Use of Recycled Concrete Materials in Base/Subbase Applications

Mark B. Snyder, Ph.D., P.E.
Pavement Engineering and Research Consultants (PERC), LLC
Engineering Consultant to CP Tech Center
What is Concrete Recycling?

• Breaking, removing and crushing hardened concrete from an acceptable source.
• Old concrete pavements often are excellent sources of material for producing RCA.
• *Concrete pavements are 100% recyclable!*
Uses of Recycled Concrete Aggregate

- PCC pavement
  - Single and Two-Lift
- HMA pavement
- Subbase
  - Unbound
  - Stabilized
- Fill material
- Filter material
- Drainage layer
Use of RCA in U.S.

- Used as Aggregate (Base), 65.5%
- Used in Asphalt Concrete, 9.7%
- Use in New Concrete Mixtures, 6.5%
- Used as Fill, 7.6%
- Use as High-Value Rip Rap, 3.2%
- Others, 7.6%

Van Dam et al, 2016, after Wilburn and Goonan 1998 and USGS 2000
Some agencies believe RCA outperforms natural aggregate in base applications (FHWA 2004)
Cement-stabilized and Lean Concrete Subbases

- Stabilization helps to prevent migration of crusher fines, dissolution and transport of significant amounts of calcium hydroxide.
- Physical and mechanical properties of the RCA must be considered in the design and production of cement-stabilized subbases.
Basic Concrete Recycling Options

• Commercial recycling yard
  – Concerns with unknown source materials and contaminants

• Mobilization of a crusher to a project
  – Haul materials to a crusher site
  – On-grade processing
On-Site Crusher

• Crushing, screening and stockpiling at a central location
  – Interchange ramps within the R.O.W. or similar areas are ideal
• Broken concrete is hauled to the crusher site
• RCA is hauled back to the grade
Typical On-Site RCA Production Site

Source: Gary Fick, Trinity Construction Management
On-Grade Crusher

- Mobile crusher processes the broken concrete on the grade
- No haul-off or haul back of RCA

Source: Gary Fick, Trinity Construction Management
Production of RCA

• Crushing plant recycling - Typical steps:
  – Evaluation of source concrete.
  – Pavement preparation.
  – Pavement breaking and removal.
  – Removal of embedded steel.
  – Crushing and sizing.
  – Beneficiation.
  – Stockpiling.

• In-place concrete recycling

• Recycling of returned ready-mixed concrete.
Pavement Breaking

• Main purpose: size material for ease of handling, transport – typically 18 – 24 inches, max dimension

• Also aids in debonding concrete and any reinforcing steel.

• “Guillotine” is most common breaking method.

• Avoid rubblizing for recycling

• Production: 1,000+ yd²/hr
Pavement Breaking and Removal
Removal of Embedded Steel

• Typically during break-and-remove
• Can also follow crushing operations
  – Electromagnets
  – Manual removal
• Recycle separately
Crushing Equipment

• Jaw crusher can be used as a primary crusher
  – Allows feeding of larger sized pieces of broken concrete (24”)
  – Helps to separate steel from the broken concrete
Crushing Equipment

• Impact crushe is the most common for RCA applications
• Most steel (dowels, crcp and mesh) should be removed prior to crushing
• Smaller feed size (approx. 12” minus)
RCA Processing: Crushing and Screening (Sizing)

- A screen is almost always used to properly size the material
  - Allows for increased production by returning oversized material to the crusher
  - Can be used to split material on a mid-sized sieve (e.g. 3/8") when specifications require
RCA Processing:
Crushing and Screening (Sizing)
• Three main crusher types: jaw, cone, and impact.
  – Tell contractor desired gradation/result
  – Contractor to select crushing process for desired gradation and material properties.
## Effects of Crushing Technique and Natural Aggregate Type on RCA Reclamation Efficiency

