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Federal Highway Administration

Transportation Applications Of Recycled Concrete Aggregate

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EXECUTIVE SUMMARY

The purpose of this review was to capture the most advanced uses of recycled concrete aggregate (RCA) for transportation uses in the United States. This knowledge would then be transferred to all State Transportation Agencies (STA) in the United States through the issuance of this report. The report summarizes the information collected during the review of practices in five states, Texas, Virginia, Michigan, Minnesota and California. These states were selected based on their level of use and supply generated of RCA as an aggregate as well as to obtain a cross-section of the country. This report identifies the applications where the use of RCA can have engineering, economic, and environmental advantages; the barriers related to these RCA applications; and the best practices that allowed State Transportation Agencies, recycled concrete producers and contractors to overcome these barriers. The report is intended to provide the State Transportation Agencies with recommendations, guidelines and specifications for furthering the use of RCA more widely throughout the country.

The overall findings of the review team was that RCA is a valuable resource, and by proper engineering it can be used for PCC pavement, aggregate base, miscellaneous. The material is too valuable to be wasted, and landfill. Some of the best aggregates used for highway, bridge, and building construction are already in use in our highways and bridges, effective recycling is a means to re-use these materials.

INTRODUCTION

The construction of highways, bridges and buildings has been increasing from the beginning of the past century, especially in areas of high population density. These facilities need to be repaired or replaced with the passing of time because their end of service life is reached or the original design no longer satisfies the needs due to the growth in population or traffic. These facts have generated two important issues. First, a growing demand for construction aggregates and, second, an increase in the amount of construction waste. Two billion tons of aggregate are produced each year in the United States. Production is expected to increase to more than 2.5 billion tons per year by the year 2020. This has raised concerns about the availability of natural aggregates and where we will find new aggregate sources.

On the other hand, the construction waste produced from building demolition alone is estimated to be 123 million tons per year. Historically, the most common method of managing this material has been through disposal in landfills. As cost, environmental regulations and land use policies for landfills become more restrictive, the need to seek alternative uses of the waste material increases. This situation has led state agencies and the aggregate industry to begin recycling concrete debris as an alternative aggregate. Commercial construction industry has been leading the reuse of this debris, but with the State Transportation Agencies (STA) recognizing the engineering , economical and environmental benefits that can be achieved for using RCA, use for highway work is on the increase.

Review Methodology:

FHWA conducted this review on the uses recycled concrete aggregate (RCA) in highway applications with the purpose of capturing the most advanced applications and technologies. RCA is general thought of as old PCC pavement, bridge structures/decks, sidewalks, curbs and gutters that are being removed from service, steel removed, and can be crushed to a desired gradation. Commercial construction debris can be used for RCA, provided the material is cleaned of unwanted material like bricks, wood, steel, ceramics, and glass. The STAs tend to want to re-use material recovered from either state projects or known source of supply. The aggregates used to produce PCC pavement and structural PCC for buildings will have similar if not the same aggregate used. This knowledge will then be transferred to the State Transportation Agencies (STA). The present report summarizes the findings of this review including the best practices on the use of RCA and the advantages and barriers associated with these uses in highway construction.

State Transportation Agencies were surveyed to determine the current uses of RCA. From the results of this survey, five states were identified as being among the highest consumers as well as large supply of RCA in the United State. The states selected were Texas, Virginia, Michigan, Minnesota, and Utah. Utah declined to participate and California was selected to replace it in the review. These states were visited in order to collect information about the state-of-the-practice on RCA uses. The following three figures depict the extent of use for recycled concrete aggregate as determined by the survey results throughout United States.

