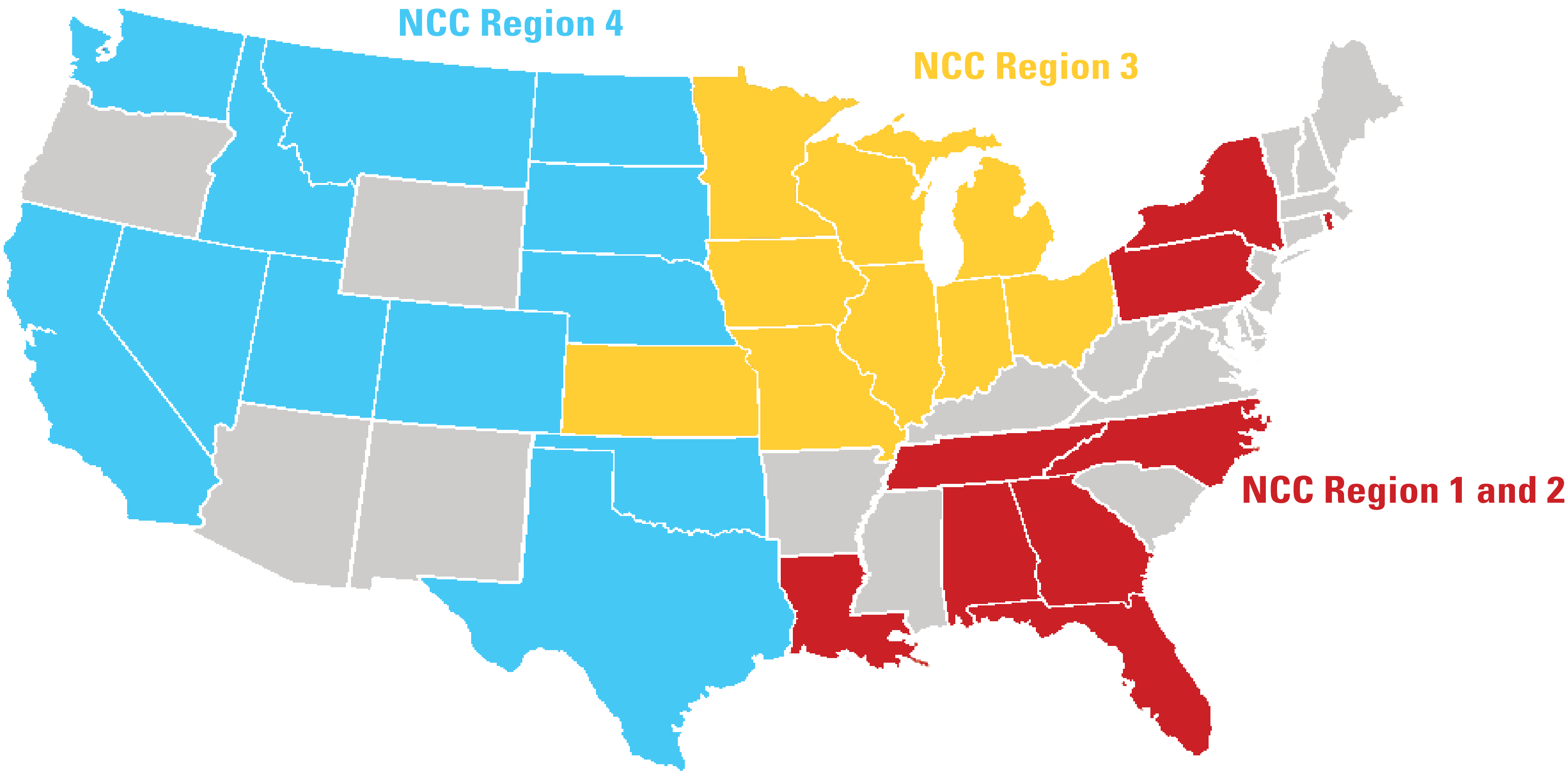
Welcome to Region 3 Webinar on Concrete Pavement Recycling
Speakers: Mark Snyder & Tara Cavalline

Subject	Regions 1 & 2 Webinar	Region 3 Webinar	Region 4 Webinar
Concrete Pavement Recycling	April 20, 2016	May 4, 2016	May 18, 2016



Webinar Procedure

- If you have questions for the presenters please type in the questions where indicated on your screen. Please refer to the slide number.
- At the end of the presentation the CP Tech Center will remove the mute for the participants to allow for open discussion.
- For questions regarding the webinar operations please contact Denise Wagner for assistance.

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- Thanks to FHWA for supporting the development of this material.

Introduction to Recycling Webinar Learning Objectives

- To understand that recycled concrete aggregate (RCA) is an engineered material
- To understand the breadth of applications it can be used in and performance expectations
- To understand how RCA is produced
- To understand mixture design basics
- To understand the quality control aspects needed for using RCA
- To be able to identify the potential benefits of using RCA

Concrete Pavement Recycling

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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!***

Reasons for Concrete Recycling

- Dwindling landfill space/increasing disposal costs
  - 50000 U.S. landfills accepting PCC in 1980
  - 5000 U.S. landfills accepting PCC in 2000
- Rapidly increasing demand for aggregates with limited resources
- Sustainability
  - Conservation of materials
  - Potential reduced environmental impact due to reduced construction traffic, reduced landfill
  - Cost savings
- Potential for improved pavement performance
- A proven technology – it works!

EC2

Sustainability

- Landfill reduction
- Energy savings
- Conservation of resources

- Reduction of greenhouse gases (GHGs).

Slide 7

EC2 Consider adding a slice on the Minnesota example with the key outcomes
Ells Cackler, 3/16/2016

Example Cost Savings: TH 59 near Worthington, MN

- 16-mile two-lane D-cracked PCCP recycled in 1980
  - Coarse RCA for new 8-inch PCCP
  - Fine RCA for 1-in lift on subbase
- Estimated 27% total project cost savings and 150,000 gallons of fuel (MnDOT estimates)

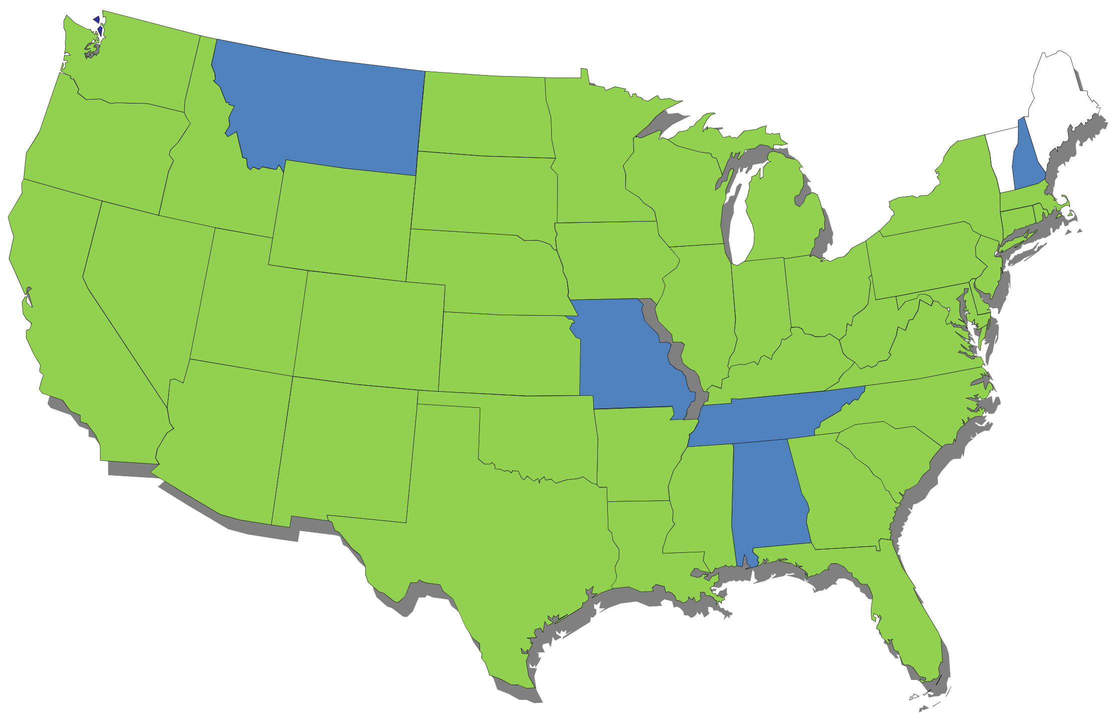
2006 Photo (after 2000 DBR and Grind)

Potential Pavement Performance Improvements

- Foundation stability; angular, rough texture and secondary cementing action.
- Concrete strength; partial substitution of RCA for virgin fine aggregate may increase concrete compressive strength.

Concrete Recycling: A Proven Technology!

41 of 50 states allow use of RCA in various applications (FHWA, 2004)



Uses of Recycled Concrete Aggregate

- PCC pavement
  - Single and Two-Lift
- HMA pavement
- Subbase
  - Unbound
  - Stabilized
- Fill material
- Filter material
- Drainage layer

Unstabilized Subbases/Backfill

- Most common application for RCA in U.S.
- Application used by 38 of 41 states using RCA in U.S. (FHWA 2004)
  - Some believe it outperforms virgin aggregate as an unstabilized subbase!
- Some level of contaminants is tolerable.

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.

EC3

Concrete Mixtures

- RCA can be (and has been) incorporated as the primary or sole aggregate source in new concrete pavements.
- Used in the U.S. concrete mixtures since the 1940s
  - Roadway surfaces, shoulders, median barriers, sidewalks, curbs and gutters, building/bridge foundations and even structural concrete.
- Common in the lower lift of two-lift concrete pavements in Europe.

Slide 14

EC3 Mark, fyi the 2-lift in Kansas used normal project materials in the bottom layer. Their main goal was to examine the constructability using normal paving equipment instead of the paver that is common in Europe that places both lifts through one machine. The project was a success. As part of the trail, they construction a number of sectiions to evaluate different materials and surface texture options.

Ells Cackler, 3/16/2016

RCA in Two-Lift Construction

- Iowa US 75 Reconstruction (1976)
  - 60-40 RCA and RAP in 7-in lower lift; 23 ft wide
  - All virgin in 4-in top lift; 24 ft wide
  - Provided more than 40 years of service!

