Use of Recycled Concrete Materials in Base/Subbase Applications

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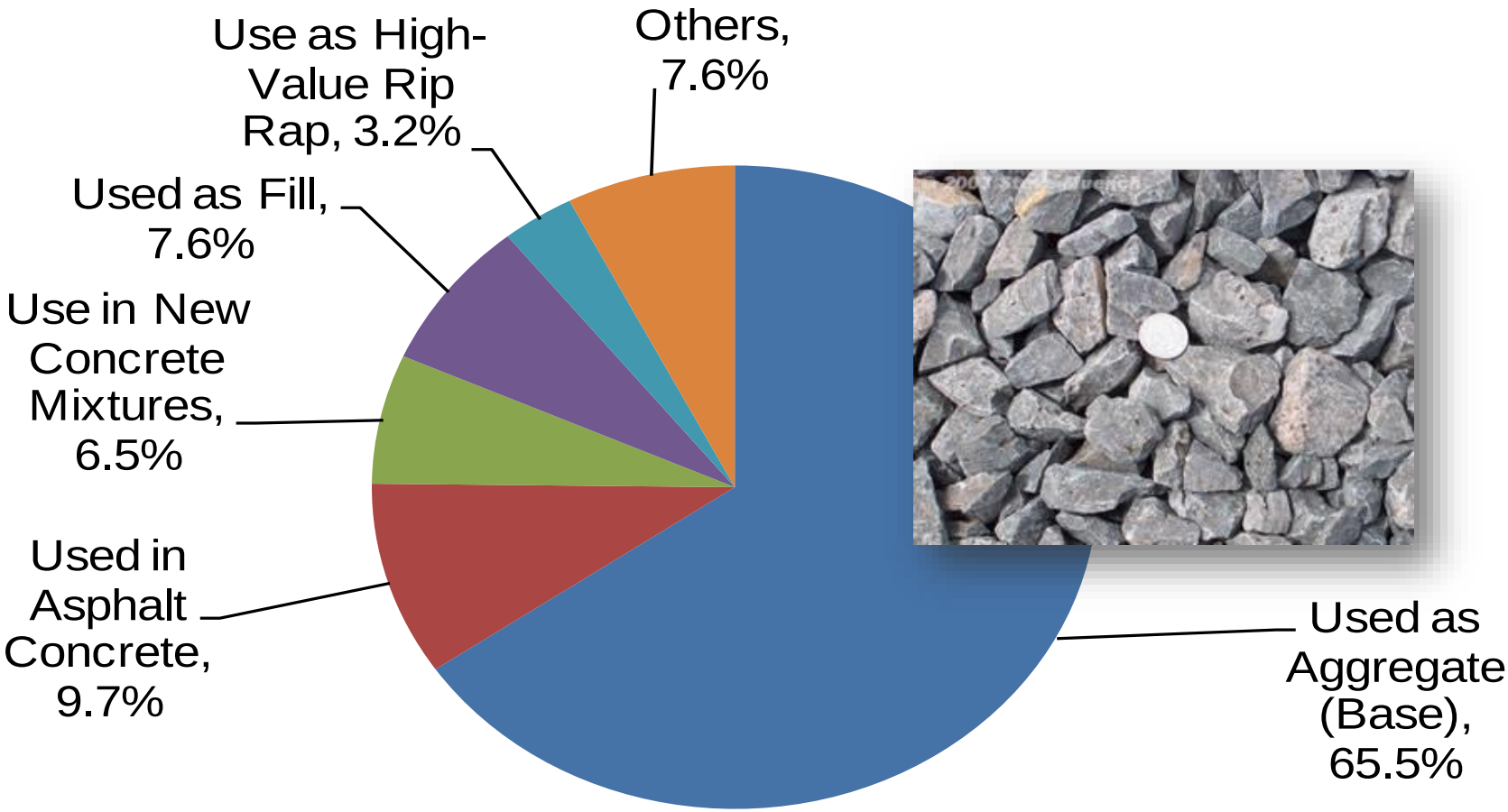
What is Concrete Recycling?