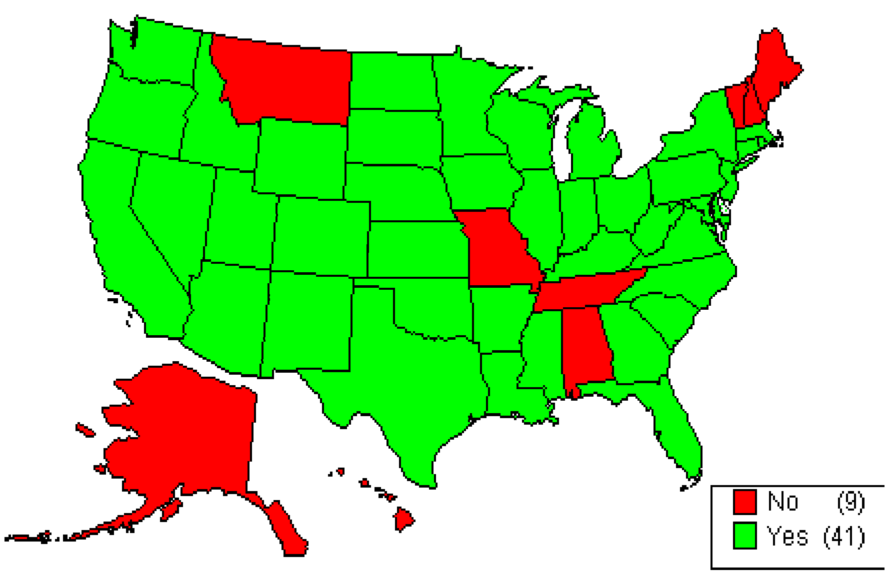

Figure 2.1. States recycling concrete as Aggregate

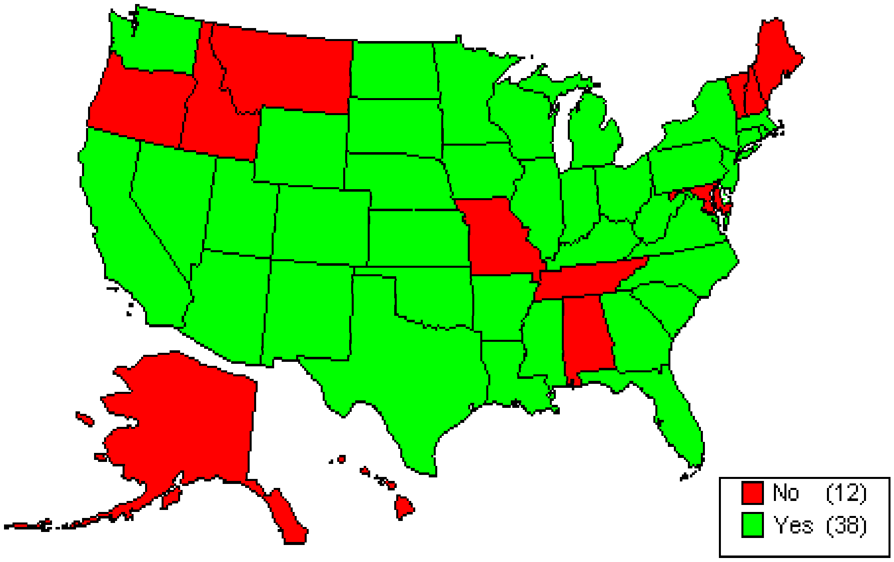

Figure 2.2. States recycling concrete as aggregate base

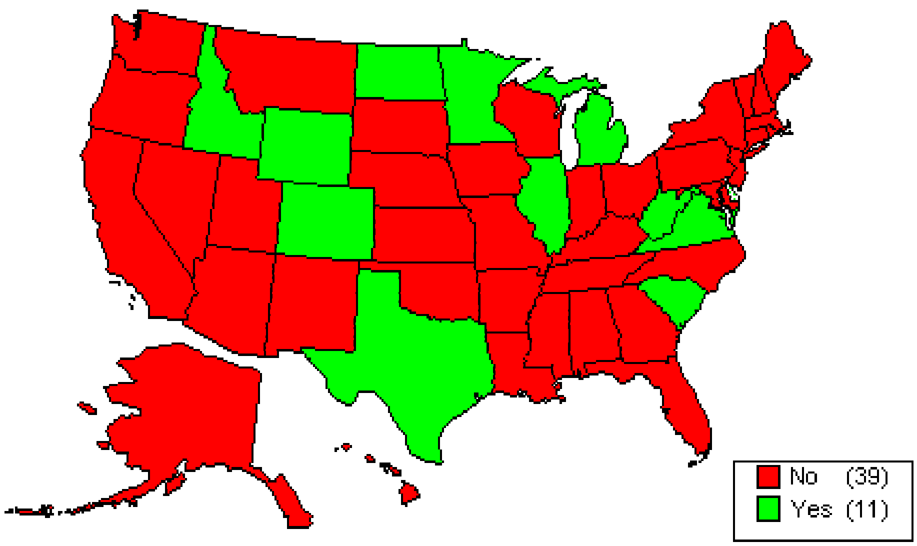

Figure 2.3. States recycling concrete as aggregate for PCC

Advantages:

Transportation agencies' experiences and research studies have shown that recycled concrete aggregate (RCA), under specific conditions, has the potential to produce strong, durable materials suitable for use in the highway infrastructure. The coarse aggregate portion of RCA has no significant adverse effects on desirable mixture proportions or workability. Recycled fines, when used, are generally limited to about 30 percent of the fine-aggregate portion of the mixture. *(1)*

Performance:

Angularity of RCA:

1. Helps to increased structural strength in the base, resulting in improved load carrying capacity:

2. Building pads (residual cementation), provides a strong, durable platform for which to build upon.

3. Better control over gradation, in this RCA is able to meet gradation and angularity requirements.

4. Potential to minimize D-cracking and ASR: D-cracking is caused by the freeze-thaw expansive pressures of certain types of aggregate, whereas Alkali Silica Reaction (ASR) is caused by the detrimental reaction between silica found in certain aggregate and the alkali (cement) paste. These forms of distress are material related and studies show that the inclusion of RCA in the concrete mix and a suitable fly ash has the potential to reduce these distresses. Freeze-thaw testing of concrete in Minnesota made with recycled D-cracking aggregate indicated a greatly reduced potential for D-cracking when fly ash was used in the mixture.*(1)*

Resource Conservation

Reduced land disposal and dumping: The use of recycled concrete pavement eliminates the development of waste stockpiles of concrete. Also, since recycled material can be used within the same metropolitan area, this can lead to a decrease in energy consumption from hauling and producing aggregate, and can help improve air quality through reduced transportation source emissions.

Conservation of virgin aggregate: The supply of virgin aggregate in many areas of the United States is or is becoming limited. In such areas, the use of recycled aggregate is beginning to serve as an environmentally friendly and economically viable solution. Many European countries have placed a tax on the use of virgin aggregates. This process is being used as an incentive to recycle aggregates. It is noted that several states have high tipping fees for disposal of RCA, this is done to control landfill usage thus increasing the reuse of RCA.

Reduce impacts to the landscape: The reuse of concrete demolition debris reduces unsightly stockpiles of concrete rubble, animal infestation of stockpiles, and an overall environmental improvement when re-used.

Metal recovery: The removal of metal, steel reinforcement, is an important step in the recycling process and can take place in several stages. Contractors usually remove continuous reinforcement on the grade, whereas dowel and tie bar removal is typically done at the plant. Most crushing plants have an electromagnet to catch steel moving along the conveyor belt between the primary and secondary crushers. Salvaged steel usually becomes the property of the crushing plant and is sold as scrap metal. Wire mesh steel generally found in reinforced concrete pipe retains a large quantity of bonded concrete and usually becomes waste. (*2)*

Defined as inert material in Solid Waste Regulations: Generally in the states that use RCA the environmental regulatory agencies have reviewed the material, where it is to be used, and have deemed it inert. After all it really is just broken up concrete pavement being reused as aggregate base or PCC aggregate.

Economic

Limit haul distance: Recycled concrete is crushed and the entire aggregate product can be used as a base material according to specifications, therefore generating no waste. This can be done on the project site or at nearby recycling plants, eliminating the transportation to distant disposal sites and the hauling in of virgin aggregate. In an urban environment concrete debris is hauled to a crushing site that is generally closer to the center of the urban area then the virgin aggregate quarry. In some cases the two operations cohabitate. Industry comments were that the RCA stockpile is usually closer to the job sites in an urban environment, thus less haul distance is less fuel burnt in delivery. Production of virgin aggregate can use more fuel to crush due to larger initial size of rock needing to be crushed to desired grade.

Reduce disposal costs: Disposal of concrete rubble and other waste construction materials by dumping or burial is a less attractive and more expensive option. Reconstruction of urban streets and expressways results in an enormous amount of waste concrete being generated and creating a massive disposal problem. Recycling can therefore alleviate some of these problems and offer savings to the owner agencies in terms of material acquisition and disposal costs.

Overall project savings: There may be considerable project savings by using a less amount of virgin aggregate. This saving is increased by the reduction of transportation and disposal costs. Another economic benefit is the recovery of steel from the recycling process. This material usually becomes property of the contractor, who can sell as scrap metal. There is also potential for cost savings in many areas where aggregates are not locally available, and have to be hauled long distances, often 50 miles or more. Environmental impacts reduction and extending available life of landfills is also a long term benefit that can be experienced by local governments due to increased recycling of RCA.

Minimize impacts to existing roads with reduced hauling: Using the existing concrete on grade as the source of base aggregate eliminates the importation of large volume of virgin material for reconstruction. This reduces the heavy vehicle loadings carried by the current highway system, an economic and public interest advantage to the owner agency. For instance in the VA I-66 rehabilitation contract the contractor set up a crushing plant at a visitor center that was within the project limits and crushed the old pavement for use as aggregate base material, with very little truck traffic impacting the large numbers of daily commuters.