- Austrian Standard Practice since late 1980s
  - A-1 (Vienna-Salzburg): 19-cm (7.5-in) lower lift (RCA and RAP), 3-cm (1.5-in) upper lift (exposed virgin aggregate), fines to stabilize foundation (100 percent PCC recycled)
  - Overall project savings >10 percent
  - More than 75km (47 miles) between 1991 and 1994; two-lift construction using recycled materials is now standard

Concrete Mixtures (cont.)

- Batching, mixing, delivery, placement and finishing techniques can be similar to those used for virgin aggregate concrete mixtures.
- Concerns with water demand and premature stiffening:
  - Limiting or eliminate fine RCA
  - Presoak RCA
  - Chemical and mineral admixtures.
- Contaminants can lead to air entrainment problems.
- *Fresh and hardened properties of RCA PCC might be different from virgin aggregate PCC.*

Other Applications

- RCA is an economical and highly stable material that is well-suited for granular fill applications.
- Most states allow the use of RCA for erosion control ("rip-rap") or slope stabilization.
- Soil stabilization, pipe bedding, landscape materials, railroad ballast, agricultural soil treatment, treatment of acidic lake waters, masonry blocks, artificial reefs, etc.

Performance of Pavements Constructed using RCA in PCC

There have been a few notable (and well-publicized) failures ....

- Deterioration of mid-panel cracks in JRCP
- Design issues (undoweled joints, panel length, foundation type, etc.)

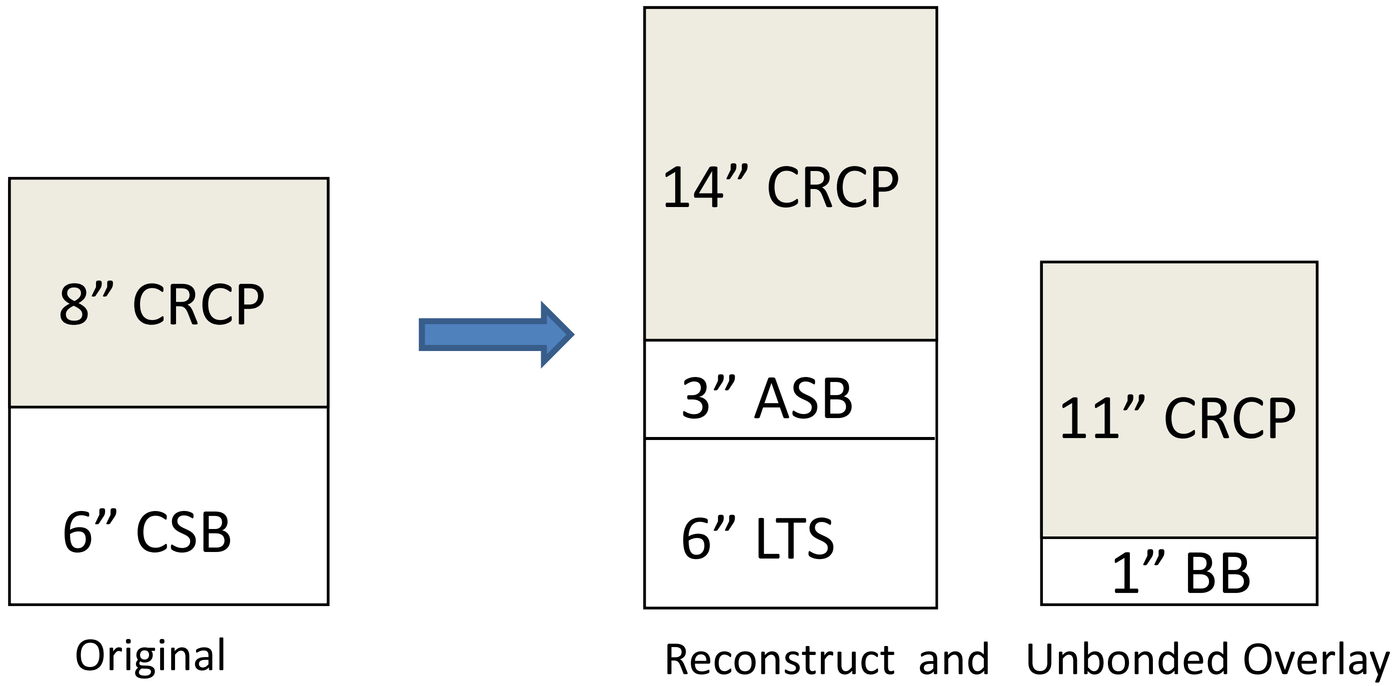
.... *but performance has generally been very good!*

No structural problems have been reported with the use of RCA in foundation layers.

Texas Interstate 10

- 1995 Rehab Project in Houston, Texas
- I-10 between I-45 & Loop 610 West
- Project Length: 6 miles
- Existing CRCP: 1968 construction
- 10 Lanes + HOV

No Virgin Aggregates Used for New Concrete: *100% RCA (Coarse & Fine)*



2007 Photo of Texas I-10 (after 12 years of service)

Property	I-10 RCA concrete
28-Day compressive strength	4,615 psi (31.8 MPa)
28-Day elastic modulus	2.58 x 10^6 psi (17.8 MPa)
Coefficient of thermal expansion and contraction (CTE)	4.7 to 5.3 με/°F (8.5 to 9.5 με/°C)
Permeability (ASTM C1202/AASHTO T277)	466 coulombs (very low permeability)

US 59 (Worthington, MN):

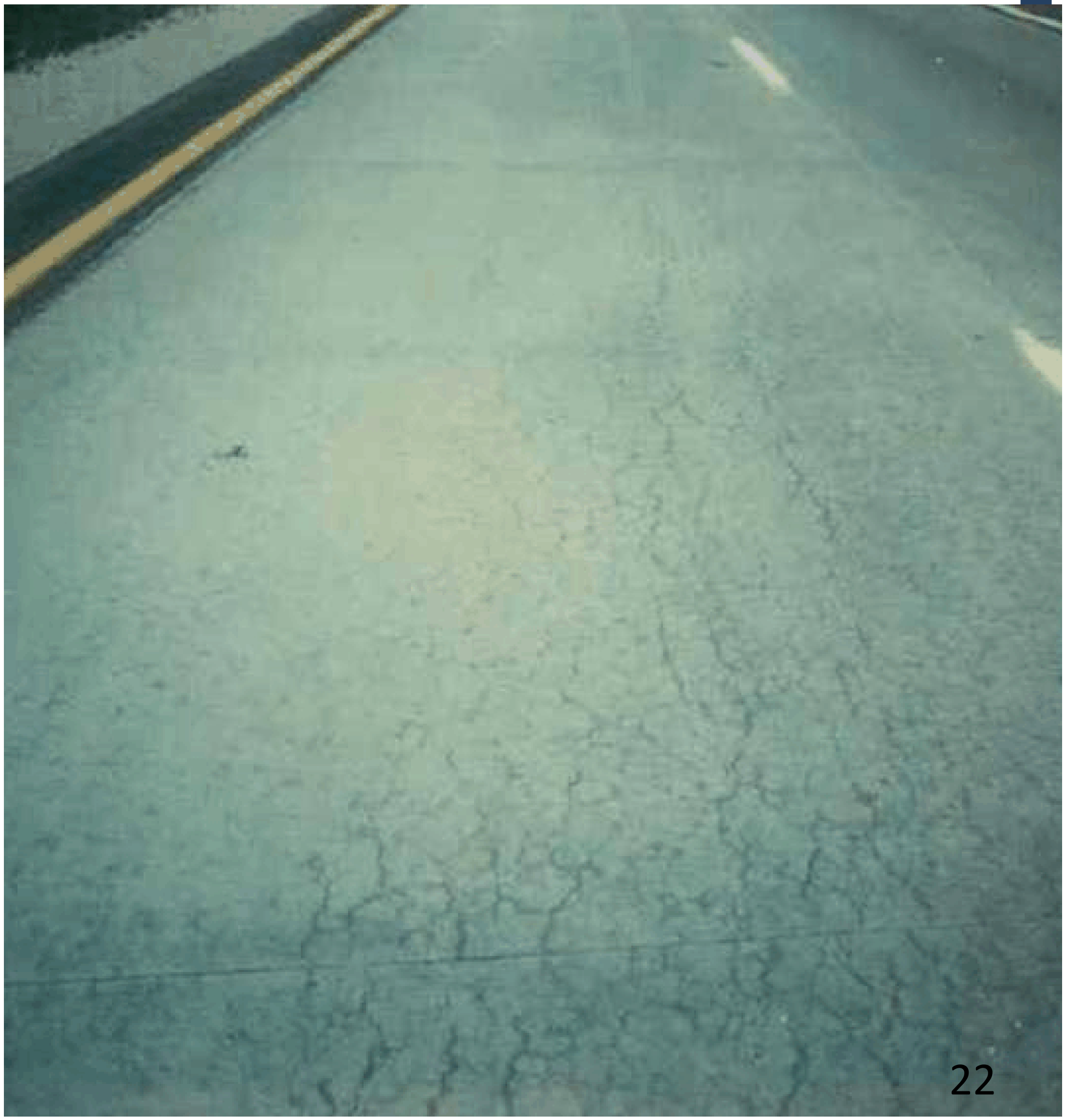
- 1st major recycling of “D-cracked” concrete into new concrete
- Reconstructed in 1980 (original 1955 construction)
    - 8-in slab, skewed joints (13, 17, 14, 19 ft panels)
    - 100% coarse RCA (3/4-in top size), edge drains
    - No dowels
    - 3000+ vpd, ~8 percent heavy commercial

- Rehabilitated in 2000
    - Slab repairs, dowel bar retrofit, joint reseal
    - Diamond grinding

- PSR = 4.3 in 2006 (3.0 in 1994)
- Faulting = 0.01 inches in 2006 (0.25 inches in 1994)
- **No recurring D-cracking**

Interstate 80 (Pine Bluffs, Wyoming):

- Extensive alkali-aggregate (ASR) damage
- Much pre-design testing



Interstate 80 (Pine Bluffs, Wyoming):