- 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!***

Uses of Recycled Concrete Aggregate

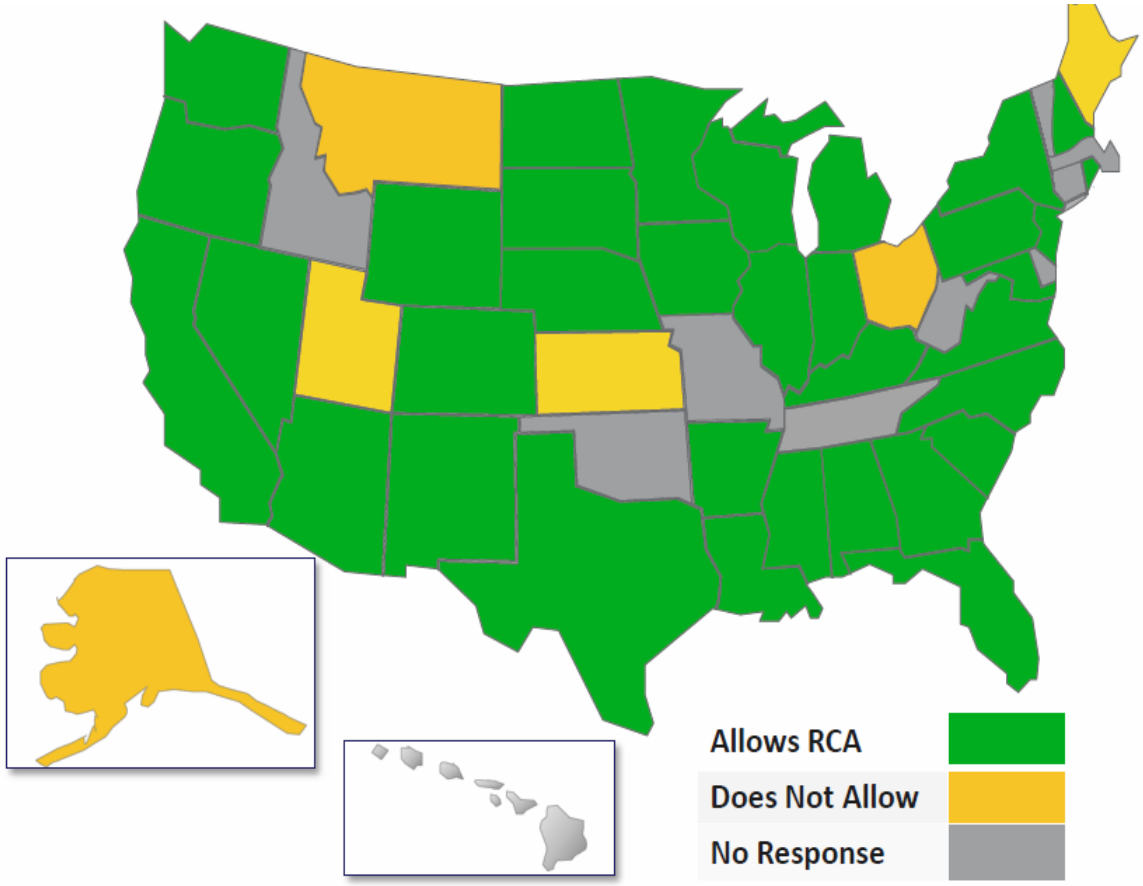
- PCC pavement
  - Single and Two-Lift
- HMA pavement
- Subbase
  - Unbound
  - Stabilized
- Fill material
- Filter material
- Drainage layer

Use of RCA in U.S.



Van Dam et al, 2016, after Wilburn and Goonan 1998 and USGS 2000

2012 CMRA Survey of RCA Use in Base Applications



- 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.