Maintaining grade on highways: The process of reusing the existing pavement as a base material or concrete aggregate allows the owner agency to redesign the new pavement structure at the existing grade. This allows the continued use of many of the existing features outside of the roadway, such at guiderails, traffic signs, and bridge clearance can be maintained. Rubblization and Crack and Seat operations usually require extensive grade increases that make relocation of the highway features mandatory.

State Experiences

Texas

TxDOT is a large user of RCA materials. However, private industry and municipalities consume over 60% of the RCA currently produced in Texas. Although the use of recycled concrete aggregate (RCA), or other recycled-concrete materials or products, is not specifically mentioned in TxDOT's strategic plan, they have created the conditions that allow for use of recycled aggregates on their projects. Through research, implementation and competition, TxDOT has found that using RCA, like many other recycled materials, provides engineering, economic and environmental benefits. TxDOT has been using RCA for the last 10 years and has overcome many hurdles. A summary of TxDOT's experiences is provided below:

The use of RCA in new concrete initially created problems with mix workability. The problem was associated with the high absorbency of water of aggregate and the difficulty in maintaining a consistent and uniform saturated surface dry condition of RCA aggregate. The Contractors overcame this hurdle by improving their process control program. Their process control program heightened their awareness of the need to water stockpiles and to conduct frequent testing of aggregate for moisture content.

TxDOT Research has identified an increase in creep and shrinkage when RCA is incorporated into new concrete. This can be a major issue when RCA is used in structural concrete. TxDOT does not currently use RCA in structural concrete because of the possible issues with creep and shrinkage. However, TxDOT has used RCA in some structural testing applications and is monitoring them.

Initially, there was a general perception among the engineers that RCA was a waste product and thus a substandard material. But over time that perception in TxDOT has change due to education and test sections findings. TxDOT has used RCA where the risk is minimal and has high potential for good performance. They have also performed training and continually present information to their Districts concerning the performance of the projects they have completed around the state.

TxDOT initially experienced lower compressive strength and workability issues. Research linked the use of RCA fines in the concrete to the lower compressive strengths and workability. At that time it was determined that 20% was the maximum amount of RCA fines that would be allowed in the concrete.

The placement of RCA base material has provided some hurdles in grading and compacting. Excessive working of the RCA base will segregate the base materials. Minimum shaping of the RCA base material should occur. Compaction of the RCA base should be in a saturated state to aid in the migration of fines throughout the mix. Overall the performance of RCA as a base material has been excellent, the material even tends to knit together and has a higher load bearing capacity due to the re-cementing action.

Virginia

The Virginia Department of Transportation's (VDOT' s) strategy for the recycling and reuse of concrete aggregate tries to provide a neutral playing field for recycled and virgin aggregates. RCA is a viable material and there are written standard specifications for its use in highway construction. RCA is not specifically mentioned in the VDOT strategic plan, and there are no conditions (shortage of natural materials, economic conditions) that mandate its use. However, statewide use of RCA is permitted. Commercial applications are the prime use of RCA.

VDOT has established an income tax credit on the purchase price of recycling machinery. Equipment must operate on a company's site and does not include mobile units. This was hoped to stimulate more recycling of various materials, RCA is one that a crushing operation would benefit from tax credit on equipment.

VDOT has provided construction recommendations for compacting RCA when it is used in base and sub-base. These recommendations include compacting the RCA in a saturated state to aid in the migration of fines throughout the mix. Compaction of the RCA should be performed with steel wheel rollers, because of minor amounts of steel are present in the material and may cause problems when using rubber-tired equipment.

Establishment of agreements on solid waste management practices, including RCA was done with Virginia’s Department of Waste Management and VDOT. They developed an executive compliance agreement that defines solid waste management practices during construction and repair of highways so that RCA could be effectively used. This also allowed the contractor to bury removed PCC materials within the highway right-of-way.

Michigan

The Michigan Department of Transportation's (MDOT) strategy for the recycling and reuse of concrete aggregate is to use it if it enhances or equals the performance of virgin material in the final product. Statewide use of recycled concrete aggregate (RCA) is permitted by the Standard Specifications of Construction, 2003, in Aggregate section 902.03 part B, 902.04 and 902.06. It allows the use of RCA as coarse aggregate in Portland cement concrete for curb and gutter, valley gutter, sidewalk, concrete barriers, driveways, temporary pavement, interchange ramps and shoulders. RCA is also allowed permitted to be used as coarse aggregate in hot mix asphalt and as dense-graded aggregate for base course, surface course, shoulders, approaches and patching. RCA was widely used in the pavement surface structure during the 1980's. Since 1983 MDOT has incorporated RCA in projects such as M-10, I-75, I-94, I-95 and I-96. Michigan has constructed 26 projects with 650 lane miles of PCC pavements using recycled concrete aggregate. US-41 in the Upper Peninsula is currently being reconstructed using RCA as the aggregate base material with an on-site mobile crushing operation. In addition, the Detroit Metro region is currently using RCA as aggregate base material on 2 projects.

MDOT and aggregate producers identified the following benefits for RCA:

D-Cracking performance problems in RCA pavements can be reduced when the old pavement is crushed to a smaller aggregate size.

Using RCA in the Detroit metropolitan region is more advantageous than in rural areas of the state. This is due to large sources of concrete rubble being readily available, with well developed RCA operation in the metro area, and virgin aggregate crushing operations having a longer haul distance.

The proximity to metro areas of the RCA production plants makes this aggregate economically attractive for commercial uses in roadway base, commercial building, and parking lots.

A recent value-engineering proposal for using RCA in the pavement base structure on US-41 resulted in savings of $114,000 on a $3 million dollar project. The Contractor and the State shared this savings equally.

Currently, the demand for disposal space for concrete debris is high in the Detroit Metro area. The incoming supply of concrete is more then what is going out, due to major highways being rebuilt, and large commercial re-development projects. The recycling plants are reaching their stock capacity and they are increasing their incoming material disposal costs. This demand would be considerably diminished if RCA would be engineered into more reconstruction projects. MDOT having recently placed a moratorium on the use of RCA in new PCC pavement, has also affected the use as aggregate subbase material. This has affected how it is used by city and county public work department.

MDOT's Detroit Metro Region has approved the following guidelines for the management of the use of recycled concrete aggregate in the Detroit Region:

- Normally commercial sources of concrete are not allowed for recycling into aggregate for use on State projects. Most recycled material must come from MDOT's reconstruction projects. This assures a consistent source of original aggregate. In turn it puts a burden on the crushing operation to maintain separate operations for feedstock and crushed piles.
- Certification of recycling aggregate producers and the approval of stockpiles, when the primary source is the concrete from highways and when the producer has displayed adequate control of the product. Several producers have used quality control measures to produce a material that meets state specifications, getting their operation pre-approved allows contractors to bid the material knowing it will pass state material testing requirements.
- Changes in the design on the permeable base to allow RCA to be used by increasing the density of the base and modifying the design of the fabric drainage system. This addresses the concerns of plugging the underdrain systems.