- 1985: Original 8-in pavement recycled into new 10-in pavement surface
  - 65 percent coarse RCA, 22% fine RCA
  - Low-alkali (<0.5%) cement, 30% Class F flyash, w/c = 0.44
  - Skewed joints (14, 16, 13, 12 ft panels)
  - No dowels
  - 4400 ADT in 1985 (30 - 40% heavy)
- Rehabilitated in 2004
  - Dowel bar retrofit, diamond grinding, joint reseal
- 2006 ADT: 8000 vpd (30-40% heavy)

- **<u>No significant evidence of recurring ASR until recently.</u>**

Performance Case Study: U.S. 52 – Zumbrota, MN (27-ft JRCP) after 22 years of service

Test and Value	MN 4-1 (Recycled)	MN 4-2 (Control)
Transverse Joint Spalling, % Joints	81	100
Avg. Faulting between Panels, in	0.04	0.04
Avg. Joint Width, in	0.47	0.43
Longitudinal Cracking, ft/mile	90	0
Transverse Cracking, % Slabs	92	24
Deteriorated Transverse Cracks/mile	201	42
Total Transverse Cracks/mile	211	47
PSR	3.0	3.8
IRI (in/mile)	102	60
Tensile Strength, psi	350	360
Compressive Strength, psi	6500	7400
Young's Modulus, psi	4.4E6	6.3E6
Average VSTR (cm^3/cm^2)	0.2902	0.3264

MN US 52 Observations:

- Foundation Stiffness (backcalculated) 30% lower for RCA section
- Aggregate Top Size
  - 1.0-in RCA
  - 1.5-in Control
- Mortar Content
  - 74% RCA (shrinkage cracks observed early)
  - 52% Control
- Similar Thermal Coefficients in 1994
  - 12.4/C^o RCA
  - 11.9/C^o Control

EC5

Effect of Reclaimed Mortar Content

(after FHWA, 1997)

Project	CT	KS	MN1	WY	MN4
Δ Mortar (%)	6.5	7	11	19	22
Panel Length (ft)	40	15	27	14	27
Δ Fault (in)a	0	0.04	0	0	0.01
Δ % Cracked Panels	-31	0	1	0	66
Δ Deteriorated Cracks/Mile	-6	0	3	0	80
Δ PSR	-0.1	0	-0.1	0	-0.2

Higher reclaimed mortar content resulted in more panel cracking and crack deterioration for long (>25 ft) panels (but had no apparent effect on short [<16 ft] panels).

Slide 26

EC5 This slide and the next 2 are kinda busy, I find myself needing to study. There may not be time. Consider some key findings added to the data or something.

Ells Cackler, 3/16/2016

Effects of RCA, Panel Length on Cracking (Section, L/ℓ, % Cracked Panels)

(from FHWA, 1997)

- Granular Base Sections
  - CT1-1, 16.6, 66%
  - CT1-2, 15.2, 93%
  - MN1-1, 7.3, 1%
  - MN1-2, 7.3, 0%
  - MN2-1, 8.2, 84%
  - MN4-1, 7.8, 88%
  - MN4-2, 8.2, 22%
  - WI1-1, 4.4, 8%
  - WI1-2, 4.6, 2%
  - WY1-1, 4.3, 0%
  - WY1-2, 4.3, 0%
- Stabilized Base Sections
  - KS1-1, 5.5, 0%
  - KS1-2, 5.5, 0%
  - MN3-1, 5.0, 2%

Long panels (L/ℓ > 6) with RCA generally experienced more cracking than when natural aggregate was used.

There was no apparent effect on shorter panels.

No Direct Influence of RCA on Development of Joint Faulting

- **Doweled Sections**
  - **CT1-1, 0.01 in**
  - **CT1-2, 0.01 in**
  - **MN1-1, 0.02 in**
  - **MN1-2, 0.02 in**
  - **MN2-1, 0.03 in**
  - **MN4-1, 0.04 in**
  - **MN4-2, 0.03 i**
  - **WI1-2, 0.02 in**
- **Undoweled Sections**
  - **KS1-1, 0.09 in**
  - **KS1-2, 0.13 in**
  - **MN3-1, 0.24 in**
  - **WI1-1, 0.11 in**

2006 Study Conclusions

- Recycled ASR concrete used successfully in Wyoming with mitigation measures
  - Isolated recurrent ASR
  - RCA performed better than control

- Recycled D-cracked concrete used successfully with mitigation measures
  - Reduced aggregate size
  - Reduced moisture exposure?

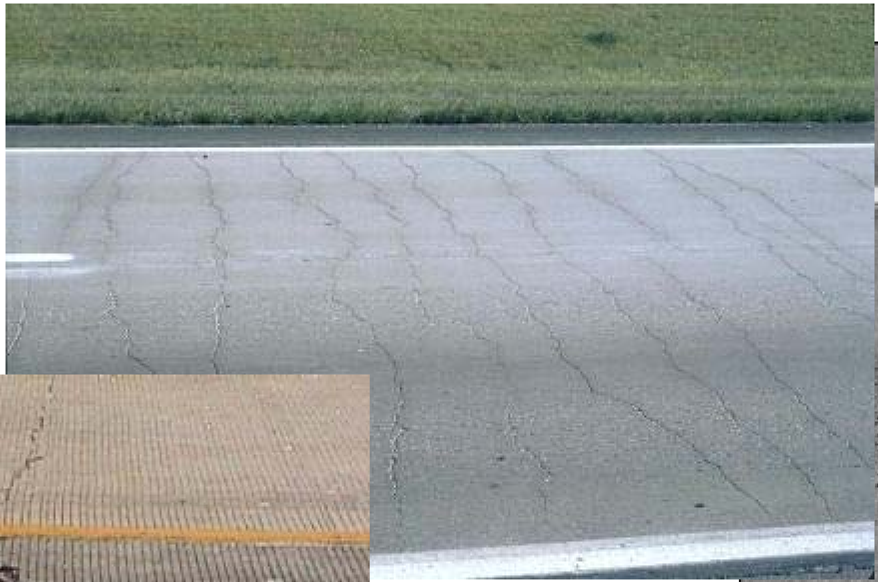
2006 Study Conclusions

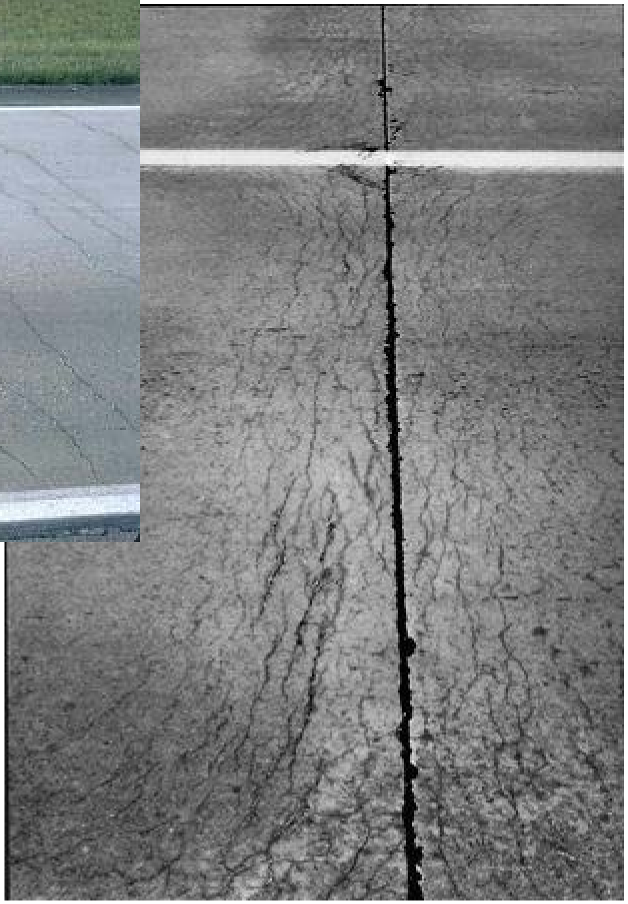
- Need to treat RCA as “engineered material” and modify mix and structural designs accordingly
  - Reduce w/c
  - ASR mitigation
  - Reduced panel lengths
  - Other modifications as needed.
- Mortar contents are generally higher for RCA
  - Varied with aggregate type, crushing process
  - Higher mortar contents often had more distress – may need to control reclaimed mortar content

Production of RCA

- 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.

Evaluation of Source Concrete





Known sources vs. unknown sources?

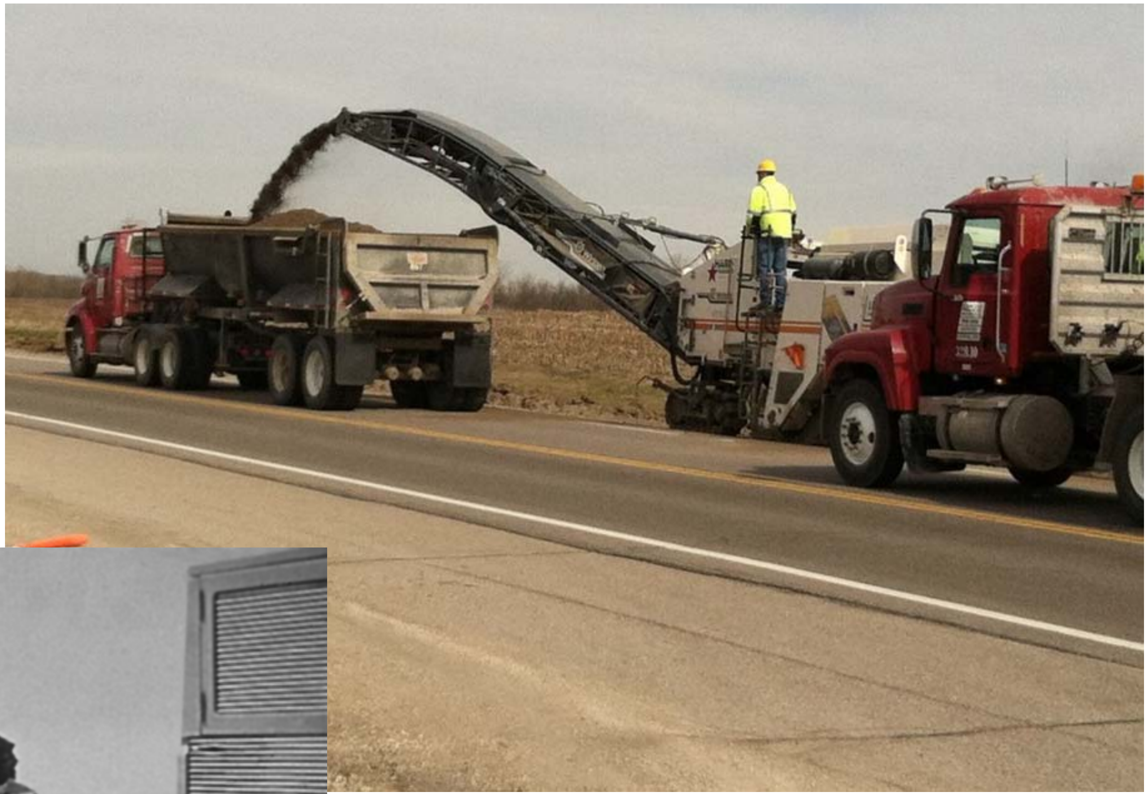
Potential Contaminants

- Reinforcing steel
- Dowel bars and baskets
- Chemical admixtures
- Deicing salts
- Oil
- Joint sealant
- Material from overlying and underlying layers

