Recycled Concrete Aggregates (RCA): The Basics

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- Photo Contributors

Photo: Gary Fick, Transtec

Concrete recycling is not new...

- Post WW 2 Europe – concrete recycling performed extensively
- First major use in U.S. pavement construction was on Historic US Route 66 in Illinois in the 1940s
- Increased concrete recycling in US in 1970s/80s (environmental initiatives)

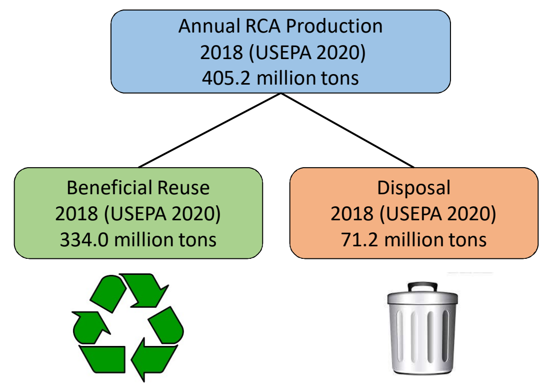
Today:

- RCA primarily used in unbound applications (base/fill)
- Over 100 pavement projects constructed in United States using RCA in concrete as partial or full replacement for coarse aggregate, fine aggregate or both
- Use driven by:
  - Need for more sustainable infrastructure
  - Demand for alternative aggregate sources
  - Cost savings

Photo: Dwayne Stenlund, MnDOT

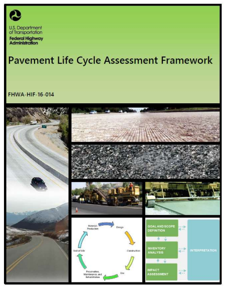
Use of RCA in Pavement Applications

- Concrete pavement
  - Conventional or 2-lift
- Asphalt pavement
- Aggregate shoulder
- Subbase
  - Unbound or stabilized
- Drainage layer
- Filter material
- Fill material



Why recycle concrete and reuse RCA?

- Environmental benefits
  - Conserve natural resources (aggregates, fuel, landfill space)
  - Reduce greenhouse gas emissions
- Economic benefits
  - Lower costs – materials, disposal, hauling
  - Can reduce project competition time
  - Can provide performance enhancements (foundation layers)
- Social (community benefits)
  - Can reduce number of construction vehicles on roadways



INVEST

ENVISION

Greenroads

NYSDOT GreenLITES

Quantifying Sustainability

- Beltline Highway – Madison, WI
  - 1.5 mile segment reconstructed using a variety of recycled materials
  - RCA used in base course or embankment fill
  - 9,870 CY of RCA from onsite material utilized, crushed and graded onsite
  - Additional RCA sourced from offsite
    - Source concrete qualified for use using WisDOT's specifications
    - Require AASHTO T 96 abrasion testing for off-site materials

Photo: Steven Theisen, WisDOT

Quantifying Sustainability

- Beltline Highway – Madison, WI
  - LCCA → cost savings of approx. $130,000 at initial construction from RCA use
- LCA → lifetime environmental impact reductions of:
  - Energy use (13% reduction),
  - Water consumption (12% reduction)
  - CO_2 emissions (13% reduction)
  - Hazardous waste (9% reduction)
  - LCA was performed with PaLATE tool (Horvath 2007, detailed in Bloom et al. 2016)

Photo: Emily Bloom, UW-Madison

The Recycling Process

- Evaluate source concrete – quality, contaminants
- Remove large amounts undesirable material (asphalt overlays/patching)
- Break and remove existing pavement
- Remove steel
- Crush and size
- RCA can be produced:
  - On-site with a mobile crusher
    - typically base and fill applications
  - On-site with a stationary crusher
    - RCA for use in new concrete
  - Off-site using a stationary facility
    - urban areas, typically crush C&D waste from multiple projec

Photo: Gary Fick, Transtec

Photos: ACPA (2009)

On-site processing with mobile crushing equipment

Photo: Manatt's

Photo: Kevin Merryman, Iowa DOT

Stationary plants – off-site or on-site processing

Photo: ACPA (2009)