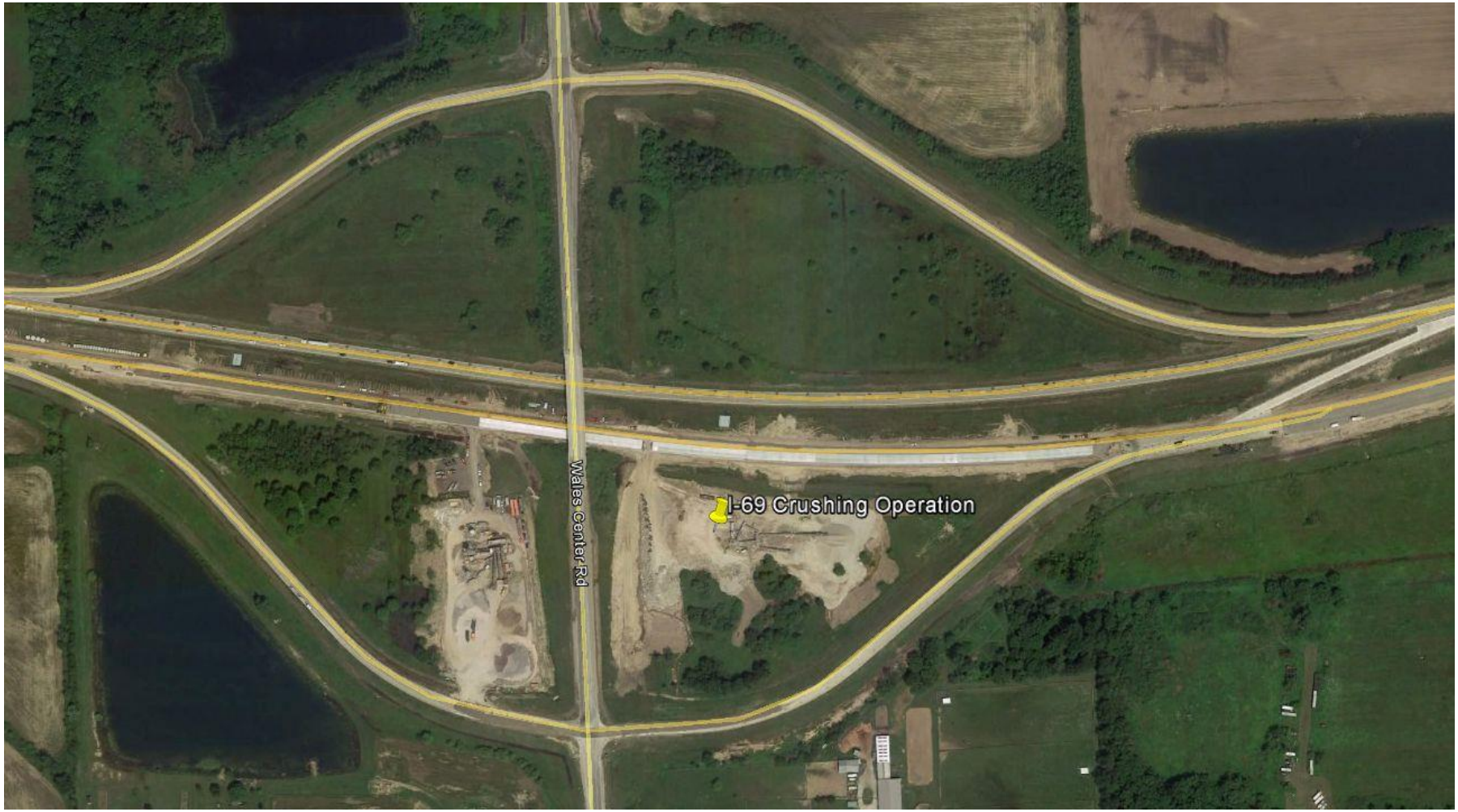
Basic Concrete Recycling Options

- 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+ yd^2/hr

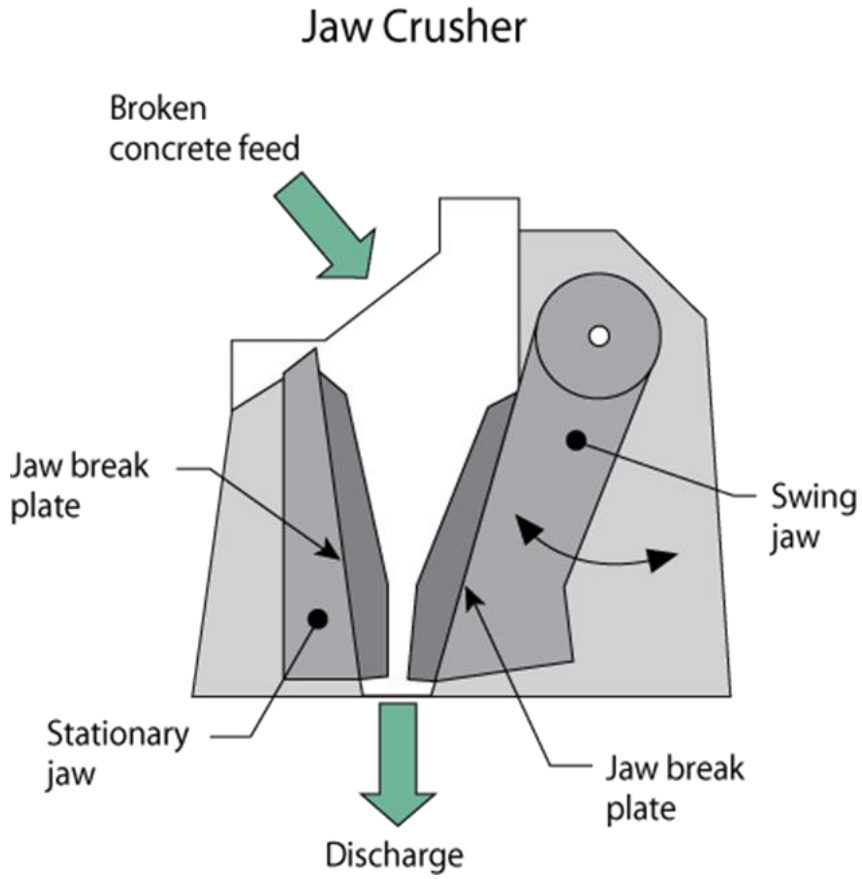
Pavement Breaking and Removal

Removal of Embedded Steel

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

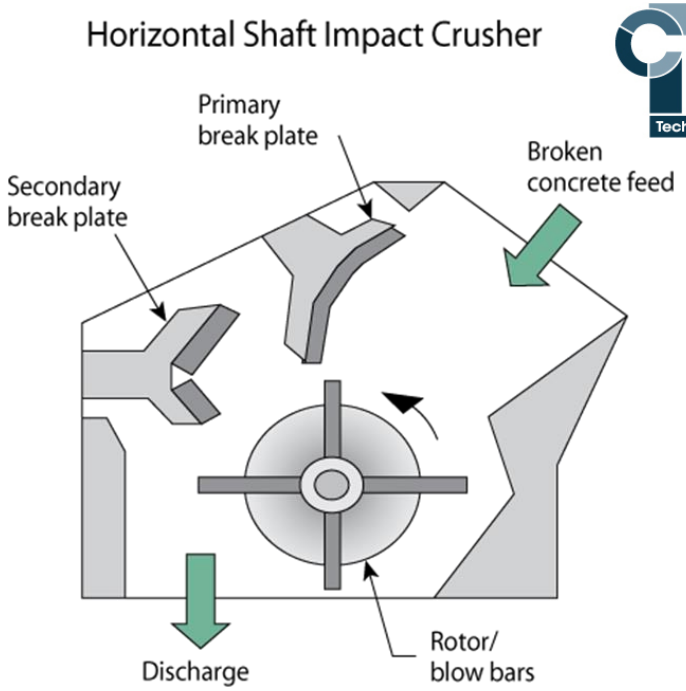