MDOT's Research Record of October 1995 provided recommendations for the reduction of cracking when using RCA in highways that enhance its performance and minimizes the reliance on aggregate interlock. These recommendations include the following:

- Increased foundation stiffness
- Reduction of slab tension
- Additional steel reinforcement
- Use of a deformed wire mesh
- Use of hinge joints

Michigan has established an Environmental Policy that provides an incentive for using recycled products. They provide a 10% price break for recycled materials versus virgin materials.

Minnesota

The Minnesota Department of Transportation, Mn/DOT, views recycling, and in particular the use of recycled concrete aggregate (RCA), as resulting in more efficient and effective use of that material from both, environmental and economic, perspectives. Statewide use of RCA is permitted in the Mn/DOT Standard Specifications for construction. The specifications establish that RCA can be used as coarse aggregate in Portland cement concrete (PCC) in section 3137.2 B, as aggregate for surface and base courses in section

3138.2 A, and as granular material in section 3149.2. Minnesota currently uses almost 100% of the concrete removed from its pavements as dense graded aggregate base. This material must meet the 3138.2 section of Mn/DOT specification and can include a maximum of 3% by mass of asphalt binder from recycled asphalt pavement.

From the late 1970's through the 1990's, RCA was used as coarse aggregate for PCC pavements on more than 20 projects. Today, Mn/DOT uses a 60-year pavement design life on its high-volume freeways and a 35-year design life on all other highways with associated warranties. These factors have Contractors shying away from its use in the concrete pavement since the belief is aggregate washing would be required to produce useable aggregates. This increase in cost is the main issue to using in PCC as course aggregate.

Mn/DOT and the industry have overcome some barriers. A summary of Mn/DOT and industry's experiences are provided below.

- Observations suggest that RCA when used in the base and sub-base material performs better than virgin aggregate. Research is underway to determine if the observed increase in base strength can be validated in a laboratory performance evaluation for RCA used in aggregate base and sub-base. Rubblization, crack & seat and un-bonded concrete overlays have been used as reconstruction strategies. All these processes have shown to provide good performance. Currently, un-bonded concrete overlay is the most widely used technique for pavement rehabilitation in the state.
- Substitution of RCA for virgin aggregate can provide savings in the final cost of the project. It is a common practice in Minnesota to crush the material on site. This lowers the transportation costs and has less effect on traffic.
- Use of RCA preserves natural aggregate resources. Mn/DOT identified the virgin supply resources in a 10-year aggregate availability or needs study as being potentially in short supply. RCA is viewed as a valuable aggregate supply for their long term needs.

Recommendations provided by Mn/DOT for using RCA in state highways are:

- Washing of RCA is required if used in PCC pavements in order to eliminate excess fines.
- Quality requirements for new aggregate do not specifically apply to RCA when the pavement comes from a known source.
- In presence of drainage layers and/or perforated drainage pipes a blend of RCA with new aggregate may be used as subgrade when at least 95% of the RCA is retained on the 4.75 mm sieve.
- RCA may be used up to 100% in construction of the filter/separation layer under a permeable aggregate base drainage layer in accordance with the applicable drainage specifications.

Use of RCA with Edge Drains

Mn/DOT Research Record of March 1995 provided recommendations for the "Uses of crushed Concrete Products in Minnesota Pavement Foundations". This publication indicated ways for the mitigation of precipitate and drainage problems. These recommendations are:

- Eliminate the intentional inclusion of RCA fines (#4-minus) in drained, unstabilized pavement foundation layers.
- Design the drainage systems to accommodate the limited quantity of crusher fines, and insoluble residue that are produced by pavement bases, both natural and recycled.
- Blend open-graded RCA products with new aggregates to produce gradations required to improve stability and density and to further reduce precipitate potential in drained pavement foundation layers.
- Use drainpipes that are either unwrapped or wrapped in filter fabrics with high initial permeability. The report also offers a more detailed analysis of drainpipe and pavement drain specifications.
- The use of unstabilized RCA fines (#4- minus materials) should be restricted to areas that are below any drainage layers or structures.
- This report also mentions that "while the effluent from RCA foundation layers is initially extremely alkaline, it has rarely been documented as being sufficiently alkaline to be considered an environmental hazard. With the effluent is usually effectively diluted at a short distance from the drain outlet, it seems likely that environmental concerns are probably restricted to a very small region in the vicinity of the drain outlet."

Minnesota Department of Environmental Quality Establishment of Environmental Policy:

- RCA is being included in a permanent rule relating to Beneficial Use of Solid Waste, where RCA will be considered a standing beneficial use and not subject to review or permitting by Pollution Control Agency.
- Beneficial Use of Solid Waste rule will be instrumental in establishing a database of information on other non-RCA recycled source materials, conditional uses, evaluation process, and stockpiling requirements.
- Lack of data and base line information on effluent leachate and particulate quality was considered a potential barrier in light of new NPDES and TMDL rules in the establishment of this policy.

California

Most of the concrete pavement removed from existing highways and streets in California is processed and reused as aggregate base throughout the State. The California Department of Transportation’s specification for aggregate base allows any mixture of recycled concrete aggregate and recycled asphalt pavement. This provides the Contractor’s with the freedom to choose the base material providing the most economical base available.

The City of San Francisco is developing a specification allowing RCA in all non-structural concrete applications. This permits its use in curbs, gutters and sidewalks. The California Department of Transportation is also working on a similar specification for their use.

Environmental Considerations

Regulatory Policies

Regulatory policies for water quality, air and noise, testing, inspection and general or site-specific operating procedures for use of RCA and virgin aggregate as a construction material are essentially the same for RCA as it would be for virgin aggregate stock piles and operation.

As a waste product, RCA typically is categorized as a construction and demolition debris that is used as a substitute for conventional aggregate. Generally, uncontaminated recognizable as concrete material, is accepted in the RCA production stream. It is typically the responsibility of the producer to ensure that the material has minimum or no risk of hazardous waste when accepted in stockpile and meets the end product meets the appropriate specifications. Any further specific categorization of RCA as a construction material would reduce the stream of employable material and greatly lengthen production time and require additional product evaluation procedures. Some states are encouraging the production of RCA by lowering the regulatory burden:

- Minnesota – state legislation will define RCA as a standing beneficial use and not subject to review or permitting from the Minnesota Pollution Control Agency.
- Virginia - VDOT and Virginia Department of Waste Management developed an executive compliance agreement that defines solid waste practices during construction and repair of highways, RCA is allowed to be buried in state right-of-way.
- California - RCA is exempted from solid waste regulation as long as it remains on the construction site. State legislation requires state agencies to divert at least 25% of the solid waste generated away from the landfill disposal stream. This is making it desirable to recycle materials, especially pavements, into viable products.
- Texas – RCA is not waste as long as the stockpile is being worked on in a yearly basis.