Pavement Preparation

- How will RCA be used? RCA for concrete mixtures might require more pavement preparation than for other uses.
- Removal of joint sealant:
  - Cutting tooth sealant plow
  - Other removal during production
- Asphalt patches/overlays/shoulders may or may not need to be removed;
  - Some European countries allow up to 30% RAP in new concrete paving mixtures (two-lift construction).
  - Remove deteriorated asphalt shoulders prior to breaking concrete on reconstruction projects.

Pavement Preparation



Pavement Breaking and Removal

- Main purpose is to size the material for ease of handling and transport to the crushing plant.
  - Broken into pieces about 18 to 24 in. max.
- Also should impart enough energy to maximize debonding of concrete to any reinforcing steel.
- The "impact breaker" is the most common breaking method.

Pavement Breaking and Removal

EC6

Pavement Breaking and Removal

- The first step in the removal process is to loosen the concrete pieces and separate any debonded reinforcing steel.
- Where steel mesh reinforcing or rebar are present and have not been broken or separated from the concrete, a "rhino horn" is used.

EC6 Notes: back hoe with rhino horn, wheel loader, or bulldozer....
Ells Cackler, 3/16/2016

Pavement Breaking and Removal

- Use of front-end loaders and dump trucks for removal and transport to off-site processing (left)

or

- On-site processing using back hoe and mobile crushing equipment (below).

EC7

Removal of Embedded Steel

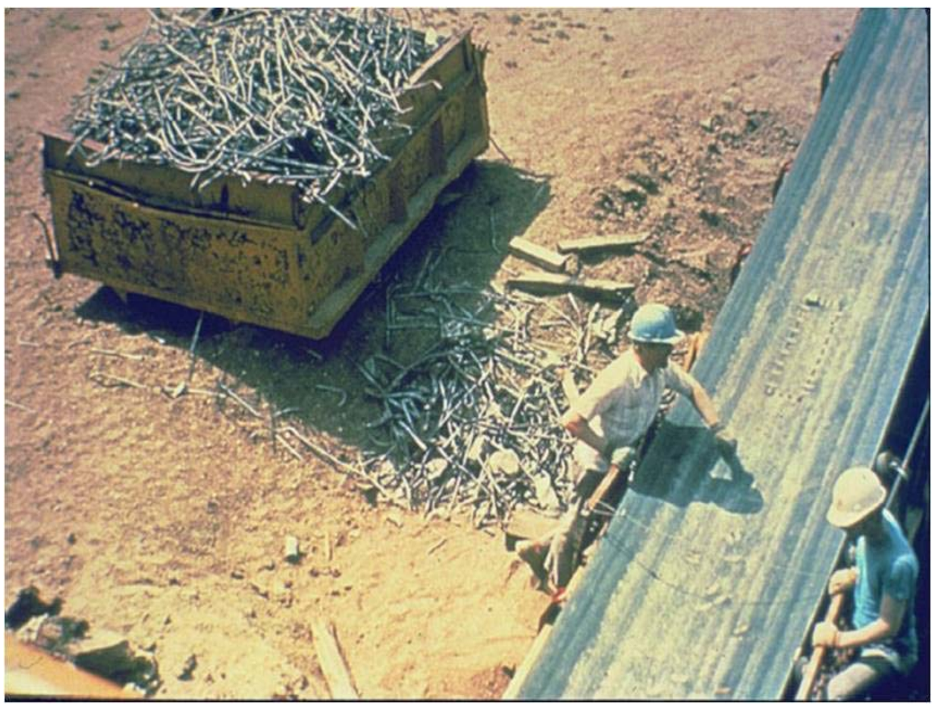
- Typically accomplished during breaking and removal

Slide 40

EC7 Note goes with following slide.
Ells Cackler, 3/16/2016

Removal of Embedded Steel

- Can also follow crushing operations
  - Electromagnets
  - Manual removal

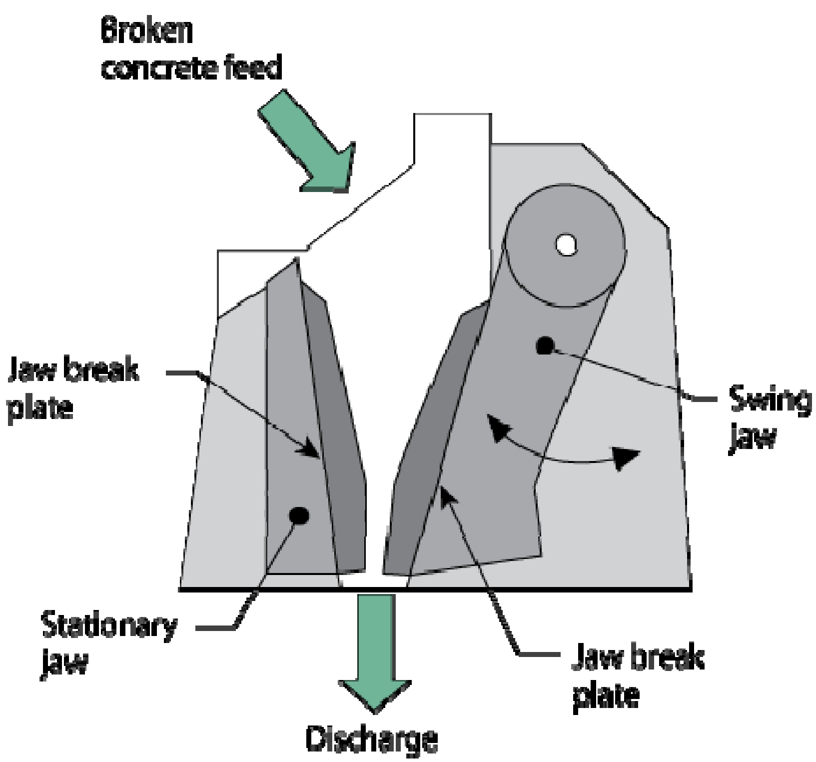


Crushing and Sizing

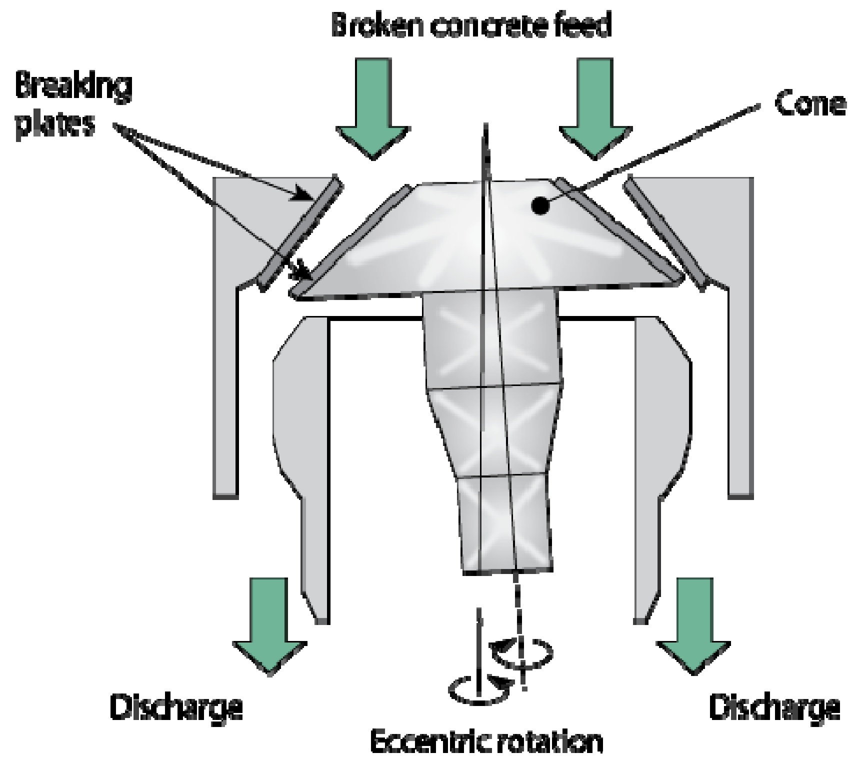
- The same basic equipment used to processes virgin aggregates also can be used to crush, size and stockpile the RCA.
- Yield depends on many factors but loss of material can be as high as 10% and may approach 0%.
- Primary crusher reduces to 3” to 4”; material then screened and anything larger than 3/8” fed to secondary crusher, which breaks to the desired RCA top size.
- Three main types of crusher: jaw, cone, and impact.
  - Tell contractor what gradation/result is desired
  - Contractor should select crushing process based on desired gradation and material properties.