Use front-end loaders and dump trucks for removal and transport

Off-site plant

Photo: John Cappello, RJ Smith

or

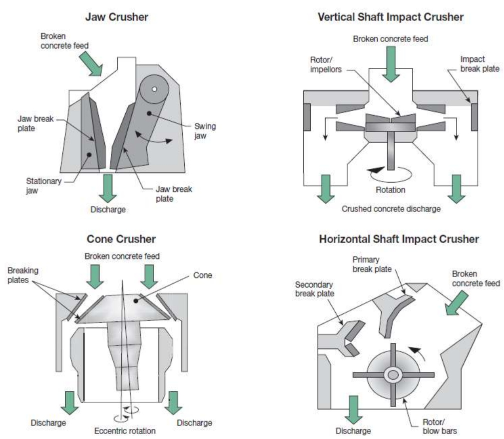
On-site plant

Photo: Gary Fick, Transtec

The Recycling Process

- Crushers
  - Jaw, cone, impact
  - Primary, secondary, sometimes tertiary
- Type and size of crusher determines:
  - quantity of RCA produced
  - gradation of RCA produced
  - quantity of fines generated

- Crushing of "clean" quality concrete can give 1-2% material finer than No. 200 sieve (Fick 2017)



From ACPA (2009)

The Recycling Process

- Screening after primary crusher to remove oversized material
- Beneficiation –to remove joint sealant, dust, other light materials
  - Air blowing
  - Washing
  - Heavy media separation
- Screening
- Stockpiling

Photo: Gary Fick, Transtec

Photo: Gary Fick, Transtec

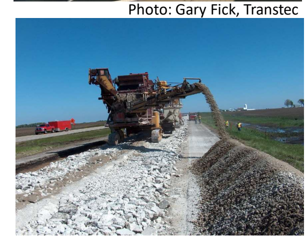


Photo: Tom Cackler

Characteristics of RCA

- RCA are composites – natural coarse aggregate + adhered mortar
- Differences in performance driven by mortar fraction
- Mortar makes RCA
  - more porous
  - lower unit weight
  - higher abrasion loss
- Smaller sized particles = typically more mortar
- Volume of mortar fraction
  - quality of source concrete
  - crusher type
  - particle size being produced
- Often more angular than virgin aggregates, rougher texture


Photos: Meras Mamirov, Univ. of Nebraska

Characterization Tests for RCA

- Similar to virgin aggregates
  - Gradation, abrasion, susceptibility to ASR/D-cracking
- Many agencies require RCA meet same quality requirements as virgin aggregates
- Some agencies have additional requirements for RCA
  - particularly from non-agency sources
  - limits on contaminants and potentially deleterious substances
- AASHTO M 319 "Standard Specification for Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course."
- ACPA (2009) provides recommended limits on contaminants
- Sulfate soundness tests should not be used for RCA (paste interferes with results)
- Alternative sulfate soundness tests in AASHTO M 319.

Typical Characteristics of RCA

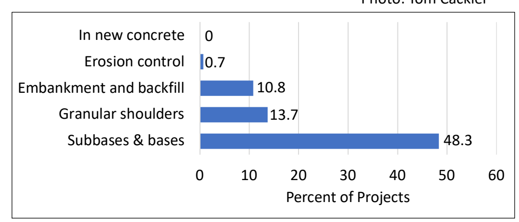
Property	Natural Aggregate*	RCA*
Shape and texture	Well-rounded, smooth (gravel) to angular and rough (crushed rock)	Angular with rough surface
Absorption capacity (%)	0.8 – 3.7	3.7 – 8.7
Specific gravity	2.4 – 2.9	2.1 – 2.4
L.A. Abrasion Test mass loss (%)	15 – 30	20 – 45
Sodium sulfate soundness test mass loss (%)	7 - 21	18 – 59
Magnesium sulfate soundness test mass loss (%)	4 - 7	1 – 9
Chloride content (lb/yd^3)	0 – 2	1 - 12

* Data for are for as-produced material, including both fine and coarse material. From ACPA (2009).