However, concerns over very site-specific and element specific issues cannot be addressed completely through classification. The effect of recycled concrete aggregate on water quality is the primary concern of most environmental agencies. Cement paste causes a rise in pH due to high concentrations of hydroxyl ions (OH-) in solution. Factors contributing to or limiting the negative effects on water quality are related to the reduction of the relative amount of free hydroxyl ions in the surrounding environment. Contributions of soil buffering has not been investigated, but it is likely that buffering capacity of soils would limit the negative effects on water quality by solutions derived from cement pastes via storm-water runoff.

Virginia DOT investigations have observed that a ratio of 60 parts water to 1 part concrete would keep in-stream pH below 9.0 for streams with a baseline pH of 8.0 or less. Minnesota DOT and CalTrans have established some independent testing to determine thresholds for deleterious compounds (asbestos, lead, etc.) in RCA, also.

Cost

Reduction in transportation costs: Substitution of new aggregate with recycled concrete aggregate can provide savings in the final cost of the project. It is a common practice in Minnesota and many other states to crush the material on site. This process eliminates the transportation costs to import virgin aggregates, lessens truck traffic on already congested highways

Reduction in disposal costs: Disposal of concrete, rubble and other waste construction materials by dumping or burial is a less attractive and more expensive option. Reconstruction of urban streets and expressways results in an enormous amount of waste concrete, creating a massive disposal problem. Recycling can therefore alleviate some of these problems by savings in terms of material acquisition and disposal costs. States with active recycling of RCA virtually use all that is being removed. Tipping fees are also aiding in crushing operations having a good supply of material. RCA crushing industry in Michigan Detroit metro area were concerned that recent changes in specifications had impacted the amount of RCA being re-used, and stockpiles yards were near capacity.

Overall project savings: There may be considerable projects savings by using less virgin aggregate and base material. Savings are induced from decreased hauling and disposal costs. An additional benefit is the recovery of the steel from the recycling process. Usually it becomes the property of the contractor, who may sell it as scrap metal. There is also potential for cost savings in many areas where aggregates are not locally available and have to be hauled long distances, often more than 50 miles.

Establishment of Environmental Policy: Some States have established policies that allow the use of recycled materials, when they cost up to 10% more than natural or virgin material. Michigan is one of these States.

Strength

Research has linked the use of recycled fines in a PCC mix to lower compressive strengths. This is documented in the American Concrete Institute's report titled "Removal and Reuse of Concrete" based on information from Detroit in 1992. This is due to natural fine aggregate having a higher strength than recycled fines. The significant portion of the fines in a recycled aggregate is mortar from the original concrete mix. The majority of this strength loss is attributed to the material smaller than 2 millimeters, or 0.08 of an inch.

On the other hand the unbound cementitious material in the RCA may improve the strength when used in base and sub-base construction. Minnesota and California have found that the residual cementitious material in recycled concrete provides bonding of the base material, over and above that provided with the fines in virgin aggregate. This provides a very good construction base for new pavements, as well as handles construction equipment on the aggregate base, giving the contractor help in construction of the highway project.

Production Issues

- The proximity to metro areas of the RCA production plants makes this aggregate economically attractive for commercial uses in roadway bases, building pads, and parking lots.

- Recycled concrete may be crushed and the entire aggregate product can be used as a durable base material, therefore generating no to very little waste.

- Private industry and municipalities consume over 60% of the RCA currently produced in Texas.

- Using RCA in the metropolitan regions is more advantageous than in rural areas, since supply sources of old concrete are readily available and virgin aggregate sources are not as plentiful.

- FHWA is drafting a new Technical Advisory on the use of RCA in Hydraulic-Cement Concrete Pavement, this will provide more guidance on the use of RCA in PCC production.

Management of Fines

Recycled fines, when used, are generally limited to about 30 percent of the fine-aggregate portion of the mixture. *(1)*

- The Research stated above linked the use of RCA fines in the concrete to the lower compressive strengths and workability. At that time it was determined that 20% was the maximum amount of RCA fines that would be allowed in the concrete. *(4)*

- Compaction of RCA in base should be in a saturated state to aid in the migration of fines throughout the mix. Compaction of RCA should be performed with steel wheel rollers, because of minor amounts of steel are present in the base that cause problems when using rubber-tired equipment.

- Washing of RCA is required when used in PCC pavements to eliminate excess fines.

- Quality requirements for new aggregate do not specifically apply to RCA when the pavement comes from a known source.

Environmental Benefits

- Reduced land disposal and dumping: The use of recycled concrete pavements eliminates the development of waste stockpiles of concrete. Also, as recycled material can be used within the same suburban area, this can lead to a decrease in energy consumption and can help improve air quality through reduced mobile source emissions.

- Reconstruction of urban streets and expressways results in an enormous waste concrete, creating a massive disposal problem. Recycling can eliminate many of these issues.

- Currently, the demand for disposal space for concrete debris is high in the Detroit Metro area. The recycling plants are reaching their stock capacity and the disposal costs are increasing. This demand is considerably diminished when RCA has an engineered use in projects around this area.

- In Minnesota, RCA is being included in a permanent rule relating to Beneficial Use of Solid Waste, where RCA will be considered a standing beneficial use and not subject to review or permitting by Pollution Control Agency. Beneficial Use of Solid Waste rule will be instrumental in establishing a database of information on other non-RCA recycled source materials, conditional uses, evaluation process, and stockpiling requirements.

Construction

Several issues appear when using recycled aggregate in lieu of virgin aggregates. The recycled aggregate generally will have a higher absorption and lower specific gravity than the original aggregate within the recycled aggregate. This is due to the inclusion of the mortar made up of the cement, water and air. These characteristics need to be considered in the design of the concrete mixture.

Water Demand

When RCA is used in new concrete achieving and maintaining plastic properties similar to concretes made with virgin aggregate requires special attention. In general, the RCA must be handled as a lightweight aggregate, which has a higher water absorption. It is important to maintain the aggregate in a moist saturated surface dry (SSD) condition to assure the PCC mix water as designed is maintained so as to produce uniform plastic properties at constant water to cementitious ratio. Lightweight aggregate piles should be constantly sprayed with a garden sprinkler to assure saturation (SSD) prior to batching. Development and control of an adequate procedure is simple and assures constant plastic properties of the RCA concrete equivalent to that of concrete made with virgin aggregate. Maintaining a consistent and uniform SSD condition is also a key to achieving a workable mix. Concrete made using RCA should need approximately 5% more water then smiliar PCC with natural course stone, additional water is needed if percent of fines increase, up to about 15% more water. In the event that freeze-thaw durability is a concern, higher amount of fines in the mix should not be used.