Crushing and Sizing

Jaw Crusher

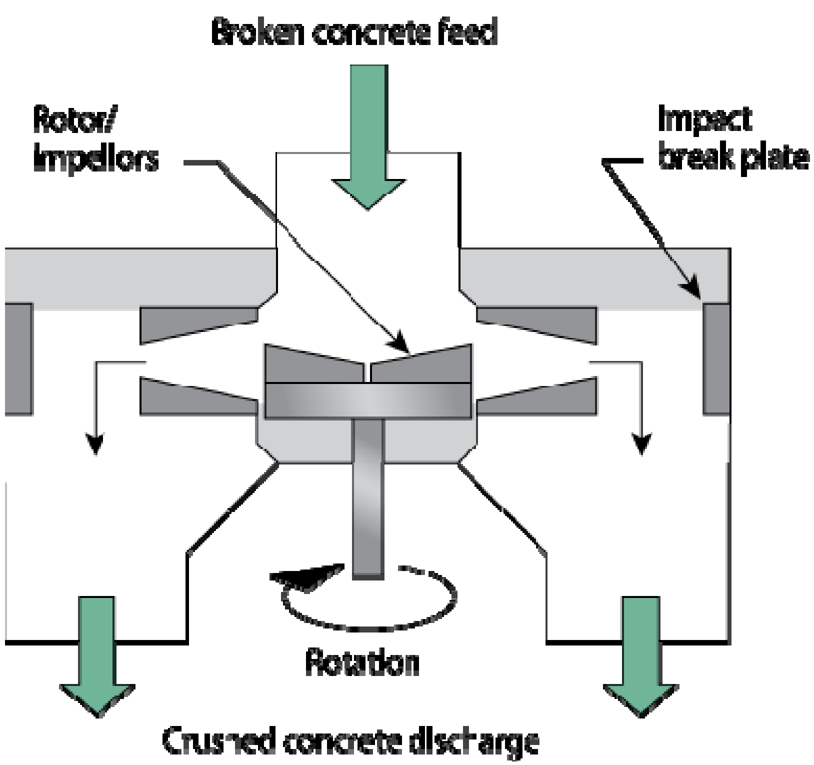


Cone Crusher

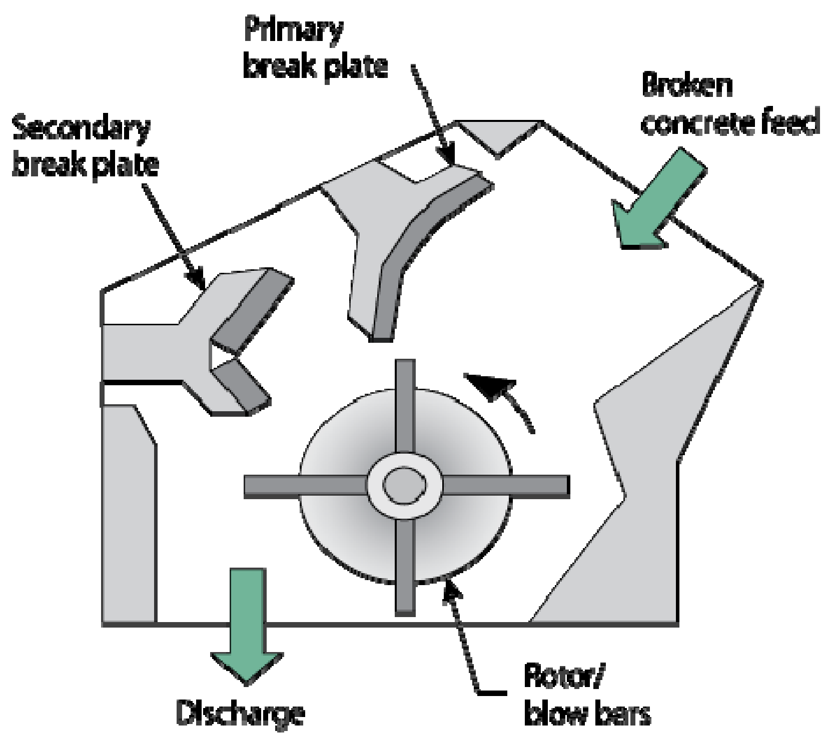


Crushing and Sizing

Vertical Shaft Impact Crusher

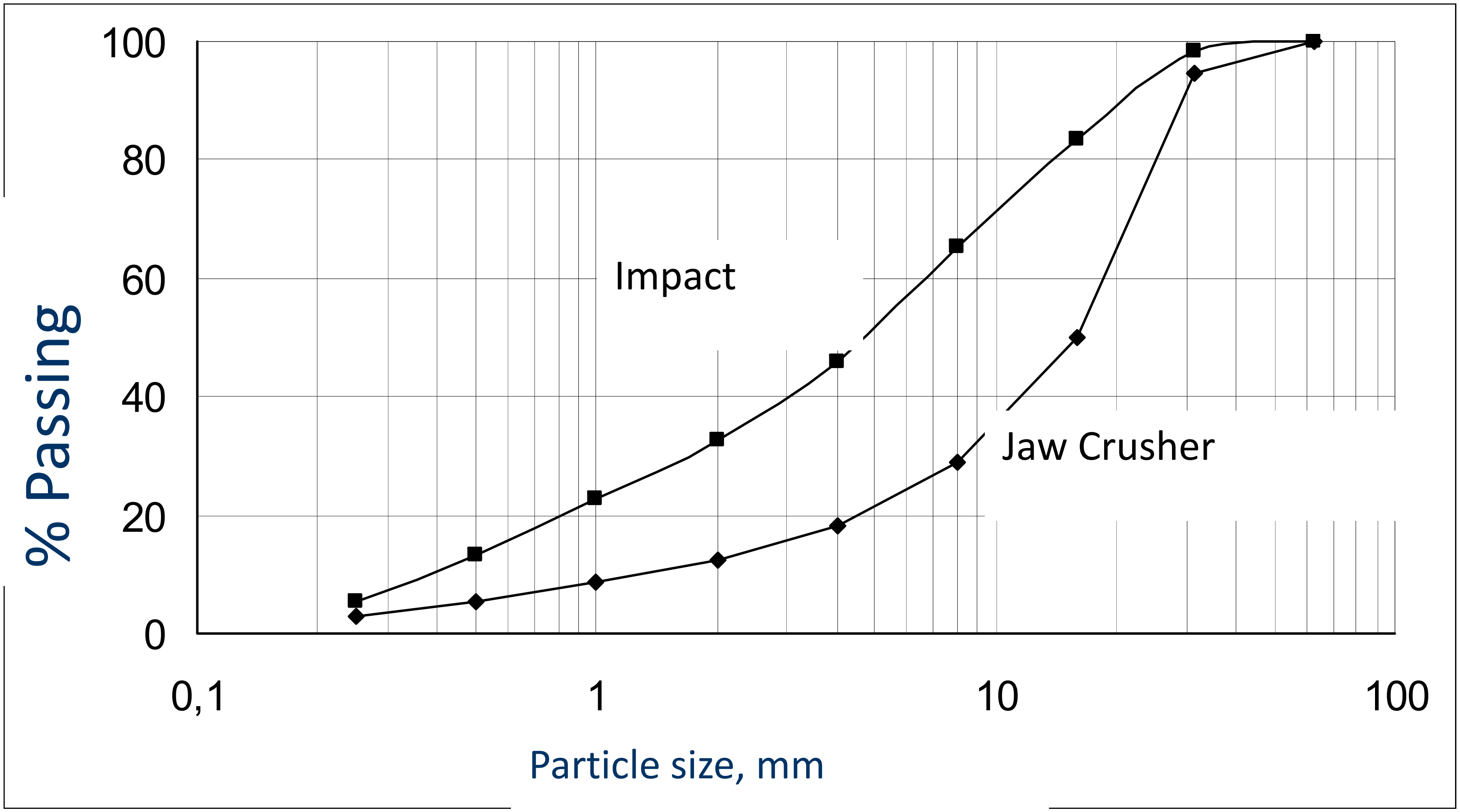


Horizontal Shaft Impact Crusher



EC8
mbs1

Effect of Crushing Process on RCA Particle Size Distribution



Slide 45

EC8 Correct note??
Ells Cackler, 3/16/2016

mbs1 Yes -- I already modifed the slide from German to English
markbsnyder, 4/4/2016

Effects of Crushing Technique and Natural Aggregate Type on RCA Reclamation Efficiency

Process	Reclamation Efficiency		
	RCA Type		
	Limestone	Gravel	Granite
Jaw-Jaw-Roller	71	73	**87**
Jaw-Cone	73	80	76
Impact-Impact	**44**	63	53

Effect of Crushing Technique on Reclaimed Mortar

Process	Average Reclaimed Mortar (%)		
	RCA Type		
	Limestone	Gravel	Granite
Jaw-Jaw-Roller	55	54	52
Jaw-Cone	**56**	51	48
Impact-Impact	51	43	**39**

Environmental Challenges from Crushing Concrete

- Silica dust (concrete)
- Asbestos (demolition debris – not paving PCC)

Dust suppression system at concrete crushing operation.

Beneficiation

- “The treatment of any raw material to improve its physical or chemical properties prior to further processing or use.”
  - Example: might need to remove accidentally included material (e.g., organic material, excessive dust, or other contaminants) from the RCA prior to use.
- Example beneficiation techniques:
  - Change crushing processes
  - Washing, wet or dry screening, etc.
  - Air blowing
  - Water floating or “heavy media separation” techniques.
- Degree of beneficiation required depends upon condition/composition of RCA and its intended use.

Stockpiling

- Coarse RCA can be stockpiled using the same techniques and equipment as are used with virgin coarse aggregate materials.

EC9

Stockpiling (cont.)

- Protect fine RCA stockpiles from moisture
  - Secondary cementing.
- RCA stockpile runoff is initially highly alkaline
  - Leaching of calcium hydroxide
  - Runoff alkalinity rapidly decreases

Slide 51

EC9 Not sure how stockpiles are protected from rain? Are you seeing this done? I can see controling the runoff if needed.
Ells Cackler, 3/16/2016

In-Place Concrete Recycling

- When RCA is to be used in a subbase layer of the roadway and/or shoulders, production can be accomplished using an in-place concrete recycling train.

Recycling Ready-Mixed Concrete

- Approximately 5% of the 445 million cubic yards of ready mixed concrete produced in the U.S. each year is returned to the concrete plant.
- Recycling this material, as with recycling any existing concrete material, presents sustainable benefits, including reduction of landfill use and virgin aggregate use.