Crushing Equipment

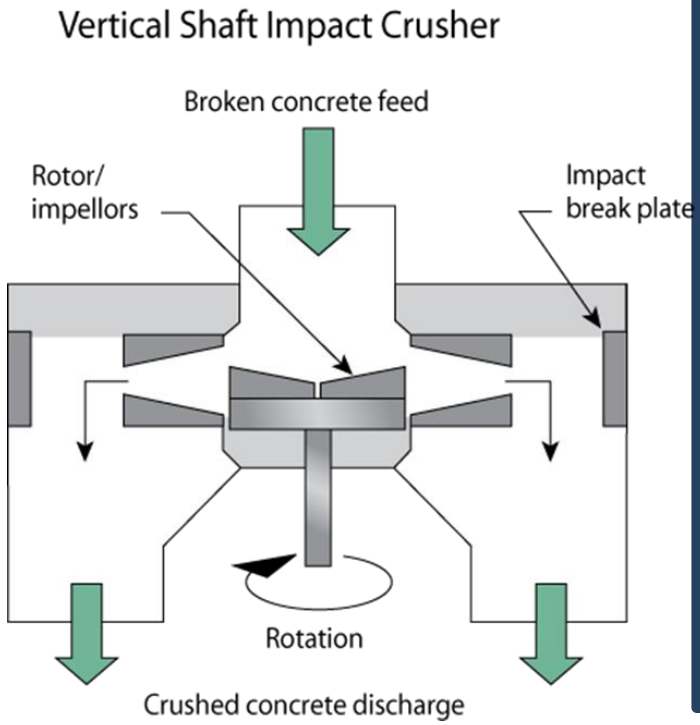
- Jaw crusher can be used as a primary crusher
  - Allows feeding of larger sized pieces of broken concrete (24”)
  - Helps to separate steel from the broken concrete



Crushing Equipment

- Impact crusher 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)