Workability

Workability of a properly designed RCA mix is no different than a conventional concrete mix using similarly shaped virgin aggregates. Conventional equipment and procedures commonly used to mix, place and finish conventional concrete work equally well for RCA concrete. Some agencies have initially experienced workability issues, but research has linked the use of RCA fines to this issue. These agencies limit the amount of RCA fines to 20% in the mix. This has been documented in the American Concrete Institute and work from Michigan in the early 1990's.

Air entrainment

Concrete must be evaluated for use as RCA in new concrete as would any new aggregate. One important property of the original concrete feedstock is that it contains ample entrained air for its proposed use. Although possible, it is not economical, to attempt to make quality concrete out of inferior feedstock concrete. The new mix must contain entrained air like any other concrete if it is to be placed in a freeze thaw environment. Conventional criteria for specifying the air void system are appropriate for RCA concrete. Dosages required to achieve a given level of air entrainment tends to be slightly less than required for conventional aggregates due to increased angularity and possibly increased fines in the mixing process. It should be noted if the RCA had poor resistance to freezing, the PCC made from that will also experience poor durability.

Compaction and Drainage Requirements

When RCA is used as base material, special handling procedures are required to assure proper transportation, placement, and compaction are achieved. Environmentally, it is necessary to wet the material so as to prevent fugitive dust particles from becoming airborne just like any other aggregate base material that contains dust. Proctor testing, typically required for conventional base materials, is not required when RCA is specified for a base. Excessive working of the RCA base should be avoided as it will segregate the base materials. Minimum shaping of the RCA base material should occur. Compaction of the RCA base should be in a saturated state to aid in the migration of fines throughout the mix. Moisture levels are maintained and compaction is continued until the maximum level of compaction is achieved for the equipment being used. This procedure has been found to be very effective in obtaining very dense bases. One agency recommended that compaction should be performed with steel wheel rollers, because of minor amounts of steel present in the RCA base that could cause problems when using rubber tired equipment. Quality crushing operations should eliminate this concern.

When a base is adjacent to longitudinal drains and geofabrics are specified, a special placement of the geofabric is required. If the longitudinal drain is enveloped with a geofabric there is a likelihood that dust from the fines and Ca(OH)2 will collect on the surface of the geofabric and cause reduced efficiency of the drain. The proper design is to <u>not</u> envelop the fabric, which is commonly done. Leaving the top open allows entrance of water into the longitudinal drain without the need of water only being able to flow through the fabric. The fabric is placed with a U cross-section covering only the sides of the drainage trench but not it’s top. The fabric is still available to prevent the intrusion of the subgrade fines into the drain but not to filter the water flowing into the drain from the base itself. This design precludes a drainage failure due to surface coating of the geofabric.

Over-stiffness of base leading to reflective cracking

High angularity combined with the unique grading of approximately 50 percent passing the number four sieve results in an almost optimum grading for achieving maximum density of RCA base material. The end result is the development of superior bases of higher then normal stiffness. The down side to greatly increased rigidity for any base material is that it becomes so stiff that it is capable of causing reflection cracking in the new overlying pavement. If this is problematic for a given application it may be necessary to apply an additional layer between the very rigid base and the pavement. This additional layer would be designed to interface stiffness between the base and the pavement thus preventing reflection cracking from occurring. Often this interlayer may be an asphalt lift with high asphalt cement content.

State of the Practice

Production

The production of Recycled Concrete Aggregate (RCA) is similar to the production of virgin aggregates. One of the primary differences occurs in the elimination of contaminants. Light materials such as wood, joint sealants and plastics can be removed with air knives. This device removes the light contaminants with a blast of air. Reinforcing steel and dowel bars are removed with electro-magnets. Many plants are now incorporating two magnets. The first one will be located after the primary crusher, generally a jaw type of crusher. This magnet removes the large pieces of steel, such as dowel baskets. The second magnet is located after the secondary crusher, which is either a cone type crusher or jaw type. This second magnet is used to remove the small pieces of steel that became free during secondary crushing. The steel removed in this manner will also be recycled for scrap metal.

The inclusion of these additional pieces of equipment could increase the cost of crushing concrete when compared to virgin aggregates. However, factoring in the additional cost for virgin aggregate to be blasted or mined from the quarry, excavated by equipment and loaded onto either trucks or into a hopper belt to be hauled or moved to the crushing area, the costs for additional equipment become more comparable. The concrete crushing operation often charges a tipping fee for dumping on site the raw material to be crushed into RCA. This may actually make the cost difference to be a negative, where RCA is cheaper to produce. The business plans of RCA manufacturers were not part of this review, but items gleaned during the review indicate that the crushing operations are in business to make money and the areas with well developed markets are realizing profits. An additional cost savings in transportation cost is often realized since recycled aggregate is being produced in metropolitan areas, whereas quarries are generally found further and further from the core metropolitan area.

Another advancement in the use of Recycled Concrete Aggregate is the advent of the mobile crusher. Crusher units are being moved to stockpile sites in Virginia and Michigan whenever enough material is present to justify the crusher set-up. Mobile in-place crushing equipment is also coming into greater use. Mobile units have been used on the paving grade in Iowa crushing the old pavement in-place into base material. This technology is being applied on the Michigan US-41 project in the Upper Peninsula. This type of crushing operation essentially removes all of the transportation costs replacing it with only the mobilization of the crusher unit. Currently there is an NCHRP-IDEA project, concrete road recycler – hammer-anvil test rig Project 79, targeting development of in-place recycling machine. *(5)*

Recycling is also entering the realm of fresh concrete that is returned to the originating concrete plant, be it for over supply or rejection. Why wait for the concrete to harden before recycling? This question is being answered in California with reclaiming and recycling units. These units are reclaiming aggregates by washing the aggregate and allowing its reuse. This technology is being furthered by the reuse of the washed paste. The paste is being dosed with admixtures to retard the set and activators upon remixing to restart the hydration process. This allows the reuse of the paste into new mixtures removing the cement from the waste stream. This has brought up new questions concerning the value of this reused paste. Current practice is to disregard it as added cement, requiring new cement at the proper content to be added to the mix. This technology has been utilized in the European market and is just starting to see practice here in the United States. This process reduces the use of fresh water by up to 40%. An article in “Concrete Products” pointed out the economical and environmental benefits of using reclamation systems that not only recycle the sand and gravel from returned concrete, but also the cementitious paste and water. The system's operational merits are potentially applicable to all batch plants that need a cost-effective method to recycle returned concrete. *(6)*

"Reclaim systems have been around for about 20 years, but I felt the technology only recently met the needs of smaller batch plant operations," notes Harbor Ready Mix General Manager Bob Mann. The producer previously disposed of returned concrete at a nearby concrete recycling center that converted it into road base aggregate. Disposing of the returned mix, ranging from five yards up to thirty yards a day, presented a significant cost of doing business, Mann affirms. Reducing the ongoing expense was a primary incentive for having a recycling system at his plant. "We expect to save most of the $30,000 to $35,000 a year that we previously paid out to dispose of our returned concrete," Mann says. The new system enables them to recycle virtually all of the returned mix and the grey water accumulated from flushing the mixers and washing of trucks. In addition to reducing disposal costs, the new system will help them comply with California's increasingly stringent environmental regulations.