Properties of RCA

Property	Virgin Agg.	RCA
Shape and Texture	Well–rounded; smooth to angular/rough	Angular with rough surface
Absorption Capacity	0.8% – 3.7%	3.7% – 8.7%
Specific Gravity	2.4 – 2.9	2.1 – 2.4
L.A Abrasion	15% – 30%	20% – 45%
Sodium Sulfate	7% – 21%	18% – 59%
Magnesium Sulfate	4% – 7%	1% – 9%
Chloride Content	0 – 2 lb/yd^3	1 – 12 lb/yd^3

FC10
mbs2

Effect of Particle Size on RCA Properties (after Fergus, 1980)

Sieve size	Percent retained	Bulk specific gravity	Percent Absorption
1.0 in. (25 mm)	2	2.52	2.54
¾ in. (19 mm)	22	2.36	3.98
½ in. (12.5 mm)	33	2.34	4.50
⅜ in. (9.5 mm)	18	2.29	5.34
No. 4 (4.75 mm)	25	2.23	6.50
Weighted average	100	2.31	5.00

Slide 55

EC10 Not sure what this slide is adding?

Ells Cackler, 3/16/2016

mbs2 Intended to show impact of particle size on mortar content ... smaller particles (fine aggregate) tend to be higher mortar content, so absorption goes up and specific gravity goes down. Explains need to treat coarse and fine RCA a bit differently, especially in PCC mixtures.

markbsnyder, 4/4/2016

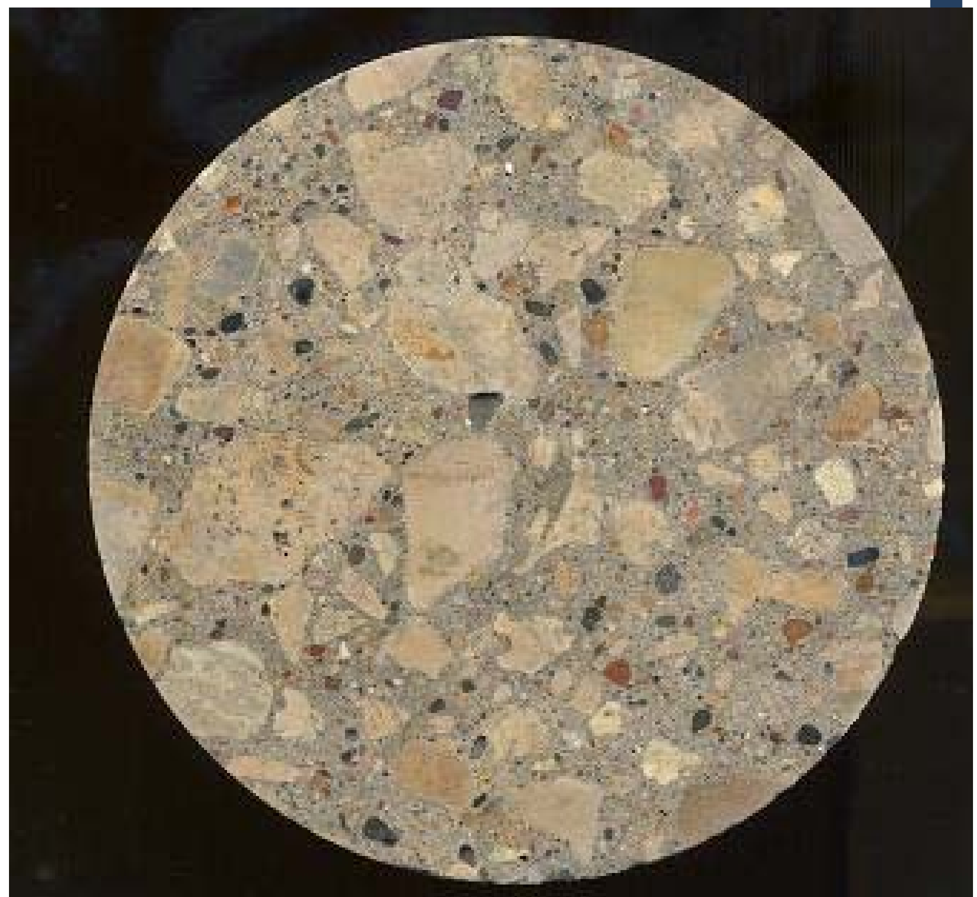
Recycling Concrete Pavements

PROPERTIES OF CONCRETE WITH RCA

EC11

Properties of Concrete with RCA
(Hint: it's all about the mortar …)

MN 4-1 (Recycled)



MN 4-2 (Control)

EC11 Might add a note for future presentators
Ells Cackler, 3/16/2016

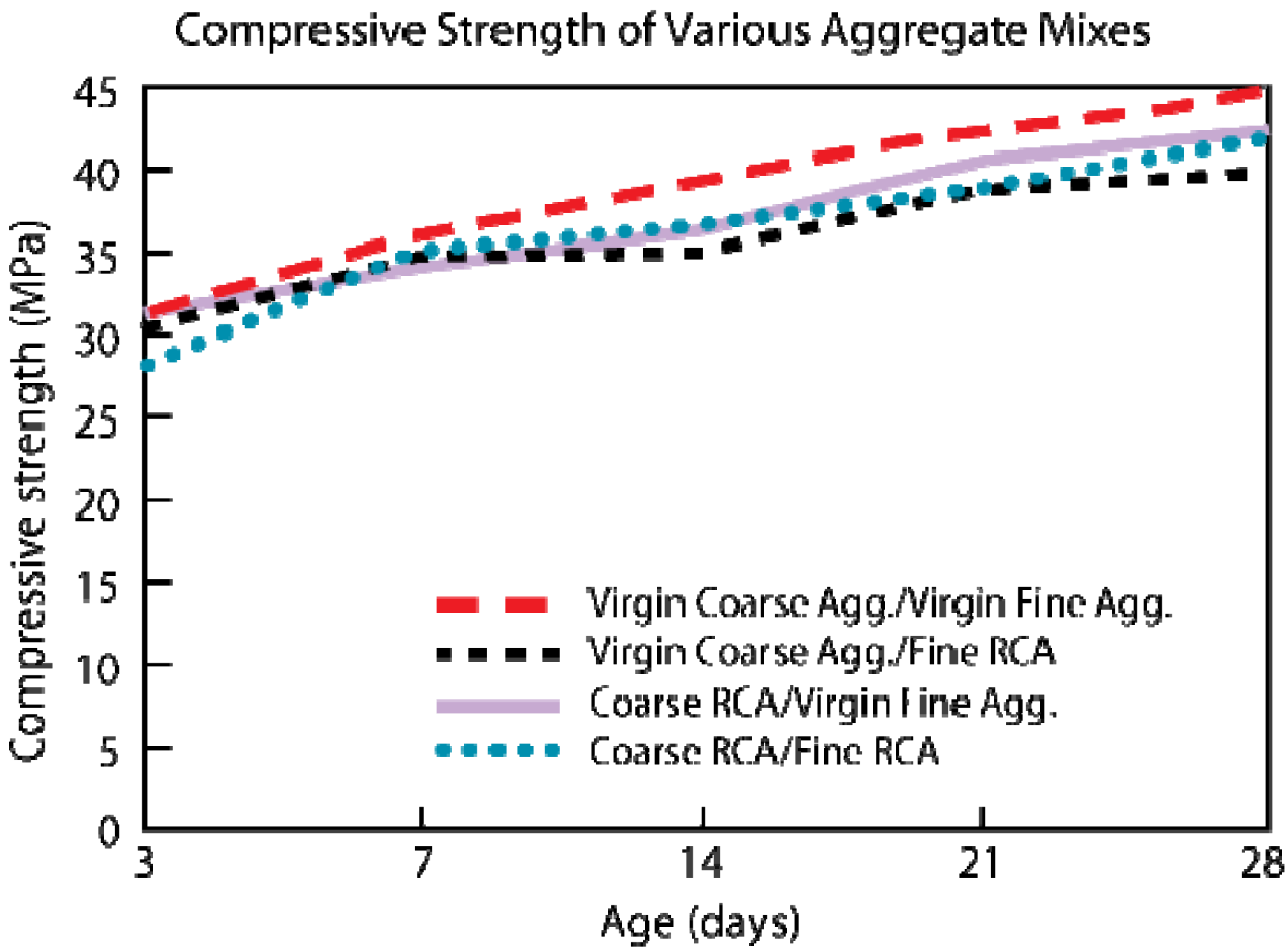
Fresh (Plastic) Properties

Property	Coarse RCA	Coarse and Fine RCA
Workability	Similar to slightly lower	Slightly to significantly lower
Finishability	Similar to more difficult	More difficult
Water bleeding	Slightly less	Less
Water demand	Greater	Much greater
Air content	Slightly higher	Slightly higher

Hardened Properties

Property	Coarse RCA	Coarse and Fine RCA
Compressive strength	0% to 24% less	15% to 40% less
Tensile strength	0% to 10% less	10% to 20% less
Strength variation	Slightly greater	Slightly greater
Modulus of elasticity	10% to 33% less	25% to 40% less
CTE	0% to 30% greater	0% to 30% greater
Drying shrinkage	20% to 50% greater	70% to 100% greater
Creep	30% to 60% greater	30% to 60% greater
Permeability	0% to 500% greater	0% to 500% greater
Specific gravity	0% to 10% lower	5% to 15% lower

Hardened Properties



Effects of RCA and Mix Design on Strength and Thermal Properties

(after FHWA, 1997)

Project	CT		KS		MN1		WY		MN4	
Section	**RCA**	**Natural**	**RCA**	**Natural**	**RCA**	**Natural**	**RCA**	**Natural**	**RCA**	**Natural**
w/cm	0.40	0.45	0.41	0.41	0.47	N/A	**0.38**	**0.44**	**0.44**	**0.47**
% Fine RCA:	0	0	**25**	**0**	0	0	**22**	**0**	0	0
f'c (psi)	**5690**	**5130**	7210	6340	6860	6740	**7060**	**6480**	**6210**	**6900**
E (10^6 psi)	4.60	4.76	5.12	5.20	5.25	5.95	5.01	5.32	5.13	6.06
α (10^{-6}/°F)	6.4	5.9	**5.8**	**5.2**	6.2	6.3	**7.4**	**6.0**	6.4	6.2

Reducing w/cm and/or adding some RCA fines often resulted in RCA concrete mixtures with improved properties!