<table>
<thead>
<tr>
<th>Process</th>
<th>Reclamation Efficiency</th>
<th>RCA Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Limestone</td>
</tr>
<tr>
<td>Jaw-Jaw-Roller</td>
<td>71</td>
<td>73</td>
</tr>
<tr>
<td>Jaw-Cone</td>
<td>73</td>
<td>80</td>
</tr>
<tr>
<td>Impact-Impact</td>
<td><strong>44</strong></td>
<td>63</td>
</tr>
</tbody>
</table>
On-Grade (Mobile) Recycling

- Same equipment – just moving!
- No hauling required
  - Significant cost savings
  - Reduced exposure to traffic
- Typically used for producing dense-graded or semi-drainable base
- Stockpile on the existing shoulder if subgrade manipulation is required
# Properties of RCA

<table>
<thead>
<tr>
<th>Property</th>
<th>Virgin Agg.</th>
<th>RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape and Texture</td>
<td>Well–rounded; smooth to angular/rough</td>
<td>Angular with rough surface</td>
</tr>
<tr>
<td>Absorption Capacity</td>
<td>0.8% – 3.7%</td>
<td>3.7% – 8.7%</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.4 – 2.9</td>
<td>2.1 – 2.4</td>
</tr>
<tr>
<td>L.A Abrasion</td>
<td>15% – 30%</td>
<td>20% – 45%</td>
</tr>
<tr>
<td>Sodium Sulfate</td>
<td>7% – 21%</td>
<td>18% – 59%</td>
</tr>
<tr>
<td>Magnesium Sulfate</td>
<td>4% – 7%</td>
<td>1% – 9%</td>
</tr>
<tr>
<td>Chloride Content</td>
<td>0 – 2 lb/yd³</td>
<td>1 – 12 lb/yd³</td>
</tr>
</tbody>
</table>
Effect of Particle Size on RCA Properties (after Fergus, 1980)

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Percent retained</th>
<th>Bulk specific gravity</th>
<th>Percent Absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 in. (25 mm)</td>
<td>2</td>
<td>2.52</td>
<td>2.54</td>
</tr>
<tr>
<td>¾ in. (19 mm)</td>
<td>22</td>
<td>2.36</td>
<td>3.98</td>
</tr>
<tr>
<td>½ in. (12.5 mm)</td>
<td>33</td>
<td>2.34</td>
<td>4.50</td>
</tr>
<tr>
<td>¾ in. (9.5 mm)</td>
<td>18</td>
<td>2.29</td>
<td>5.34</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>25</td>
<td>2.23</td>
<td>6.50</td>
</tr>
<tr>
<td>Weighted average</td>
<td>100</td>
<td>2.31</td>
<td>5.00</td>
</tr>
</tbody>
</table>
RCA Design/Construction Considerations - 1

• Construction processes for RCA
  – Shaping and compacting of unbound base is the same as for virgin material
  – However, absorption is higher so even more water will be necessary to attain optimum
RCA Design/Construction Considerations - 2

• Fines in RCA
  – Approx. 1% to 2% passing the #200 from crushing clean concrete pavement
  – Additional fines come mainly from excavating underlying soils when loading the broken concrete
  – Gradation specifications should consider:
    • Underlying material – subgrade vs. treated base
    • Modify specification as needed (reduce the low end of % passing the #200)
RCA Design/Construction Considerations: Constraints

• RCA use and applications are impacted by:
  – Volume of RCA available from the project
  – Timing of that availability (phasing)
  – Material specifications
    • Drainable base specifications have fewer fines than a granular base
    • Coarse aggregate for concrete has fewer fines than drainable bases
Specified gradation impacts usable amount of RCA that is produced

<table>
<thead>
<tr>
<th>Sieve</th>
<th>RCA Granular Base Percent Passing</th>
<th>Drainable Base Percent Passing</th>
<th>Concrete Stone Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½&quot;</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1&quot;</td>
<td>95-100</td>
<td>95-100</td>
<td>95-100</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>65-85</td>
<td>75-85</td>
<td></td>
</tr>
<tr>
<td>½&quot;</td>
<td></td>
<td>55-65</td>
<td>25-60</td>
</tr>
<tr>
<td>⅜&quot;</td>
<td>40-60</td>
<td>40-50</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>25-45</td>
<td>15-25</td>
<td>0-10</td>
</tr>
<tr>
<td>#8</td>
<td></td>
<td>0-5</td>
<td>0-5</td>
</tr>
<tr>
<td>#10</td>
<td>15-30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#40</td>
<td>5-15</td>
<td>0-5</td>
<td></td>
</tr>
<tr>
<td>#200</td>
<td>0-10</td>
<td>0-3</td>
<td>0-2</td>
</tr>
</tbody>
</table>
RCA Design/Construction Considerations