Aggregate Characterization

Most States in this review required Recycled Concrete Aggregate (RCA) to meet regular aggregate specifications. The Appendix contains specifications from Minnesota and, Texas that exemplify that position. Normally, it will have a lower specific gravity and higher absorption than the virgin aggregate that originally made up the concrete. However, States such as Minnesota and California have found it to be an excellent base material. In fact, it is becoming the base aggregate of choice in these States. This may be due to the cementing capabilities of the residue cement in the recycled aggregate making it a very strong base material.

Minnesota allows the use of Recycled Concrete Aggregate (RCA) into the concrete pavement. The aggregate in the original pavement must come from a known source. This essentially limits the source of concrete to existing State Highways and excludes commercial sources that receive material from a variety of sources. The usage of this specification is low at this time due to the 60-year life cycle requirement for concrete pavement. Its use is also reduced by a new requirement to wash the aggregate to remove dust and clays. The set-up of a washing unit at the project plant site has proved to be a hurdle that Contractors haven't overcome to date.

Michigan has instituted the acceptance of Recycled Concrete Aggregate (RCA) at the manufacture's level through the use of a quality control program. Producers of RCA may request pre-approved status. The State reviews the producer's process control plan and takes process verification samples. If the tests indicate proper control of the product, the plant can be placed on pre-approved status. This allows the producer to supply aggregate to State projects, without getting test samples approved at the start of the Project. This has been limited to RCA being used for base aggregate at this time. Several plants in the Detroit Metro Area have achieved this status. These plants have achieved a consistent gradation and quality of aggregate, even when using material from a variety of commercial sources. This instance is one of the first departures from the known source requirement specifications. It is a technical method that should be considered for adoption by all the states. RCA should be considered as a material source, and the producers need to focus on quality production and controls, same as they would for crushing virgin aggregate. Let the crushing operation produce quality material based on state material requirements and properties, environmental properties of the material should also be well defined for producers to have in hand when obtaining the materials.

One of the keys to producing a uniform Recycled Concrete Aggregate product is inspection of the incoming material. All of the locations visited indicated the criticality of this inspection. Dirty loads with a high quantity of contaminants are either rejected or accepted with a high dumping fee. The producers have used employees to hand pick debris such as plastics, wood and glass from the stockpiles or belts to remove this material. This process is expensive and provides results only as good as the assigned employee. The use of an air knife has helped cull unwanted light weight material from the supply, but overall visual inspection when receiving material is critical.

Specifications Applications

The most common use of Recycled Concrete Aggregate (RCA) encountered was its reuse as an aggregate base. A common theme heard in Texas, Minnesota and California was that RCA performed better than virgin aggregate as an aggregate base. As alluded to earlier, this may be due to the material re-cementing properties. Many of these States indicated that almost all of the concrete removed from State Highway pavements is being reused as aggregate base. Yet, there are states that are not actively using or allowing RCA as aggregate base material.

The specifications in these two States provide clauses to expedite production in the field. Minnesota's specification allows up to 3.0% asphalt cement by aggregate weight to be present in the base aggregate. Using an original asphalt mixture with a 6.0% asphalt cement content, this would allow up to 50% Reclaimed Asphalt Pavement (RAP) to be in the base mixture. This specification allows the removal and crushing of a composite pavement in one phase. The asphalt-milling phase can be eliminated saving valuable construction time. Figure 6.1 illustrates this specification.

Figure 6.1. Aggregate Base. Stockpile on I-94 Project in Minnesota

California takes this specification a step further. Their specifications allow the base aggregate to be a mixture of RCA and RAP at <u>any</u> desired percentage. This provides total flexibility to the Contractor. Whatever the pavement being removed, it can be crushed and reused as base material. It also allows the use of the least expensive materials in the area to be reused as a quality aggregate base.

RCA is being used in many large aggregate applications. Most States allow processed recycled concrete to be used for riprap and erosion control. These uses are limited by the original use of the concrete. Sizing is critical. The thickness of the original pavement will affect the maximum size of the processed aggregate. If aesthetics are an important consideration, large flat pieces will generally not be aesthetically pleasing. A normal rider on these specifications is to require removal of all protruding reinforcing steel.

Virginia has found another use of Recycled Concrete Aggregate (RCA). They have approved the use of recycled concrete for the establishment of oyster beds. The RCA is used to create an artificial reef. The reef is then covered with crushed oyster shells creating an oyster bed. Concrete with a high salt content (chloride)is acceptable as the material is being placed in a saline environment.

Several States allow the use of Recycled Concrete Aggregate (RCA) into hot mix asphalt. This product is being used to a small extent in Western Michigan. This practice does not seem promising due to the high absorption of the RCA. This increases the demand for asphalt cement. This in turn increases the cost of the mixture.

The use of Recycled Concrete Aggregate (RCA) into concrete pavement is allowed in specifications for Michigan, Minnesota and Texas. Texas is the most advanced with this process. They are using RCA as a viable aggregate in the Dallas and Houston Metro Areas. This is due to the dwindling supply of virgin aggregates and the knowledge that their best aggregates have been used in their oldest pavements. The economics of this issue has dictated this response. TXDOT has evaluated the performance of the in place concrete pavements using RCA to be satisfactory. This allows them to design the new pavements with RCA as the intended aggregate. Virgin aggregates were going to have to be transported from further and further away, increasing the aggregate cost. On-site crushing removes this expense allowing for less expensive aggregates while maintaining a quality product.

A moratorium has been in place on the use of RCA in concrete pavement in Michigan since the early 1990's. This moratorium stems from failures of concrete pavements built using RCA, as well as blast furnace slag. Research accomplished by **Mark Snyder, University of Michigan,** places most of the distress issues on some of the design features. The only aspect assigned to the RCA is a minor loss of aggregate interlock. This is most likely due to the smaller aggregate size obtained when producing the recycled aggregate. The requirement for aggregate interlock to provide load transfer has been displaced by the use of dowel bars.

At the time of this review, there were not any States using RCA in structural components. Texas DOT is conducting experiments for this use, but data has not been compiled at this time. One brand new specification was forth comingfrom the city of San Francisco, California. Their specifications would allow the use of RCA in all non-structural flatwork. This includes sidewalks, curbs and other features other than pavements. The State of California (CalTrans) was following their lead with a similar State specification in the development stage.