Durability and other Properties

Property	Coarse RCA	Coarse and Fine RCA
Freeze-thaw durability	Depends on air voids	Depends on air voids
Sulfate resistance	Depends on mixture	Depends on mixture
ASR	Less susceptible	Less susceptible
Carbonization	Up to 65% greater	Up to 65% greater
Corrosion rate	May be faster	May be faster

SUSTAINABILITY CONSIDERATIONS IN CONCRETE RECYCLING

Sustainability Benefits

Concrete recycling addresses sustainability "Triple Bottom Line":

- Environmental benefits
  - Conservation of aggregates
  - Reduction of landfill use
  - Reduction of greenhouse gases, sequestration of carbon
- Economic benefits
  - Metals recovery
  - Fuel savings due to reduced haul distances
  - Reduced disposal costs
  - Extension of landfill life
  - Potential tax credits, other incentives
- Societal benefits
  - Reduced land use and reduced impact to landscape

Quantifying Sustainability Benefits

- Environmental and societal benefits of concrete recycling are well documented.
- Economic benefits are not as readily evident, or can be at equivalent cost.
  - Decisions made based on initial cost can eliminate options that include recycling.
  - Quantification of sustainability benefits (particularly environmental and societal) benefits support choice of recycling.

Projects should be approached in a manner that gives the contractor options so recycling opportunities can be incorporated into the bidding process.

Quantifying Sustainability Benefits

Measurement tools can be used to quantify sustainability benefits, weigh alternatives and facilitate decision-making.

- Economic Analysis
  - Life Cycle Cost Analysis, LCCA
- Environmental Assessment
  - Life Cycle Assessment, LCA
- Rating Systems
  - INVEST
  - Greenroads
  - Envision
  - Others

Incorporate recycling activities into these tools to quantify sustainability benefits

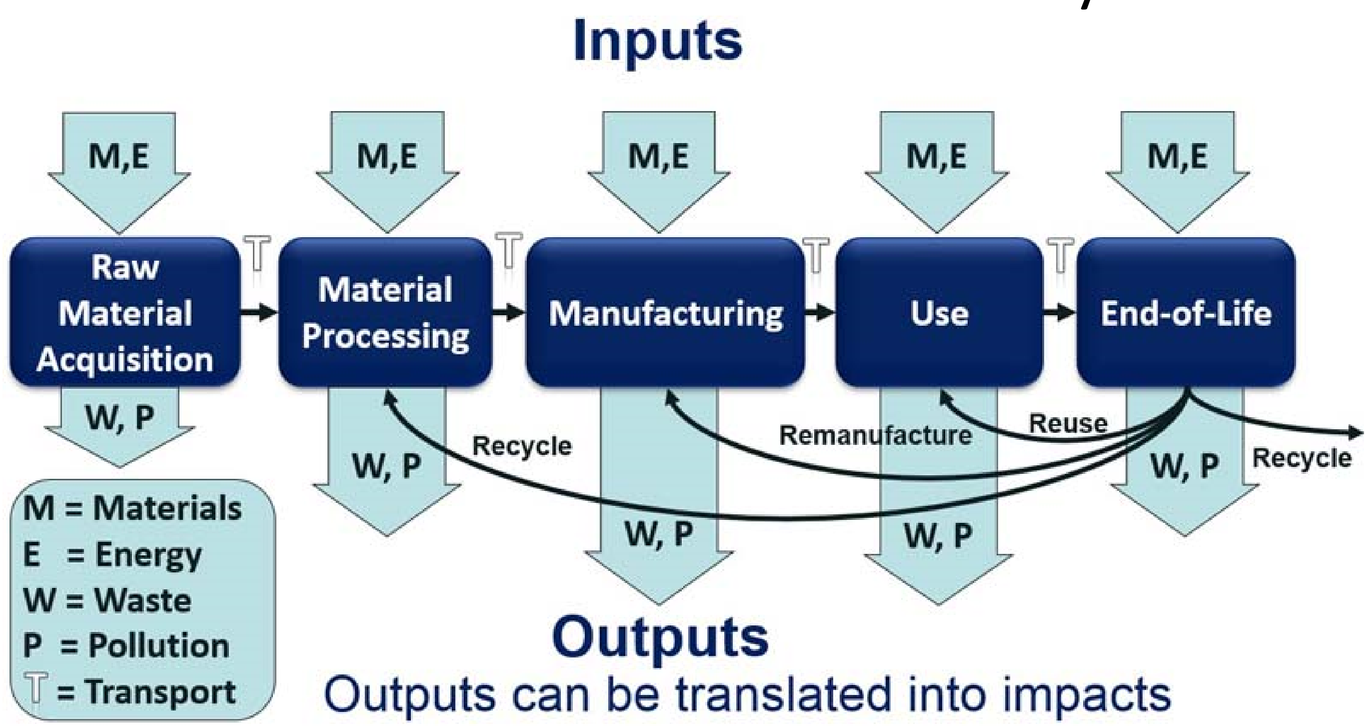
Economic Analysis

- Lifecycle Cost Analysis (LCCA) quantifies economic cost over the lifetime of a project.
  - FHWA RealCost
  - Does NOT quantify environmental or societal benefits associated with recycling.

- Initial construction, future maintenance and rehabilitation, and end of life considered.
- Cost savings from recycling concrete can include:
  - Lower initial costs for recycled aggregates
  - Lower hauling costs
  - Reduced tipping fees
  - Salvage value of project, if recycled
    - Avoid double-counting

Environmental Assessment

- Lifecycle Analysis (LCA) quantifies impact of a product or process on the environment over the life cycle.



(from FHWA, Kendall 2012)

  – Quantifies environmental impacts
  – Societal and economic impacts quantified to some extent

Life Cycle Assessment (LCA)

- ISO 14140 and 14044
- LCA software programs include Athena, SimaPro, or TRACI
  - No generally accepted LCA framework for pavements
- Data to support LCA for highway projects is available
  - Life cycle inventory (LCI) and Environmental Product Declarations (EPD) for specific products
  - Federal agencies
    - FHWA, US Environmental Protection Agency, US Energy Information Administration, US Department of Energy, US Bureau of Economic Analysis
- Level of detail required makes LCA project-specific
- Comparisons are only possible with equivalent bounding assumptions.

Concrete Recycling in LCA

- Concrete recycling can be considered in several LCA impact categories
  - Fuel consumption
  - Emissions
  - Non-renewable resource use
  - Fresh water use
  - Hazardous and non-hazardous waste
- Concrete must be defined as either a waste or a product
  - Avoid double-counting
- Use of pay items as primary input is one approach to provide consistency in analysis between projects (Harrell et al. 2015)

Rating Systems

- Facilitate rating based on environmental and social equity metrics
- Provide means of relative evaluation and differentiation of projects
- Also an avenue for recognition of stakeholders

INVEST
ECONOMIC • SOCIAL • ENVIRONMENTAL

ENVISION™

Greenroads™

NYSDOT GreenLITES

Rating Systems

- Rating systems differ by grouping of:
  - Performance criteria
  - Delineation and computation of metrics
  - Thresholds for obtaining points and ratings status
- Certification methodology
  - INVEST and Envision are self-certification programs
  - Greenroads is a third-party certification system

- Credits or points for concrete recycling earned by:
  - Reuse of concrete materials
  - Recycling of concrete materials
  - Emissions reductions
  - Noise reductions
  - Planning initiatives
  - End-of-life considerations

Quantifying Sustainability

- Illinois Tollway
  - Move Illinois: 15-year, $12.1B program started 2011
  - Extensive use of recycled materials
  - LCCA used to identify $50M in savings (through 2014) by use of recycled concrete rather than virgin aggregate in pavement bases.
  - Modified version of INVEST rating system developed to adapt to Tollway needs, used to score (and compare) over 15 projects
  - Tools for LCA for pavements developed and are in proof-testing stages (early 2016)
  - Plans to integrate LCA with LCCA software and INVEST rating system (Gillen et al. 2015 and Gillen and Vavrik 2016)

Environmental Impacts

Recycling is inherently a beneficial practice, but must mitigate potential adverse environmental impacts

- Water quality
  - Contaminants in runoff and drainage
  - Alkalinity, chemical contaminants, other
  - Transported sediments

Often identified as key concern by state agencies

- Air quality
  - Equipment emissions
  - Fugitive dust
- Noise
  - Additional processing, handling
- Waste generation and disposition
  - Solids, wastewater, slurries, residuals

Traditional Environmental Controls
Water Quality

- Minimize jobsite footprint
- Stockpiles
  - Minimize fines
  - Select location to mitigate impact on surface waters
  - Erosion control
    - Berms, straw bales, filter channels
- Unbound bases
  - Minimize fines
  - Use of appropriate geotextile fabrics
- Compliance testing to meet regulatory guidelines
- Personnel training

Environmental Regulation and Compliance

- Regulatory policies differ by state
  - RCA is typically defined as an inert material
- Some regulations/categorizations of RCA can cause delays, expense, risk (perceived or real)
  - Decreases potential for recycling
- Policies can be modified for RCA
  - Both on-site and off-site activities
  - Increases potential for recycling

Environmental Regulation and Compliance

- Reducing regulatory burden can increase use of RCA
  - Legislation/compliance agreements related to waste definition(s) and practices
  - Guidance for allowable (and encouraged) recycling activities
  - Up-front guidance and "clear path" through regulation
    - Minimizes risk for contractor, can provide cost savings for Owner
  - Training of personnel

RECOMMENDATIONS FOR USING RCA

RCA Production Considerations

- Consider RCA an "engineered material"; test thoroughly.
- Determine material properties and quality (before recycling, if possible)
- Consider product type/quality requirements
  - Gradation requirements will determine crushing equipment selection
  - Maximize reclamation?
  - Minimize reclaimed mortar?
- Give contractor options for determining the most cost-effective point for recycling
- Stockpile management plan (contamination, moisture)

Recommendations: Use in Subbases

- AASHTO M319
- Quality requirements (Saeed and Hammons, 2008)
- Grade according to subbase function
  - Free-draining
  - Dense-graded
  - See ACPA EB204P