Unbound uses of RCA

Photo: Tom Cackler

- Unstabilized base and fill material
- Most common application for RCA in United States
- 38+ of 44 states using RCA
- Some states believe RCA outperforms virgin aggregate as an unstabilized subbase
  - Secondary cementing from exposed cement in crushed RCA
- Some level of contaminant material is tolerable
- 2016 RCA benchmarking survey (Cackler 2018)



Influence of RCA on Unbound Applications

- Potential for improved performance of RCA compared to virgin aggregates
  - RCA particles tend to be more angular, rough-textured
  - Potential for re-cementation of particles (particularly fines) can improve stability
- Literature appears to have no reports of pavement performance problems related to structural deficiencies in properly designed/constructed RCA bases

Photo: Gary Fick, Transtec

Benefits of on-grade recycling (Fick 2017):

No hauling required
✓ significant cost savings
✓ reduced exposure to traffic

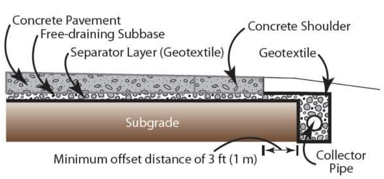
Potential drainage issues

- RCA used successfully in dense-graded undrained foundation layers and fill
- Can have precipitate formation in drainable bases, drain-pipe backfill, and dense-graded base layers that carry water to pavement drain systems
  - "Calcareous tufa" – crushed concrete dust and calcium carbonate precipitate
  - Can clog fabrics and form deposits, but often do not completely prevent discharge flow
  - Often occurs early in pavement life, and rate of accumulation dissipates.

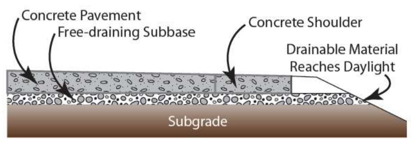
Photos: PennDOT

Preventing drainage structure clogging

- Minimize use of RCA fines
- Blend RCA and virgin materials
- Use largest practical RCA particle sizes
- Wash the RCA to reduce insoluble residue (crusher dust) deposits
- Use high-permittivity fabric
- Wrap trench, not pipe
- Consider daylighted subbase
- Stabilize the base



Typical edge drain piping (ACPA 2009)



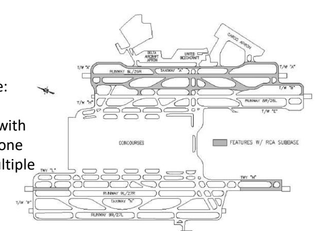
Typical daylighted subbase (ACPA 2009)

Cement-stabilized and lean concrete bases

- Stabilization helps to prevent migration of crusher fines, mitigates high pH runoff
- Physical and mechanical properties of the RCA must be considered in the design and production

Photo: Michael Roe, Flatiron

Notable use:
ATL airport
6 inch CTB with RCA under one runway, multiple taxiways



From Saeed et al. (2016)

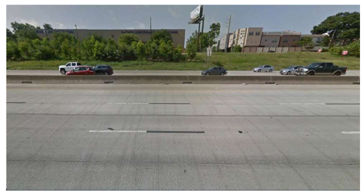
- RCA used in lean concrete base on I-710 in Los Angeles, CA
- RCA produced from existing concrete pavement used to provide 100% coarse and fine aggregate

New Concrete Mixtures

- RCA can be (and has been) used as the primary or sole aggregate source in new concrete pavements
- Can also be used as partial substitute for virgin fine or coarse aggregate

Concrete shoulders using RCA on I-16 in Georgia
Photo: Georgene Geary, GGfGA

- 1995 IH 10 project – Houston, TX
- CRCP with 100% RCA (fine & coarse aggregates), still in service



IH 10 in Houston, TX (2013) Photo: Andy Naranjo, TxDOT

- RCA commonly used in the lower lift of two-lift concrete pavements in Europe

Influence of RCA on Fresh Concrete Properties

- RCA concrete can be batched, mixed, transported, and placed using the same methods as conventional concrete.
- Differences in RCA from natural aggregate cause changes in concrete properties

Property/Characteristic	Range of Expected Changes from Similar Mixtures using Virgin Aggregates	
	Coarse RCA Only	**Coarse and Fine RCA**
Water demand	Greater	Much greater
Air void system	Similar	Increased (reported air content will include air in the source concrete paste)
Unit weight	Slightly lower	Lower
Finishability	Slightly more difficult	More difficult
Bleeding	Slightly less	Less
Finishing characteristics	Similar	May be harsher to finish
Setting time	May be accelerated	May be accelerated

From FHWA 2007, ACI 2001

Mitigating reduced workability

1) Select and use crushing equipment and operating practices that decrease dust and reduce angularity of RCA
2) Maintain high moisture content of RCA prior to batching using sprinklers
3) Adjust mixture proportions to improve workability
   - increase paste content
     - increase both water and cementitious materials while maintaining w/cm ratio
   - use SCMs
     - research has suggested water demand of RCA concrete can be reduced by 12.5% with use of fly ash at 20% replacement with a superplasticizers
   - limit use of RCA as fine aggregate
     - ACPA (2009) recommends no more than 30% replacement rate

