Case Studies in Concrete Pavement Recycling

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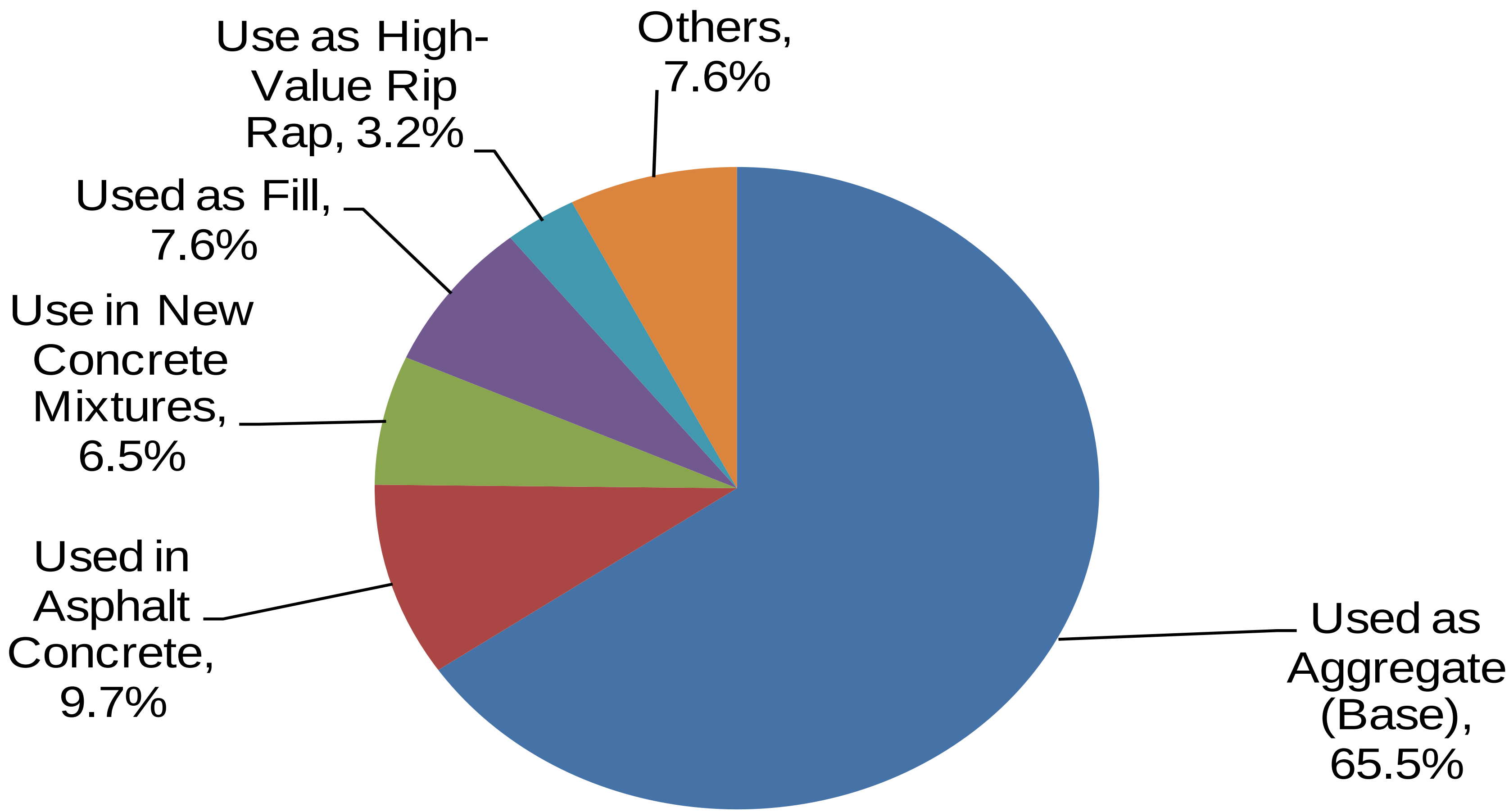
What is Concrete Recycling?