Slide 80

EC15 Should the quality requirements (Saeed & Hammons) be summarized or at least the top few? Also as we produce our manual of practice, these would be good spec resources to include.
Ells Cackler, 3/17/2016

EC16

Test Criteria for RCA Unbound Subbase Applications

(after Saeed and Hammons, 2008)

<table>
<tr><th rowspan="3">Tests and Test Parameters</th><th>Traffic</th><th colspan="2">High</th><th colspan="2">Med.</th><th colspan="2">High</th><th colspan="2">Low</th><th>Med.</th><th>Low</th></tr>
<tr><th>Moisture</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th><th colspan="2">Low</th><th colspan="2">High</th><th>Low</th></tr>
<tr><th>Climate</th><th colspan="4">Freeze</th><th colspan="2">Nonfreeze</th><th>Freeze</th><th colspan="3">Nonfreeze</th></tr>
<tr><td colspan="2">Micro-Deval Test (percent loss)</td><td colspan="3">< 5 percent</td><td colspan="4">< 15 percent</td><td colspan="2">< 30 percent</td><td>< 45 percent</td></tr>
<tr><td colspan="2">Tube Suction Test (dielectric constant)</td><td colspan="3">≤ 7</td><td colspan="4">≤ 10</td><td colspan="2">≤ 15</td><td>≤ 20</td></tr>
<tr><td rowspan="2">Static Triaxial Test (Max. Deviator Stress)</td><td>OMC, σ_c = 5 psi (35 kPA)</td><td colspan="3">> 100 psi (0.7 MPa)</td><td colspan="4">> 60 psi (0.4 MPa)</td><td colspan="2">> 25 psi (170 kPa)</td><td>Not required</td></tr>
<tr><td>Sat., σ_c = 15 psi (103 kPA)</td><td colspan="3">≥ 180 psi (1.2 MPa)</td><td colspan="4">≥ 135 psi (0.9 MPa)</td><td colspan="2">≥ 60 psi (410 kPa)</td><td>Not required</td></tr>
<tr><td rowspan="2">Repeated Load Test (Failure Deviator Stress)</td><td>OMC, σ_c = 15 psi (103 kPA)</td><td colspan="3">≥ 180 psi (1.2 MPa)</td><td colspan="4">≥ 160 psi (1.1 MPa)</td><td colspan="2">≥ 90 psi (620 kPa)</td><td>Not required</td></tr>
<tr><td>Sat., σ_c = 15 psi (103 kPA)</td><td colspan="3">≥ 180 psi (1.2 MPa)</td><td colspan="4">≥ 160 psi (1.1 MPa)</td><td colspan="2">≥ 60 psi (410 kPa)</td><td>Not required</td></tr>
<tr><td colspan="2">Stiffness Test (Resilient Modulus)</td><td colspan="3">≥ 60 ksi (0.4 MPa)</td><td colspan="4">≥ 40 ksi (275 kPa)</td><td colspan="2">≥ 25 ksi (170 MPa)</td><td>Not required</td></tr>
</table>

Note: Low traffic: < 100,000 ESALs/year; Medium traffic: 100,000 to 1,000,000 ESALs/year; High traffic: 1,000,000 ESALs/year.

Slide 81

EC16 Not clear here. Does this replace the 2008 recommencations of Saeed & Hammons? Source of recommendations?

Ells Cackler, 3/17/2016

Recommendations: 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

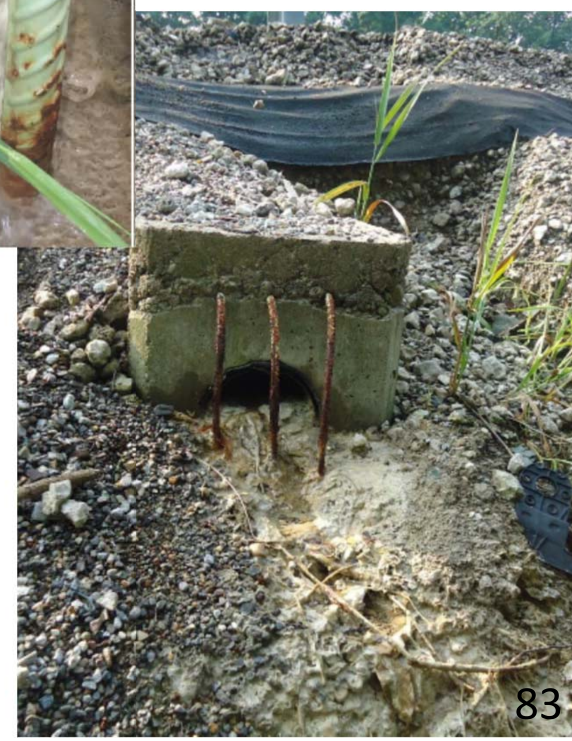
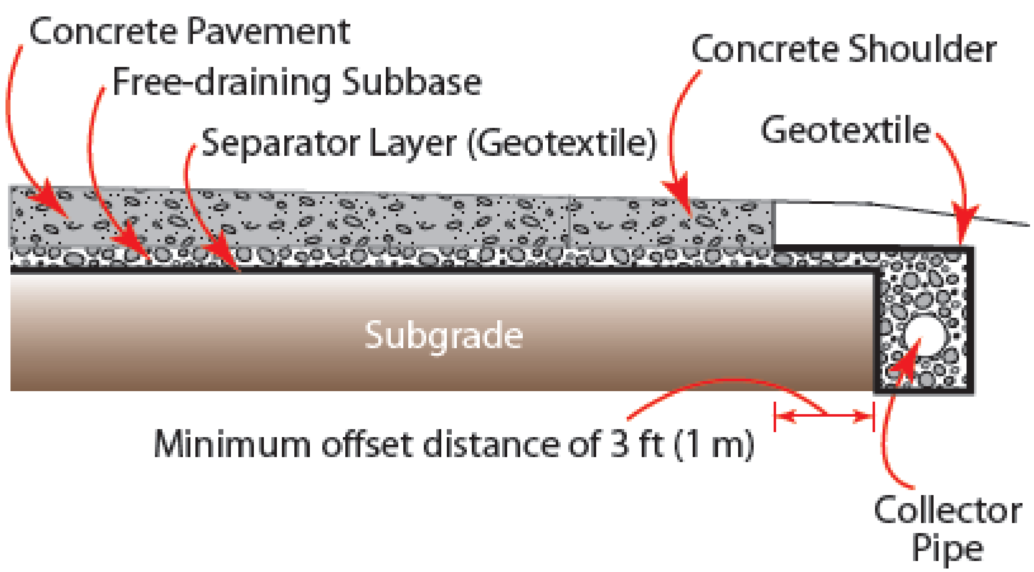


Photo credits: Iowa DOT and PennDOT

EC17

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



Slide 84

EC17 What iare ISR deposits? Maybe "consider washing"? The washing has the potential to really limit base applications and on site recycling which has been done successfully for a long time. We should discuss as a team, this is a major isssue with unbound bases.
Ells Cackler, 3/17/2016

Recommendations: Pavement Structural Design

- RCA Subbase:
  - Consider possible stiffening of RCA subbase and adjust panel length, thickness as required
- RCA Slab:
  - Consider CTE and shrinkage
    - Adjust panel length
    - Adjust sealant reservoir dimensions and sealant materials
    - Higher reinforcing quantities (CRCP, JRCP)?
  - Reduced aggregate interlock potential
    - LTE may require dowels
  - Evaluate abrasion resistance (surface friction and wear)

Recommendations: RCA in Mixture Design

- AASHTO MP16-13
- Quality Requirements and Properties
  - Generally the same as for PCC with virgin aggregate
  - Exception: sulfate soundness (unreliable for RCA)
- Materials-Related Distress
  - Alkali-silica reactivity
    - Lithium
    - Class F fly ash and/or slag cement
    - Limit RCA fines
    - Reduce water access (joint sealing, drains, etc.)
  - D-cracking
    - Reduce coarse aggregate top size
    - Reduce moisture exposure
  - Test effectiveness of all treatments before construction!

Recommendations: RCA in Mixture Design Proportioning

- Consider Specific Gravity and Absorption Capacity
- Consider higher strength variability
- To maintain workability, add 5 – 15% water

OR

- Use admixtures (chemical and/or mineral)
- Verify air content requirements (adjust for air in reclaimed mortar)
- Trial mixtures are essential

Summary

- Recycling is becoming an increasingly cost-effective alternative due to scarcity of virgin aggregate
- Requires adjustment to mix design and pavement design
- Good performance has been reported
- No specialized techniques or equipment

Resources: ACPA EB043P

- Production of RCA
- Properties and Characteristics of RCA
- Uses of RCA
- Properties of Concrete Containing RCA
- Performance of Concrete Pavements Constructed Using RCA
- Recommendations for Using RCA
- Appendices:
  - Guidelines for Removing and Crushing Existing Concrete Pavement
  - Guidelines for Using RCA in Unstabilized (Granular) Subbases
  - Guidelines for Using RCA in Concrete Paving Mixtures
  - Relevant AASHTO/ASTM Standards
  - Glossary of Terms and Index

Resources: CP Tech Center Deployment Plan

A Technology Deployment Plan for the Use of Recycled Concrete Aggregates in Concrete Paving Mixtures

National Concrete Pavement Technology Center

Final Report
June 2011

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Federal Highway Administration
(through DTFH61-06-H-00011, work plan 27)
National Concrete Pavement Technology Center
Sponsored Research Fund

- Use of RCA in concrete mixtures is not common, but implementation efforts are underway.
- Report outlines barriers to implementation (perceptions, lack of experience, risk, etc.) and recommends approaches to overcoming them.
- Report available at: http://www.intrans.iastate.edu/reports/RCA%20Draft%20Report_final-ssc.pdf
- **Also: FHWA Technical Advisory TT 5040.37: Use of Recycled Concrete Pavement as Aggregate in Hydraulic-Cement Concrete Pavement**

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- Moon Won, Texas DOT and University of Texas

Questions?

Concrete Pavement Recycling Webinar Schedule

Subject	Regions 1 & 2 Webinar	Region 3 Webinar	Region 4 Webinar
Concrete Pavement Recycling	April 20, 2016	May 4, 2016	May 18, 2016