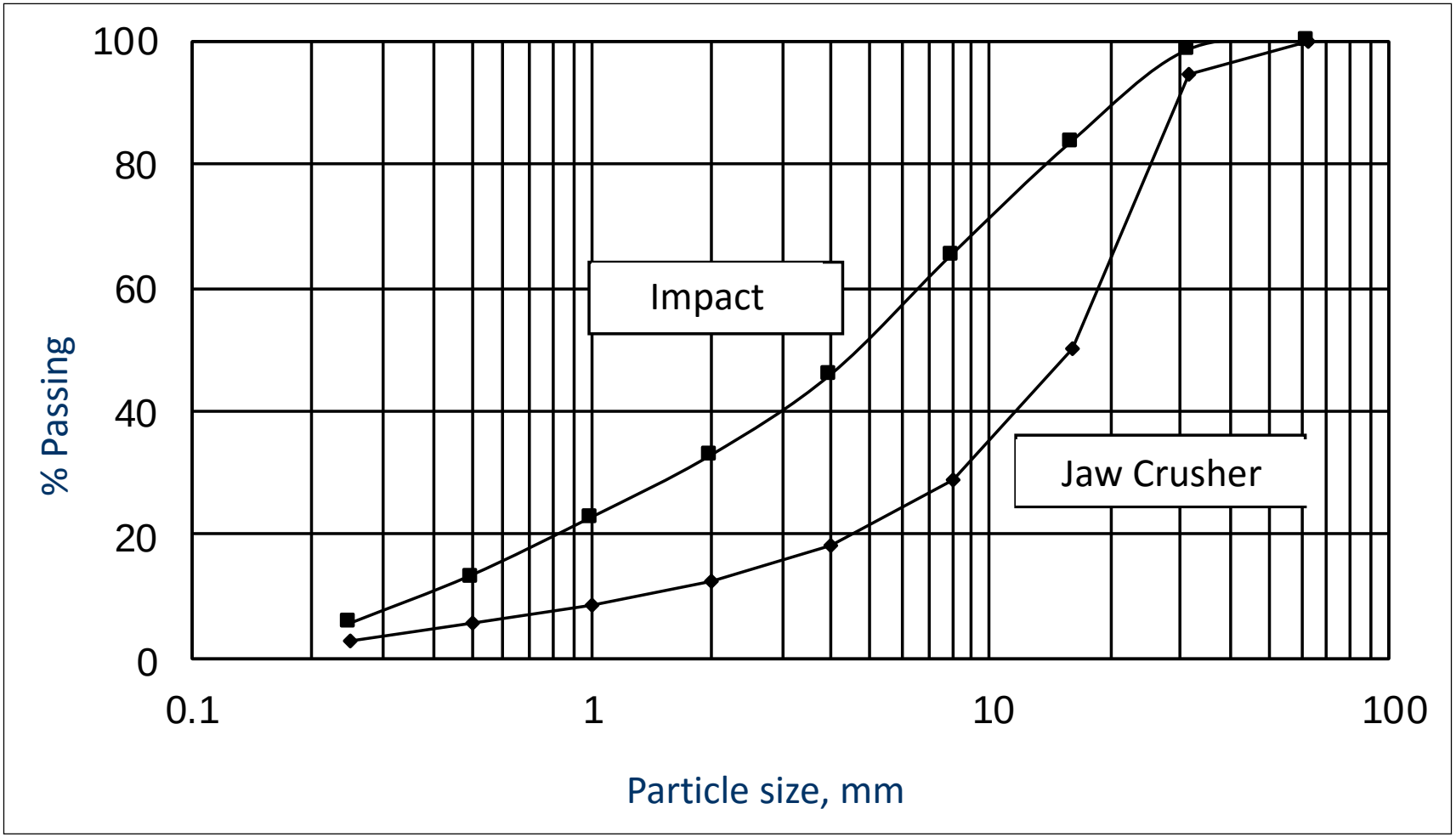


RCA Processing: Crushing and Screening (Sizing)