Other Fresh Concrete Properties

- Air void system
  - RCA concrete includes air void system of mortar fraction of RCA
  - “clean” RCA does not significantly influence performance of air entraining admixtures
  - Pressure method is sensitive to porosity – use aggregate correction factor or volumetric air content for RCA with high absorption
- Unit weight
  - Tends to be 10-15% lower than conventional concrete
- Bleeding/Finishability
  - Bleeding often reduced
  - If mechanical methods used, finishability not significantly affected.
- Setting time
  - Can be 30-60 minutes shorter than conventional mixtures (Obla et al. 2007)

Influence of RCA on Hardened Concrete Properties

- RCA successfully used to produce concrete with adequate mechanical properties and good durability
- Hardened properties will be influenced by RCA characteristics

Property	RCA used as Coarse Aggregate	RCA used as Coarse and Fine Aggregate	Potential Adjustments
Compressive strength	0% to 24% less	15% to 40% less	Reduce w/cm ratio
Tensile strength	0% to 10% less	10% to 20% less	Reduce w/cm ratio
Strength variation	Slightly greater	Slightly greater	Increase average strength compared to specified strength
Modulus of elasticity	10% to 33% less	25% to 40% less	This may be considered a benefit with regard to cracking of slabs on grade
Specific gravity	0% to 10% lower	5% to 15% lower	None recommended
CTE	0% to 30% greater	0% to 30% greater	Reduce panel sizes
Drying shrinkage	20% to 50% greater	70% to 100% greater	Reduce panel sizes
Creep	30% to 60% greater	30% to 60% greater	Typically not an issue in pavement applications
Bond strength	Similar to conventional concrete, or slightly less	Similar to conventional concrete, or slightly less	None recommended
Permeability	0% to 500% greater	0% to 500% greater	Reduce w/cm ratio

From FHWA 2007, ACI 2001, Hansen 1986

Mitigating Impacts of RCA on Concrete Properties

- RCA can reduce strength
  - Adjust (lower) the w/cm ratio while using water reducing admixtures to achieve the desired workability
  - Prewet the RCA – supports enhanced hydration of residual cement and supports internal curing benefits
  - Use RCA as only a fraction of the natural aggregate
  - Try to reduce variability of the source concrete
- RCA can increase drying shrinkage
  - Reduce the paste content
  - Lower the w/cm ratio
  - Use SCMs

Mitigating Impacts of RCA on Concrete Durability

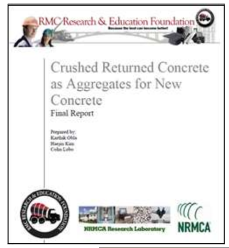
- RCA can increase permeability
  - RCA contains an interfacial transition zone (ITZ)
  - Using RCA in new concrete adds another ITZ
  - Use higher quality source concrete
  - Lower the w/cm ratio
  - Use RCA as only a fraction of the natural aggregate
- RCA can decrease freeze-thaw resistance
  - Use known sources of RCA with acceptable entrained air void systems
  - Ensure adequate air entraining admixture used for new concrete
- Abrasion resistance – depends on quality of source concrete aggregates
  - Use source concrete with good performance
  - If virgin aggregates in source concrete were not associated with skid resistance issues, the RCA concrete will likely not have issues

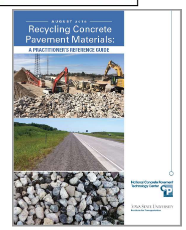
Mitigating Impacts of RCA on Concrete Durability

- Alkali-Aggregate Reactivity
  - Susceptibility of RCA concrete to AAR depends on remaining reactivity of aggregates in the source concrete
  - Crushing process may also result in exposure of new unreacted or partially reacted material in the RCA
  - Follow AASHTO R 80 protocol for assessing risk of alkali-silica reactivity (ASR)
  - Conventional AAR mitigation approaches can be used
    - SCMs and lithium compounds
    - Blending of AAR-susceptible RCA with non-reactive aggregates
- D-cracking
  - Susceptibility of RCA concrete to D-cracking depends on source concrete's aggregates
  - May be reduced since new concrete contains a lower volume of original aggregate
- Certain pavement projects constructed with RCA susceptible to ASR and D-cracking have showed acceptable field performance (Snyder et al. 2018, Zeller 2016)