- 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!***

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 2

Performance of Pavements Constructed using RCA

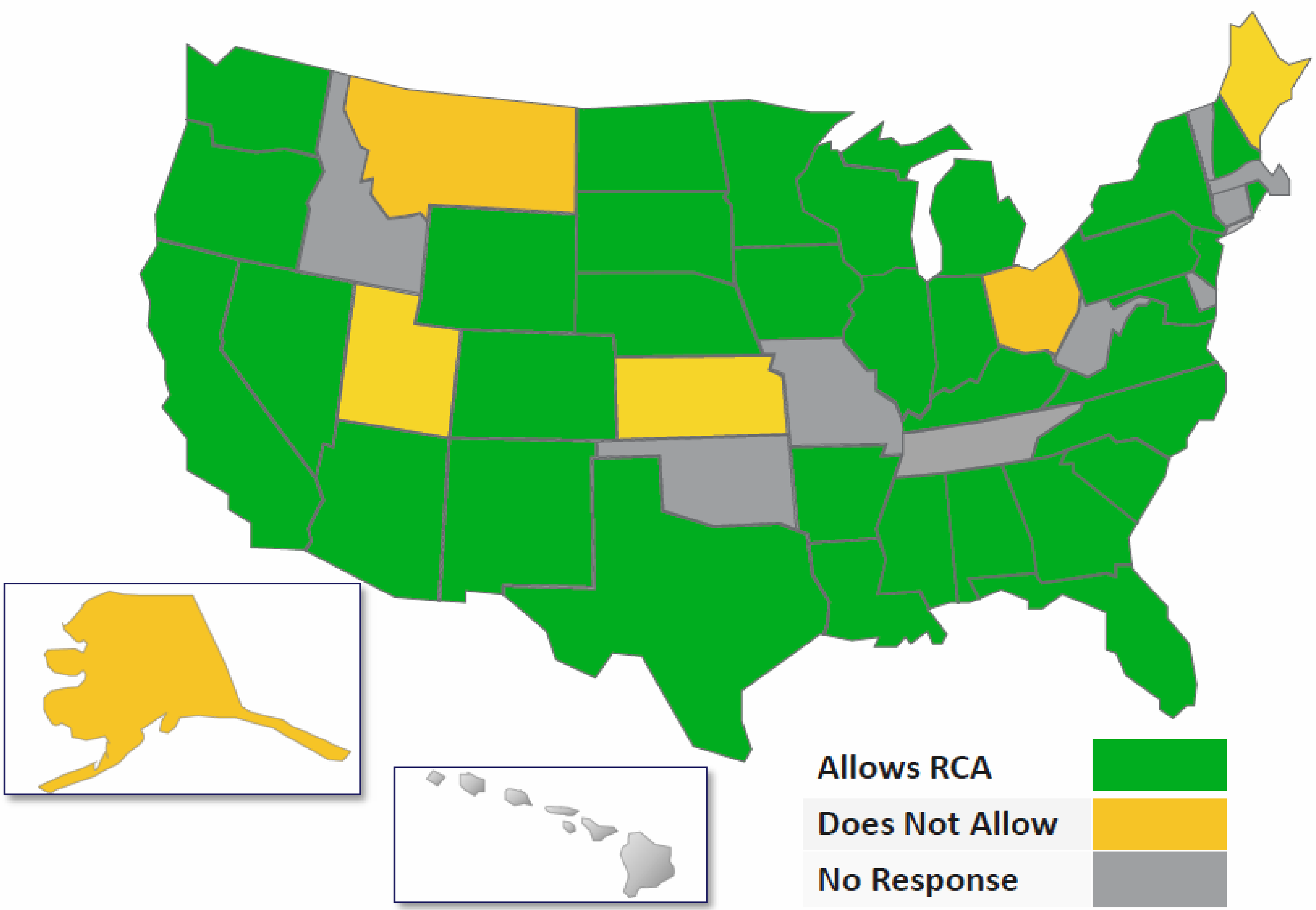
There have been a few notable (and well-publicized) failures when used in PCC ....

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

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

Very rarely have structural problems been reported with the use of RCA in foundation layers.

2012 CMRA Survey of RCA Use in Base Applications



Case Study: 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.

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

Tollway Objective is to Rebuild in the Greenest and Cleanest Way Possible

- **The goal is to recycle 100% of the original pavements and structures back into the new pavements**
  - RAP
  - RCA
  - Existing Subbases
- **Improve sustainability further using as many waste products as possible**
  - Fly Ash / Slag in PCC
  - Roof shingles in Asphalt
  - Ground tires in Asphalt

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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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On-Site Processing for Porous Granular Embankment (PGE) Subbase - Mobile

- Processing RCA as a PGE (6” max.) aggregate was initiated by IDOT to construct 12” min. thickness bases (3” dense graded cap over 9” PGE)
- On initial Tollway reconstruction projects mobile processors followed the excavation process down the road
- Too much subbase / subgrade contamination and segregation resulted

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On-Site Processing for Porous Granular Embankment (PGE) Subbase - Stationary

- Today with stricter control on gradation, the 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 reduced to 5" to allow for thinner bases

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Off-Site Processing for Porous Granular Embankment (PGE) Subbase - Stationary

- When the base design requires a 9” or greater layer of PGE, then IDOT certified off-site RCA processing sites are sometimes used
- These sites commonly blend up to 50% of the RCA with clumps of asphalt

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

Other RCA Options

- **RCA may be used as a pre-saturated coarse aggregate in concrete for new PCC pavements**
  - Not yet used because of base stone demands
  - With pavement design controlling criteria revisions more applications to new pavement concrete may be coming
- **Specifications are being developed to allow for dense graded 1.5” RCA to be used for compacted cement treated bases and for unbound subbase aggregates under cement treated bases where underdrains will not exist**

Weighted Cost Savings Replacing Virgin Subbase Aggregate with Rubblization

- **Extra quantities without rubblization (27.9 miles of four lane I-88 rebuilt with full depth asphalt in 2005)**
  - Excavation (14” PCC removal + undercuts) – 584,841 cu. yds.
  - 12” Subgrade Aggregate + undercut backfill – 818,400 cu. yds.
  - 2” of HMA added w/ weaker nonrubblized base – 45,830 tons

