Dakota, Texas, Colorado, Wyoming, and Idaho currently allow use of RCA in PCC. The FHWA has conducted surveys of key personnel in these states to determine their experiences. The principals involved in this original work have been identified and will be contacted as part of this task. In addition technical societies such as ACI and PCA have technical committees addressing the use of RCA in PCC and the expertise of the committee members will be sought.
There have been no changes since the previous progress report.

**Task 2.1 Analysis of regional RCA capacity** – The number of producers of RCA, their capacity, and the characteristics of the material they produce will influence the PCC applications where RCA might be considered. The primary sources of RCA will be Class B Recyclers and waste material produced in precasting plants. There are currently approximately 30 producers of RCA approved by NJDOT for dense graded aggregate base course who would be likely candidates to provide coarse aggregate for concrete. During this task the project team will identify the regional RCA producers and their current capacity. Approval by NJDOT for use of RCA in PCC could clearly increase the demand for this type of aggregate therefore the team will also determine the potential capacity of the plants to expand and quantify the amount of material currently being landfilled that could be processed. This work will be accomplished through discussions with the regional plant operators, contacts with municipal waste handlers, and the results of national studies identifying trends in other regions.

There have been no changes since the previous progress report.

**Task 2.2: Sampling of regional RCA for material properties and stockpile control** – Samples of material will be collected from regional plants. Rowan University will perform gradation, chloride, specific gravity, absorption tests on the material. The material will also be screened for foreign inclusions such as asphalt waste and steel. The sampling program will be confirmed with the research panel but at this time the proposal team suggests sampling from the ten plants with the largest capacity to produce RCA. Sampling at these sites will be performed on two different dates to determine how much the properties vary depending on the raw material being processed. Stockpiles at selected precasters will also be sampled although it is anticipated that the precasters will have a more consistent product but less capacity. It is important to verify properties of the regionally produced materials conform to those used for the previous research studies and are comparable to those available in other states already using RCA. The variability of the material properties must also be reflected in the final recommendations and guide specifications generated from this work. In addition it is possible that a tiered system of approved aggregate suppliers may need to be established based on stockpile management practices.

Additional laboratory testing was performed during this quarter related to runoff from stockpiles of virgin aggregate and RCA. Initially a series of tests was performed in which clean water was poured over a confined aggregate sample. The runoff was collected and the pH was measured. The process was repeated daily reusing the original water. This was based on testing performed by the Ohio Department of Transportation. The test was then modified by using fresh water each day in order to determine if the pH from runoff from an RCA stockpile will remain elevated or if it will quickly stabilize to be comparable to virgin aggregate.

**Task 3: Summary Report and Recommendation** – Results from the literature review, contacts with other STAs, contacts with technical societies, and the capacity analysis and material characterization program will be summarized in a report to the Research Project Selection and Implementation Panel. This task will include a recommendation on whether to allow use of RCA in PCC and additional recommendations for any suggested limitations on the use. Following review of the report by NJDOT, the Rowan Project Team and the Research Panel will need to discuss preliminary plans for field trials.
The team has moved forward with field trials and final recommendations should not be made until after the completion of the field studies.

**Task 4: Guide Specifications and Field Trials**

**Task 4.1 Guide Specifications** - *Working with input from the Research Panel, other personnel in the materials and construction divisions and using the results of the previous tasks, guide specifications for use of RCA as aggregate in PCC will be developed. Issues to be addressed in the specifications will include items such as stockpile management, percentage of replacement aggregate allowed, and permitted chloride levels.*

Work has continued to develop recommendations for guide specifications for use of RCA in Portland cement concrete based on the findings from this work and the research into how other states are handling RCA. These will be finalized following results of the field trials.

**Task 4.2 Field Trials** - *Trial field installations will be planned and implemented in consultation with the Research Panel. The purpose of these trials is to pilot the guide specifications and determine if there are other unresolved issues that need to be addressed before full implementation of the new guide specification. Specific applications for field trials will need to be determined based on the results of the previous work. However, it is suggested that precast applications are the best initial candidates. Given that increased shrinkage is one of the larger concerns for PCC cast with recycled aggregates, applications where shrinkage is not critical to the success of the installation would allow NJDOT and its contractors to gain experience with the material with “safe” applications and later expand the allowed uses as experience is gained. Perhaps later research contracts could focus on specific, more difficult applications after the work under this contract establishes the first specification and quality control parameters. Therefore the following are proposed as potential candidates for field trials:*

1) A series of roadside barriers cast and placed throughout the state,
2) Stormwater structures, utility vaults or boxes,
3) Precast slabs,
4) Test slabs in pedestrian areas (subject to salt exposure) throughout the Rowan campus

*The research team will work with precasters under this task to develop the mix designs and cast the trial sections. Significant budget has been included to support the precast manufacturers in this task however it is anticipated that many of the manufacturers will want to be involved at this stage as it will improve their chances of being an early supplier of NJDOT products that carry LEEDS points for use of recycled materials. The project team has an ongoing relationship with Old Castle Concrete in Hammonton, NJ through its current work with self-consolidating concrete. The plant is used as a casting yard for the concrete specimens used in the work. This plant manufactures concrete utility products approved by NJDOT and also manufactures precast slabs. The close proximity to Rowan suggests this is...*
one location for manufacture of trial casts. The team will work with the research panel to identify other candidates.