- RCA as granular base
  - 93,866 CY available
  - 93,866 CY used
RCA Design/Construction Considerations

• RCA as cement treated drainable base
  – 93,866 CY available
  – 79,786 CY used
  – 14,080 CY screened and stockpiled

• Where can this material be incorporated in the project?
Base Design and Construction Considerations - 1

• Use same design tools as for conventional unbound aggregate base, should get similar layer thickness.
  – Typical minimum thickness = 4 inches (constructability, stability)
  – Typical maximum thickness = 6 inches for PCC pavement
    • Greater thickness for frost protection, if necessary
  – Blend with virgin aggregate if designed base requirements exceed volume of recoverable RCA base.

• Minimize waste and hauling by using RCA base across full pavement section (including shoulders) when excess material is produced (e.g., 12-inch PCCP is recycled to produce material for 4-inch base layer).
• Avoid excessive handling and movement of the RCA
  – Produces additional fines, which can change stability and drainage characteristics, increase potential for precipitate
• Place at moisture content near optimum to ensure efficient compaction efforts (higher than for natural aggregate)
• Control compaction density using standard Proctor test (AASHTO T99 or ASTM D698)
  – Require minimum in-place density > 95%
  – May need to relax density requirements for “free-draining” material (k = 150 – 350 ft/day) or crushing may result
  – Alternate density control through procedural standard of compaction (i.e., require X compaction passes based on agency experience) – see Appendix X1 of AASHTO M 319
Design of Pavements over RCA Base - 1

• Stiffening of unstabilized RCA base materials is possible
  – Secondary hydration of cementitious materials (especially for dense-graded RCA)
  – Can cause unstabilized bases to behave more like stabilized bases
    • Excellent strength and erosion resistance
    • Higher curling and warping stresses?
    • Higher levels of slab restraint?
Design of Pavements over RCA Base - 2

• AASHTO PavementME, can directly consider effects of base stiffening on pavement design and predicted performance with appropriate design inputs.

• Agencies have not modified pavement designs for base stiffening.
• No evidence of poor performance associated with base stiffening.

• Therefore, there appears to be no significant design implications for using RCA in unbound base layers for concrete pavements.
Performance of RCA in Unbound Foundation Layers

• RCA has been widely and successfully used in unbound subbase and fill applications.

• Literature: contains no reports of highway pavement performance problems related to structural deficiencies when properly designed and constructed.

• Some agencies believe RCA outperforms natural aggregate in these applications.
  – Angular, rough-textured particles
  – Secondary cementing

  *BUT* ....
Structural Considerations for RCA in Unbound Foundation Layers

• Anecdotal reports of possible frost and/or moisture heave in some dense-graded RCA base materials in MN and MI.
  – Most problematic with high fines contents
  – Problem disappears with less dense gradations ($k>300$ ft/day)

• Sulfate attack of RCA in high-sulfate soil at Holloman AFB, NM
Recommendations for Use in Subbases: Preventing Drainage Structure Clogging

- All RCA is capable of producing precipitate and insoluble residue (“crusher dust”)
  - Potential increases with surface area (smaller particles)
- Usually no problem below drains or in undrained layers
- In drained layers, you could get infill of drain pipes and/or clogging of rodent screens.
Effects of Ca\((CO_3)_2\) and Crusher Dust on Drainage Systems

Photo credits: Iowa DOT and PennDOT
Preventing Drainage Structure Clogging

- Minimize use of RCA fines.
- Crush to eliminate reclaimed mortar
- Blend RCA and virgin materials
- Use largest practical RCA particle sizes.