Commercial use of RCA remains strong. Numerous building and parking lot pads are constructed using RCA as the base material. One of the world largest recycled concrete projects is the Denver Stapleton Airport demolition and redevelopment. The concrete runways and aprons were crushed into aggregate for the construction needs of redevelopment and building on the seven square mile former airport site.

Recommendations and Conclusions

Recommendations – RCA, a Valuable Material with Many Uses

The use of RCA as an aggregate base for commercial projects is widespread throughout the United States. However, about one fourth of the States still do not use this material. The engineering, economic and environmental benefits of using this material make this an item to be seriously considered. Specifications such as the ones developed by Minnesota and California can be used as an example. Another item to consider in base aggregate specifications is the inclusion of construction and demolition debris such as bricks. These materials may be used in aggregate base without detrimental impacts to the base. But we recognized that this is an area where more research is desirable to validate what we saw happening during our review.

It is desirable to get standard rulings on the consideration of RCA in the environment. Minnesota is including RCA in a permanent rule relating to Beneficial Use of Solid Waste. This makes RCA a material with a standing beneficial use and not subject to review or permitting by State Department of Environmental Quality. Beneficial Use of Solid Waste rule will be instrumental in establishing a database of information and permitting needs on other non-RCA recycled source materials, conditional uses, evaluation process, and stockpiling requirements. A process similar to this would be helpful in other States and may reduce the material being buried or placed in landfills.

Additional research is a continuing need. There are questions in the aspects of engineering . Are virgin aggregate specifications and test procedures applicable to RCA? Do some of them eliminate the use of RCA without addressing the performance of the material? Of course, performance based specifications would be beneficial for both RCA and virgin aggregates.

Environmental questions also persist. Leaching questions when RCA is used in a drainage layer, or near a water source needs to be answered. Most of the current research indicates that only a small area near the drainage outlet is affected, and only for a short period of time after the initial construction. These question, and other environmental issues, needs to be fully answered and accepted eliminating the need to retest and reevaluate every time RCA is used.

Conclusions – RCA, an Aggregate of Choice

Many States are currently using recycled concrete aggregate as aggregate base. Figure 2.2, contained earlier in this document, shows usage by thirty-eight States. This material is becoming the aggregate base of choice in States such as Minnesota and California. This may be due to the high strengths provided by RCA base material due to some bonding of the residue cementitious material in the processed aggregate. Their specifications, which appear in the appendix, are making this usage less restrictive by allowing the inclusion of asphalt material. Minnesota allows 3% asphalt cement by dry weight of the aggregate. This allows the inclusion of about 50% recycled asphalt pavement. California takes this a step further by allowing a mixture of any percentage of recycled concrete aggregate and recycled asphalt pavement. This allows the Contractor to use the most economical material in any percentage combination. The specifications in both States allow the Contractor to remove a composite pavement, process it and use it without separate operations. These specifications are providing a base aggregate with superior qualities while providing economic and environmental benefits.

Texas is a leader in the use of recycled concrete aggregate (RCA) as an aggregate in the concrete pavement. The Texas Department of Transportation (TxDOT) has been using recycled concrete aggregate in Portland cement concrete highways for the past ten years. TxDOT has learned that using RCA provides engineering, economic and environmental benefits. This use eliminates the need for the solid waste to go to the landfill. Instead, the existing concrete is processed into RCA and used within the same urban area. In Houston, for example, the total amount of concrete rubble generated is reused as RCA. This saves time and money when compared with delivery of aggregates from distant quarries. Figures 7.1 and 7.2 show the coarse and fine recycled concrete aggregate used as components in concrete pavement. Texas is an illustration of how recycled concrete aggregate can be reused as an aggregate in a quality concrete pavement surface.

Figure 7.1 Coarse Recycled Aggregate RCA)

Figure 7.2 Fine Recycled Concrete Aggregate (RCA)

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APPENDIX 1. Additional Research and Specifications

Research

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Appendix 2. Field Visit Pictures

Figure 1. Virgin Aggregate Resource. Luck Stone Aggregate Plant. Fairfax, VA.

Figure 2. Natural Stone Resource. Luck Stone Aggregate Plant. Fairfax, VA

Figure 3. Stockpile of Concrete Debris. . Luck Stone Aggregate Plant. Fairfax, VA

Figure 4. Recycled Concrete Aggregate (RCA). Luck Stone Aggregate Plant. Fairfax, VA

Figure 5. Stockpile of RCA. Luck Stone Aggregate Plant. Fairfax, VA

Figure 6. Truck preparing to unload concrete debris Iafrate Crushing Plant Visit. Taylor, MI.

Figure 7. Truck unloading concrete debris. Iafrate Crushing Plant Visit. Taylor, MI

Figure 8. Primary Crusher. . Iafrate Crushing Plant Visit. Taylor, MI

Figure 9. Loading Hopper, Primary Crusher. . Iafrate Crushing Plant Visit. Taylor, MI

Figure 10. Vibrating-feeder transporting RCA from Primary Crusher to sorting screen. Iafrate Crushing Plant Visit. Taylor, MI

Figure 11. Vibrator feeder, sorting Screen, and Secondary Crusher. Iafrate Crushing Plant Visit. Taylor, MI

Figure 12. Steel rebars stockpile. Iafrate Crushing Plant Visit. Taylor, MI

Figure 13. Recycled Concrete Aggregate (RCA) Stockpile. Iafrate Crushing Plant Visit. Taylor, MI.

Figure 14. Recycled Concrete Aggregate. Iafrate Crushing Plant Visit. Taylor, MI.

Figure 15. FHWA Team. Iafrate Crushing Plant Visit. Taylor, MI.

Figure 16 I-694 Reconstruction Project Visit. Brooklyn Center, MN.

Figure 17. FHWA team. I-694 Reconstruction Project Visit. Brooklyn Center, MN.

Figure 18**.** Recycled concrete aggregate (RCA) stockpiles on site. I-694 Reconstruction Project Visit. Brooklyn Center, MN

Figure 19. Recycled concrete aggregate. I-694 Reconstruction Project Visit. Brooklyn Center, MN

Figure 20. RCA placed as base material. I-694 Reconstruction Project Visit. Brooklyn Center, MN.

Figure 21. Truck Dumping Plastic Portland Cement Concrete (PPCC) to the Reclaim System. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA

Figure 22. PPCC Receptacle. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA

Figure 23. Ready Mix Truck leaving the Reclaim Area. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA

Figure 24. Reclaim System. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA

Figure 25. Reclaim System Output Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA

Figure 26. Reclaimed PPCC Coarse Aggregate. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA

Figure 27. Reclaimed PPCC Fine Aggregate. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA

Figure 28. Washout Water Drain System. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA.

Figure 29. Washout Water Drain System. Red-I-Mix Concrete Inc. Facility Visit. Irwindale, CA.