The Project Team and Research Panel may also want to consider test pavement installations however costs for this type of trial will be higher and failure in the trial more disruptive to the public. The proposal team feels NJDOT is better served waiting for results from trials from precast applications before performing paving installations. Any trial installations will be monitored for the duration of the contract period however it is suggested that the plan for the field trials include arrangements for longer term monitoring by NJDOT.

In consultation with NJDOT project personnel it was decided that the field trials will focus on precast stormwater control structures and the concrete pedestrian areas on Rowan’s campus. The project team is met with the New Jersey Precast Concrete Association on September 22, 2010. As a result of that meeting a source of RCA was identified (following the failure to get a New Jersey Class B Recycler to produce a coarse aggregate for the project). A. J. Trunzo produced 60 tons of crushed stone for use in the Rowan campus field trials and possibly for casting stormwater control structures.

On March 18th, 2011 a slab for a loading dock area was cast outside of Rowan Hall on the Rowan University campus. The shrinkage of this slab was monitored throughout the previous quarter.

A twenty foot length of sidewalk was placed along Carpenter St. on the Rowan campus (5.5 cubic yards) using the RCA with slag mix on June 30, 2011 and a companion section of sidewalk with virgin aggregate was placed on July 2, 2011. Control points were set in each of these and shrinkage measurements have continued throughout the quarter. Cylinders were prepared for strength testing and comments from the field crew recorded.

A test slab was placed outside of Wilson Hall on the Rowan campus on August 2nd, 2011 with virgin aggregate and the companion slab using the RCA mix without slab was placed August 4th, 2011. Each of these were approximately 4.0 cubic yards. Control points were set in each of these and shrinkage measurements have continued throughout the quarter. Cylinders were prepared for strength testing and comments from the field crew recorded.

A test section using the RCA with slag mix was placed August 29th, 2011 outside Robinson Hall on the Rowan campus. This area was a placement of sidewalk with monolithic curb. Control points were set in each of these and shrinkage measurements have continued throughout the quarter. Cylinders were prepared for strength testing and comments from the field crew recorded.

The team has developed a SCC mix for RCA based on the mix used at Old Castle Precast for storm control structures. There is some concern with the plastic and wood materials within the aggregates floating to the surface with this mix. Arrangements are being made to cast water control structures using this mix at Old Castle. These trials have been delayed because the company has closed another plant which has resulted in a significant increase in the workload at the Hammonton plant. It is
anticipated these trials will be performed during this quarter as the construction season slows down.

Because changes in temperature and humidity and the effects of constraint of the slabs result in some difficulty interpreting field measured shrinkage (general trends can be gleaned but little quantitative data) additional test beams were cast in the lab using RCA and virgin aggregate mixes to provide better comparison of shrinkage of the concrete.

**Task 5: Final Report**

*This task will develop a final report which will document the findings of this project. A draft final report based on the technical memoranda prepared in prior tasks shall be prepared for Project Panel review and comment. The research team will produce a revised final report incorporating all changes needed to resolve the comments of the Project Panel.*

The team has continued compiling all of the literature review, guide specifications and laboratory results into the final report.

2. **Proposed activities for next quarter by task:**

Tasks 1.1 and 1.2 which encompass the literature review and contacting state transportation and others regarding their RCA experiences are essentially complete however as work continues to team is bound to find additional information that should be included in the final literature review and final report.

Task 2.1 Analysis of Regional RCA Capacity – this task will be completed.

Task 2.2 Sampling and testing of RCA – The team will continue to monitor the shrinkage of the lab cast beams. The team also plans to prepare some additional test cylinders of the various mixes in order to measure the elastic modulus of the various concretes produced.

Task 3 Summary report and recommendations – Based on further literature reviews, laboratory testing and the experiences of the field trials, these recommendations will continue to be refined.

Task 4.2 Field trials – The team anticipates one additional test slab being placed on the Rowan campus. In addition, the team hopes to perform trials of precast structures during this quarter.

Task 5 Final Report – Work continues on the final report.

3. **List of deliverables provided in this quarter by task (product date):**

Only a progress report is provided this quarter. Specific new findings will be highlighted at the quarterly progress meeting.
4. Progress on Implementation and Training Activities:

This task will not occur until later in the project schedule.

5. Problems/Proposed Solutions:

The only problem encountered is the delay in field trials of precast structures. The team is working with Old Castle Precast to resolve scheduling of this work.

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NJDOT Research Project Manager Concurrence: ____________________ Date: _________