Use of RCA in Concrete Mixtures

- Recycling Concrete Pavement Materials: Practitioners Reference Guide (2018)
- ACPA EB043P - Recycling Concrete Pavements
- NRMCA Report - Crushed Returned Concrete as Aggregates for New Concrete (2007)
- AASHTO M319, MP16.
- U.S. FHWA TA 5040.37
- ASTM, ISO, (BS) EN and other standards





Mixture Proportioning Approaches for RCA Concrete

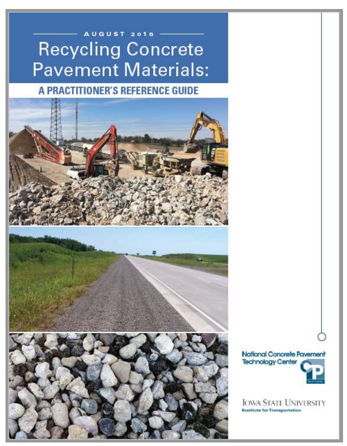
- <u>Direct replacement method – treats RCA as conventional aggregate</u>
  - Absolute volume method (ACI 211, ACI 325) used successfully for many projects

- <u>New methods recently developed specifically for RCA</u>
- Equivalent mortar volume method (Fathifazl et al. 2009)
  - Ensures mortar content of RCA mixture is equal to that of the conventional mixture
- Empirical method (Hu et. al 2013)
  - Nomograph-based procedure
- NJIT method (Adams and Jayasuriya 2019)
  - Developed using models produced from statistical analysis of more than 100 published studies on RCA concrete
- University of Nebraska method (Mamirov et al. 2021)
  - Uses optimized particle packing models, then a minimum excess paste-to-aggregate ratio

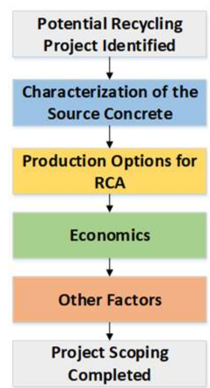
Guidance – Recent! 2018

- Ch. 1: Introduction to Concrete Pavement Recycling
- Ch. 2: Economics and Sustainability
- Ch. 3: Project Selection and Scoping
- Ch. 4: Using RCA in Pavement Base Products
- Ch. 5: Using RCA in Unbound Aggregate Shoulders
- Ch. 6: Using RCA in Concrete Paving Mixtures
- Ch. 7: Mitigating Environmental Concerns

92 pages of useful technical info, many case studies, and up-to-date implementation guidance



Ch. 3 Project Selection and Scoping



Structured around a <u>flowchart</u> showing typical project selection and scoping process

- Includes checklist of considerations for use of RCA in different applications
  - Materials considerations
  - Production considerations
  - Other considerations

Ch. 3 Project Selection and Scoping

✔ Checklist of considerations for use of RCA in different applications

RCA use	Materials considerations	Production Considerations	Other considerations
New RCA concrete and stabilized base materials	• Sources • Specifications	• Processing options • Hauling • Crusher types • Production rates/storage • QA/QC • Residuals management	• Project staging • Costs • Environmental considerations • Permitting • Public perception
Unbound bases and drainage layers			
Filter material around drainage structures			
Fill (beneficial reuse of fines) not in pavement structure			

! Highly simplified table shown here !
See Reference Guide for all details…

Guidance – Coming Soon

- Use of RCA in Concrete Paving Mixtures

- Use of Construction Byproducts in Concrete Paving Projects
  - RCA and RCA fines
  - Discusses use in bound/unbound bases, fills, concrete
- ACI 555
  - Reuse of Hardened Concrete
  - Use of Recycled Concrete Aggregate in Unbound Applications

References

- Adams, M.P. and Jayasuriya, A. (2019). "Guideline Development for Use of Recycled Aggregates in New Concrete." Final Report, ACI CRC 18.517.
- Fathifazl, G., Abbas, A. G., Razqpur, A.G., Isgor, O.B., Fournier, B., and Foo, S. (2009). New Mixture Proportioning Method for Concrete Made with Coarse Recycled Concrete Aggregate. Journal of Materials in Civil Engineering, 21(10), 601–611.
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Recycled Concrete Aggregates

Matt Fonte

Concrete Operations Manager

Castle Rock Construction Company (CRCC)