- 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

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

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

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

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

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

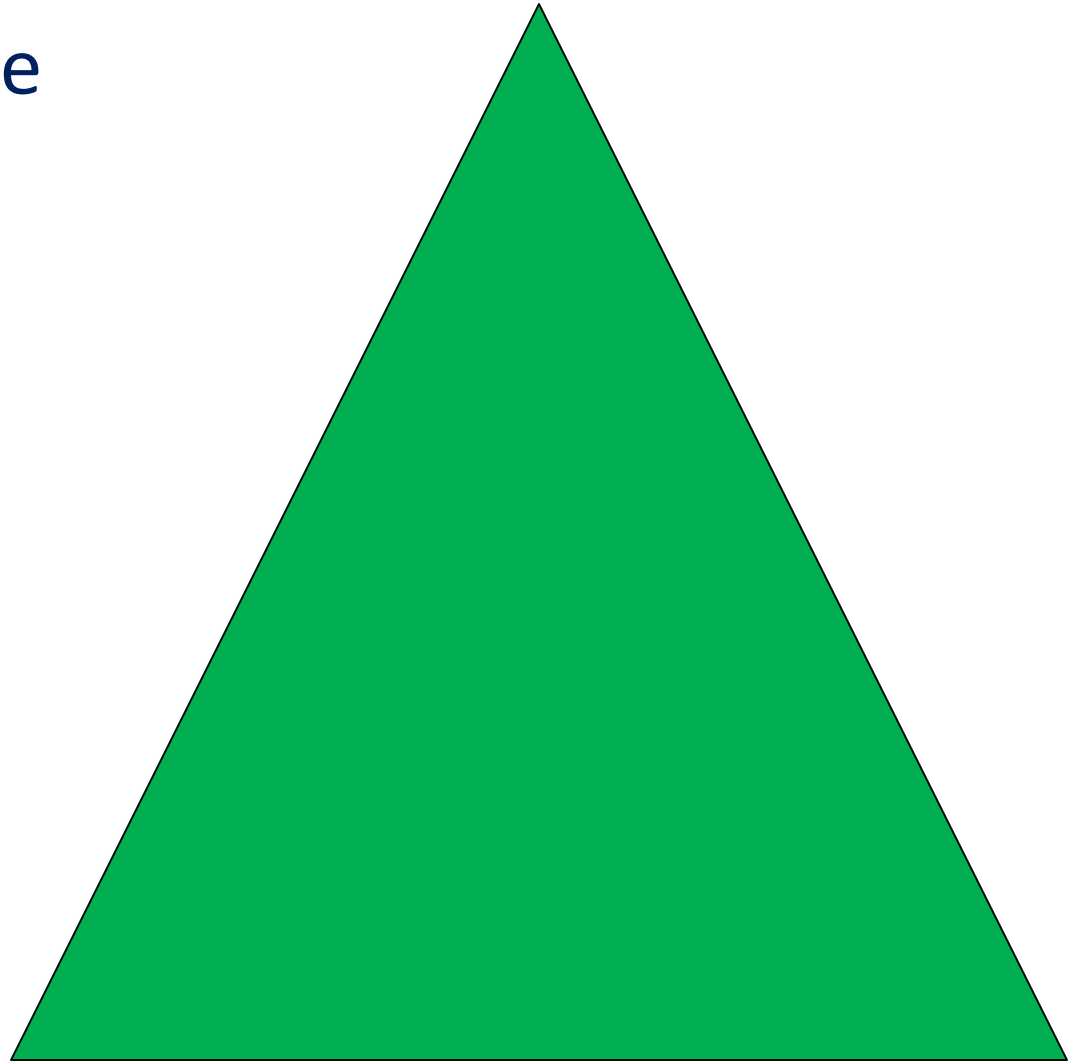
RCA Design/Construction Considerations

Specified gradation impacts usable amount of RCA that is produced

Sieve	RCA Granular Base Percent Passing	Drainable Base Percent Passing	Concrete Stone Percent Passing
1 ½"	100	100	100
1"	95-100	95-100	95-100
¾"	65-85	75-85	
½"		55-65	25-60
⅜"	40-60	40-50	
#4	25-45	15-25	0-10
#8		0-5	0-5
#10	15-30		
#40	5-15	0-5	
#200	0-10	0-3	0-2

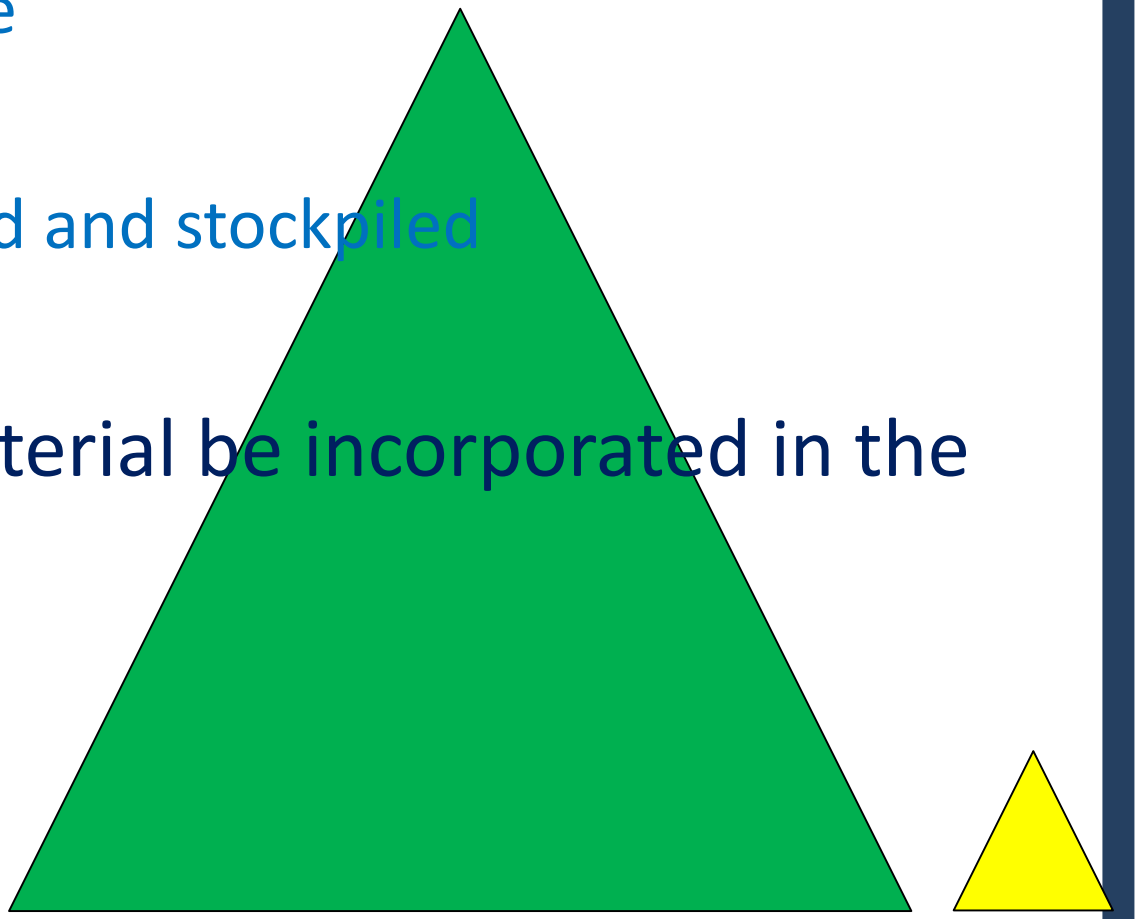
RCA Design/Construction Considerations

- 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).