- Consider washing RCA to reduce insoluble residue (crusher dust) deposits.
- Use high-permittivity fabric
- Wrap trench, not pipe
- Consider daylighted subbase
Case Studies/Examples
Eden’s Expressway – I-94 Northwest Chicago, IL (1978)
Many “firsts” ...

• First major urban freeway in U.S. to be completely reconstructed.
• Largest U.S. highway project (at the time) to use concrete recycling.
• Largest single highway contract ever awarded in U.S. (at that time): $113.5 million (1978 dollars).
• First major U.S. project to recycle mesh-reinforced concrete pavement.
Recycling Details

• Recycling chosen over 3-hour round-trip haul for virgin aggregate.
  – 200,000 gals of fuel saved in hauling virgin aggregate and demolished concrete

• Crushing plant set up in interchange cloverleaf.
  – No crushing from midnight – 6 a.m.
  – Driver’s not allowed to bang tailgates to discharge.
Construction and Performance

• 350,000 tons of old pavement recycled
  – 85% to fill areas
  – 15% to 3-in unbound subbase
• Capped with asphalt-treated base and 10-in CRCP
• Provided excellent service for nearly 40 years under very heavy traffic.
Use of RCA Fines as “Stabilizing Aggregate” Layer (MN, 1981)
Use of RCA in Stabilized Base: ATL Int’l Airport

- RCA is allowed at contractor’s option for fill and base material
- Map shows locations using cement-treated RCA subbase

Source: Saeed and Hammons, 2006
Cost Savings From Using Recycled Concrete Aggregate in Tollway Reconstruction

Steve Gillen, Deputy Program Manager of Materials
August 30, 2016
International Conference on Concrete Pavements
On-Site Processing for Porous Granular Embankment (PGE) Subbase - Stationary

- Processors are typically kept at stationary locations on-site to produce larger piles of PGE at multiple locations along the reconstructed corridor.

- Tollway PGE max. particle size is 5”

Source: Steve Gillen, Illinois Tollway
On-Site Processing for Washed Porous Granular Subbase - Stationary

- RCA has been processed on-site as a washed 1.5 inch aggregate to use as a drainable base as thin as 6 inches under new concrete pavements.

- To protect the subgrade soils from rain water stability issues, chemical stabilization of subgrade is critical before placement.
Rubblization

- Approximately 30 median miles of interstate highway concrete pavement has been rubblished on the Tollway and compacted as a base under new perpetual asphalt pavements
- 27.9 miles on one project alone (I-88)
Cost Savings to Recycle PCC Pavement as Base Aggregates vs Using Virgin Stone Since 2008

- Material cost savings of on-site RCA processing rather than virgin stone purchase = $6 per ton (2016 dollar)
  - Total 3,712,300 tons of PCC pavement material has been recycled as base stone
  - 3,712,300 tons x $6 / ton (2016 dollar) = $22,273,800 savings

- Elimination of disposal costs of excavated PCC = $3 per ton savings
  - 3,712,300 tons of PCC x $3 / ton (2016 dollar) = $11,136,900 savings

- Elimination of haul costs of virgin aggregate from pit to site = $7.50 per ton
  - 3,712,300 tons x $7.50 / ton (2016 dollar) = $27,842,250 savings
Total Capital Program Cost Savings by Using RCA based on the 2016 Dollar Value

- Rubblization Savings = $24,431,608

- Total RCA Savings
  - Material savings = $22,273,800
  - Disposal savings = $11,136,900
  - Haul cost savings = $27,842,250
    Total $61,252,950

- Total savings from recycling PCC pavements with reconstructed roadways since 2005 = $85,684,558

Presented by Steve Gillen on August 30, 2016
Concrete Recycling Resources

• ACPA EB043P
  – Details on RCA Production, Properties and Use
  – Various Guidelines and Guide Specs

• CPTech Center Deployment Plan
  – Outlines barriers to implementation and recommends approaches to overcoming them.

• FHWA Technical Advisory TT 5040.37: Use of Recycled Concrete Pavement as Aggregate in Hydraulic-Cement Concrete Pavement

• New CPTech Center Guide Document due in early 2018!
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Questions?