CRCC's Recent History with RCA

At the end of 2021:

~ 2,000,000 SY of concrete pavement with RCA

~ 500,000 CY of RCA concrete produced

~ 150,000 Tons of RCA

~ $1,500,000 saving on material alone

Why CRCC uses Recycled Concrete for Aggregates

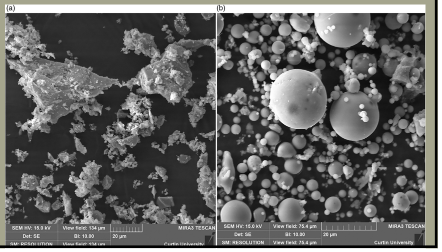
- More competitive at bid time
  - There is a large cost savings to the owner
- Improves our quality
  - We produce smoother pavements using RCA
- Recycling is the responsible way to conserve our natural resources

Aggregate Qualifications

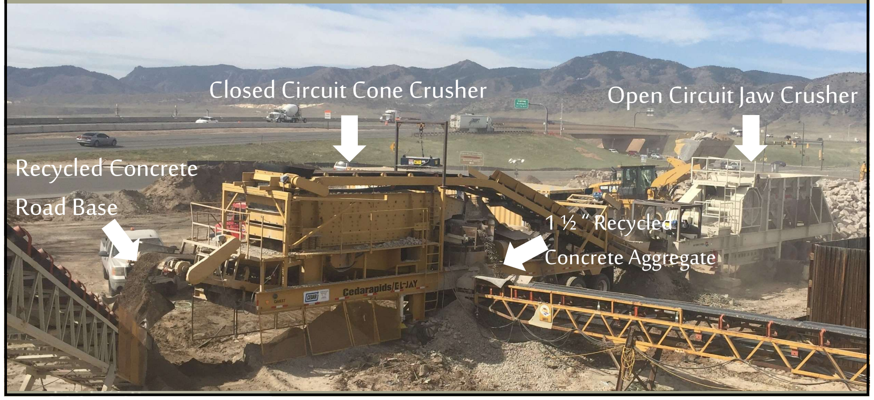
- RCA should be classified to meet C33 requirements
  - Consideration should be given to the following test.
    - Magnesium sulfate soundness test
    - Light weight particles test
    - LA abrasion test.

What about ASR?

- Can you use concrete with known ASR as an RCA? Yes
- Will Type F Fly Ash Mitigate ASR? Yes



The Crushers



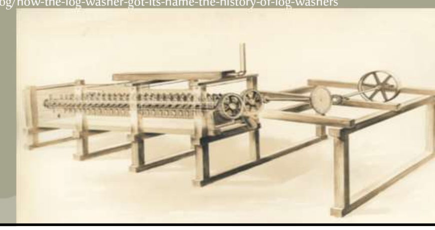
Stockpiles & Segregation

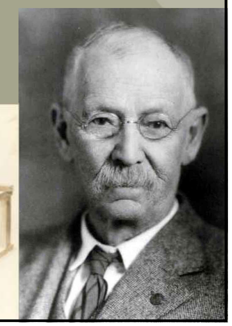
Wetting The Aggregates

The Log Washer

McLanahan Corporation

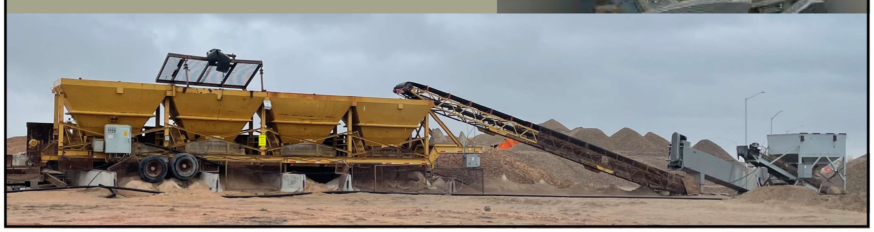
- Designed by Samuel Calvin McLanahan
- Patent was granted in 1891
- Original design the paddles attached to 2 wood log shafts.
- https://www.mclanahan.com/blog/how-the-log-washer-got-its-name-the-history-of-log-washers





Coarse Material Washer

Same principle as the log washer



What do you do with the dirty water?

Series of ponds and weirs

Occasionally clean the sediment out of the ponds

Water Clarifier

Then we go pour some concrete

Any Reason You Wouldn't Use RCA?