Base Design and Construction Considerations - 2

- 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

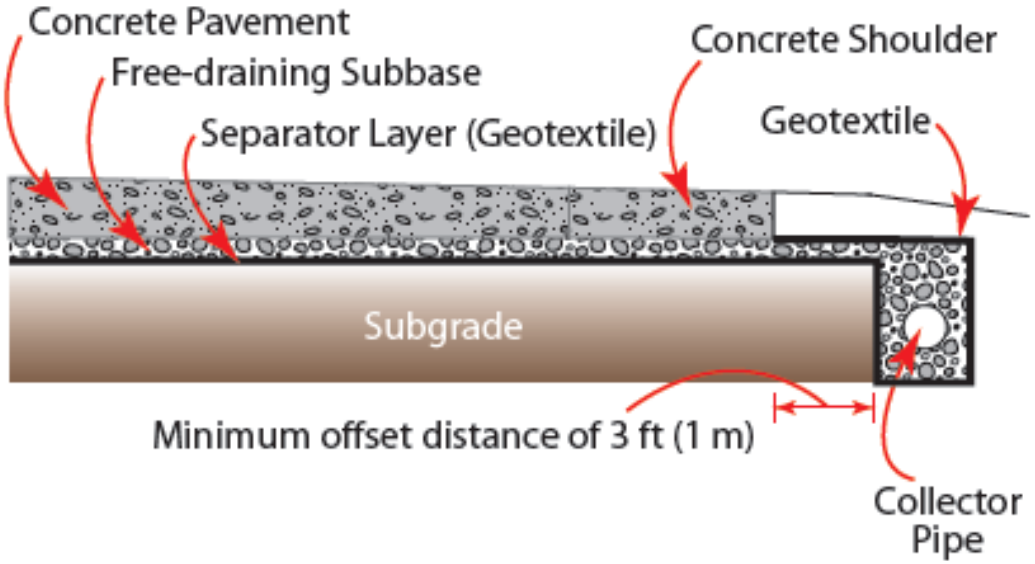
- All RCA is capable of producing precipitate and insoluble residue ("crusher dust")
  - Potential increases with surface area (smaller particles)
- Usually no problem below drains or in undrained layers
- In drained layers, you could get infill of drain pipes and/or clogging of rodent screens.

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.

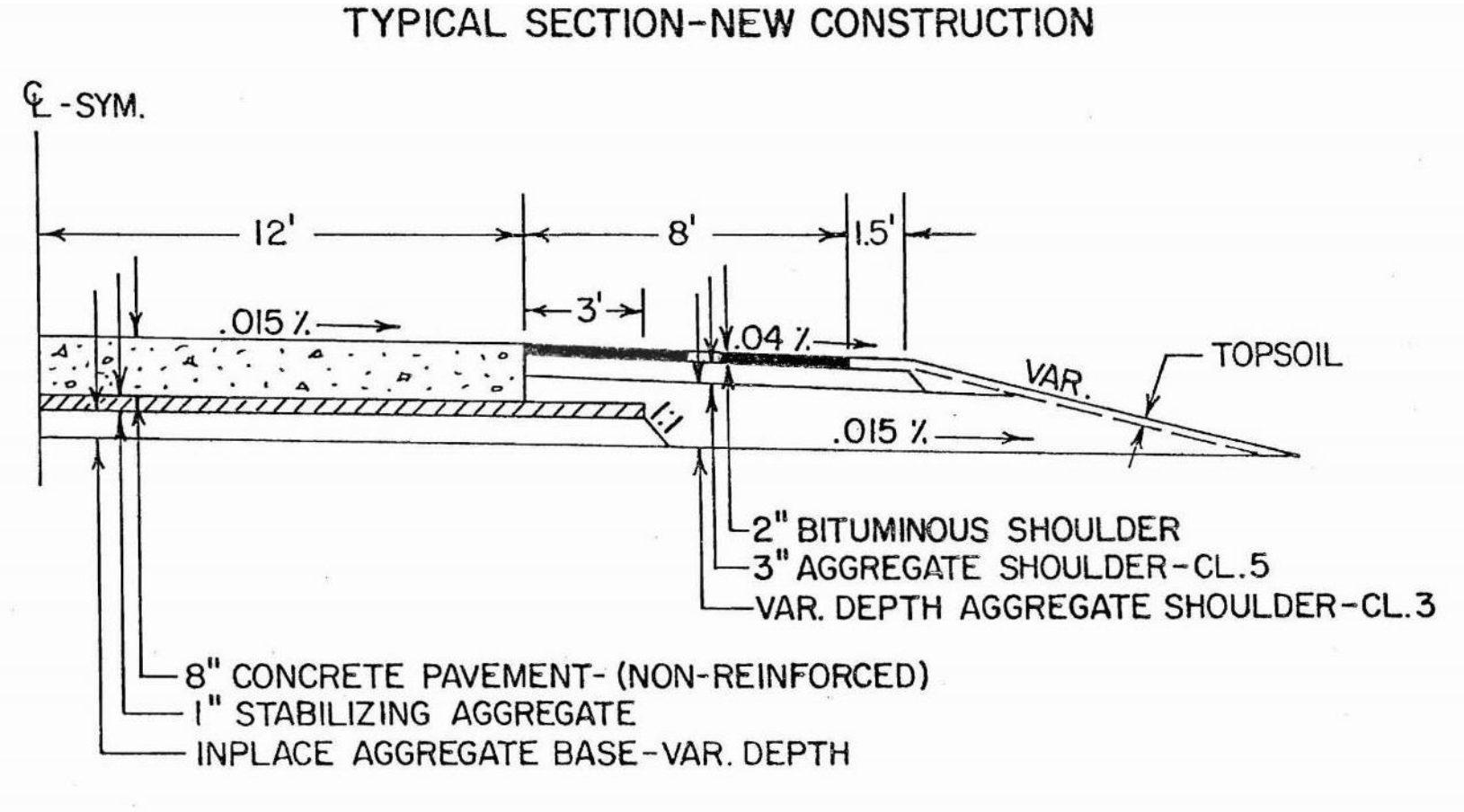
Recycling Details

- 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

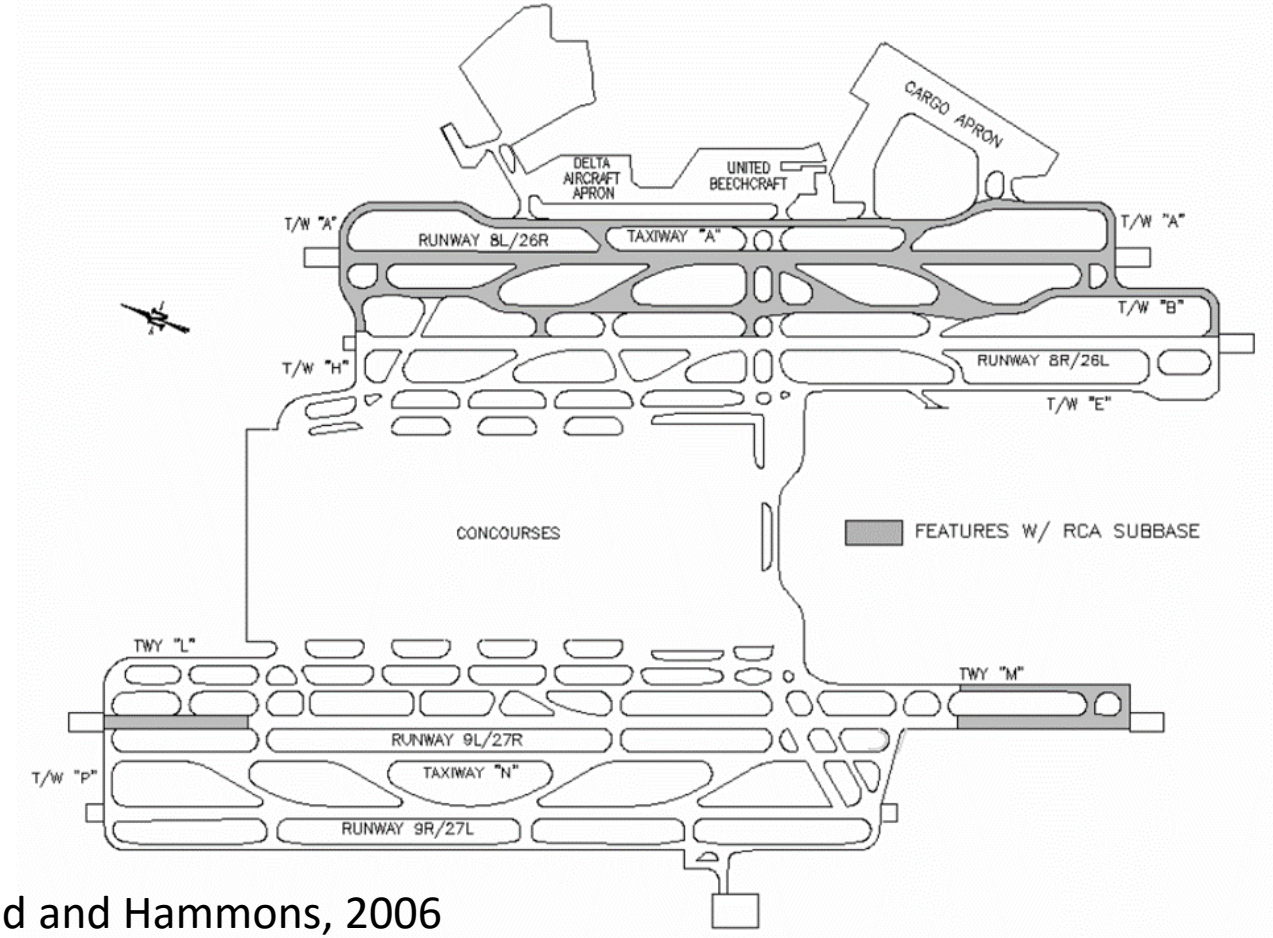
- 350,000 tons of old pavement recycled
  - 85% to fill areas
  - 15% to 3-in unbound subbase
- Capped with asphalt-treated base and 10-in CRCP
- Provided excellent service for nearly 40 years under very heavy traffic.

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”

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The Illinois Tollway
DRIVING THE FUTURE

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

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Rubblization

- Approximately 30 median miles of interstate highway concrete pavement has been rubblized on the Tollway and compacted as a base under new perpetual asphalt pavements
- 27.9 miles on one project alone (I-88)

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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

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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**

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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.
  - Report available at: http://www.intrans.iastate.edu/reports/RCA%20Draft%20Report_final-ssc.pdf
- **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!**

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

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Questions?