- **Cost to reconstruct with virgin aggregate base**
  - Excavation / disposal – 584,841 cy x $12.00/cy = $7,018,092
  - Virgin agg. & backfill - 551,056 cy x $20.00/cy = $11,021,120
  - Extra asphalt – 45,830 tons x $50.00 / ton = $ 2,291,500

Total cost = $20,330,712

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Weighted Cost Savings Replacing Virgin Subbase Aggregate with Rubblization

- **Quantities to reconstruct 27.9 miles of I-88 with PCC rubblized bases**
  - PCC Mainline area = 808,850 sq. yds.
  - PCC Shoulder area = 517,664 sq. yds.
  - Mainline rubblization bid price = $1.816/sq yd (weighted ave)
  - Shoulder rubblization bid price = $0.682/sq yd (weighted ave)

- **Costs to reconstruct with rubblized bases**
  - Mainline rubblization = $1.816 x 808,850 = $1,468,872
  - Shoulder rubblization = $0.682 x 517,664 = $353,047

Total $1,821,919

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Weighted Cost Savings Replacing Virgin Subbase Aggregate with Rubblization

- **Total savings based on 2005 dollar value**
  - $20,330,712 for total reconstruction
  - $ -1,821,918 for rubblization
  - $18,508,794 for total savings

- **Total savings normalized to 2015 dollar value using ENR construction cost indices between 2005 and 2015 that indicate a ratio of 1.32**
  - $18,508,794 x 1.32 = $24,431,608 total savings based on 2015 dollar value

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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 = $6 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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Case Studies of RCA in Minnesota Pavement Foundations

Overview

- MnDOT has used RCA in pavement base since the 1980s
- Concerns:
  - Precipitate and other fines - do they impair drainage systems?
  - Recementing of RCA to form CTB
  - Reduced stability of open-graded RCA
  - Environmental impact of runoff
- Performed field evaluations at several sites in 1980s and 1990s

I-90 Near Austin, MN

- 1985 - Reconstructed using RCA base.
- 1987 - Some drain pipes 1/4 filled.
- 1989, 1993 - Permittivity testing.
  - 50% loss after 4 years
  - 60-75% loss after 8 years
  - Greater losses on top, side of pipe.
- Mainly carbonate-based material present.

Test Beds near Lakeville, MN

- Constructed in 1989.
  - #1 - RCA fines, unwrapped pipe, fine backfill
  - #2 - RCA fines, wrapped pipe, fine backfill
  - #7 - RCA fines, unwrapped pipe, permeable backfill
- Testing terminated in 1992.
  - Some losses of permittivity, little precipitate
    - Greater on top (~40%) than bottom (5-27%)
    - Mainly carbonate materials, but 30-40% other.

Test Beds near Lakeville, MN -Conclusions-

- Drainage did not deteriorate
- Better flow using unwrapped pipe
- pH rarely exceeded that of “hard” tap water, generally decreased over time
- Some deposits in pipes, no apparent loss of drainage function
- Some cementing of fine backfill aggregate

TH 15 near Hutchinson, MN

- Constructed in 1991 after Lakeville.
  - #1 - RCA fines, unwrapped pipe NB, wrapped pipe SB, fine backfill
  - #2 - RCA coarse and fines, unwrapped pipe NB, wrapped pipe SB, fine backfill
  - #8 - open-graded RCA base, unwrapped pipe, permeable backfill
- Tipping bucket data collected for several years after construction.

TH 15 near Hutchinson, MN
-Conclusions-

- Less outflow from wrapped pipes.
- Less outflow from 100% RCA section.
- RCA blend outflow comparable to control.
- Open-graded outflow greater than blend.
- Use open-graded RCA, unwrapped pipes, permeable backfill???

Test Piles near Shakopee, MN

- Constructed summer 1993
  - Open-graded, coarse RCA
  - RCA fines
  - Dense-graded, recycled asphalt concrete
- RCA runoff pH decreased over time
  - Coarse: 10.5 to 9.7 over three months
  - Fine: ~11+ to 9.5 over three months
- RCA fines strongly recemented

Key Conclusions

- Unwrapped pipes in permeable backfill exhibit better flow characteristics than other drainage systems.
- High-permittivity filter fabrics appear to provide acceptable long-term performance in presence of precipitate and ISR.
- Accumulations of precipitate and ISR do not appear to significantly reduce flow capacity of most pipe drains.
- Recementing of fines probably does occur.
- Effluent from RCA foundation layers is probably highly alkaline at first, but decrease with time.

Structural Considerations for RCA in Unbound Foundation Layers

- RCA has been widely and successfully used in unbound subbase and fill applications.
- Literature: contains no reports of pavement performance 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.
  - Problem disappears with less dense gradations (k>300 ft/day)
- Sulfate attack of RCA in high-sulfate soil at Holloman AFB, NM

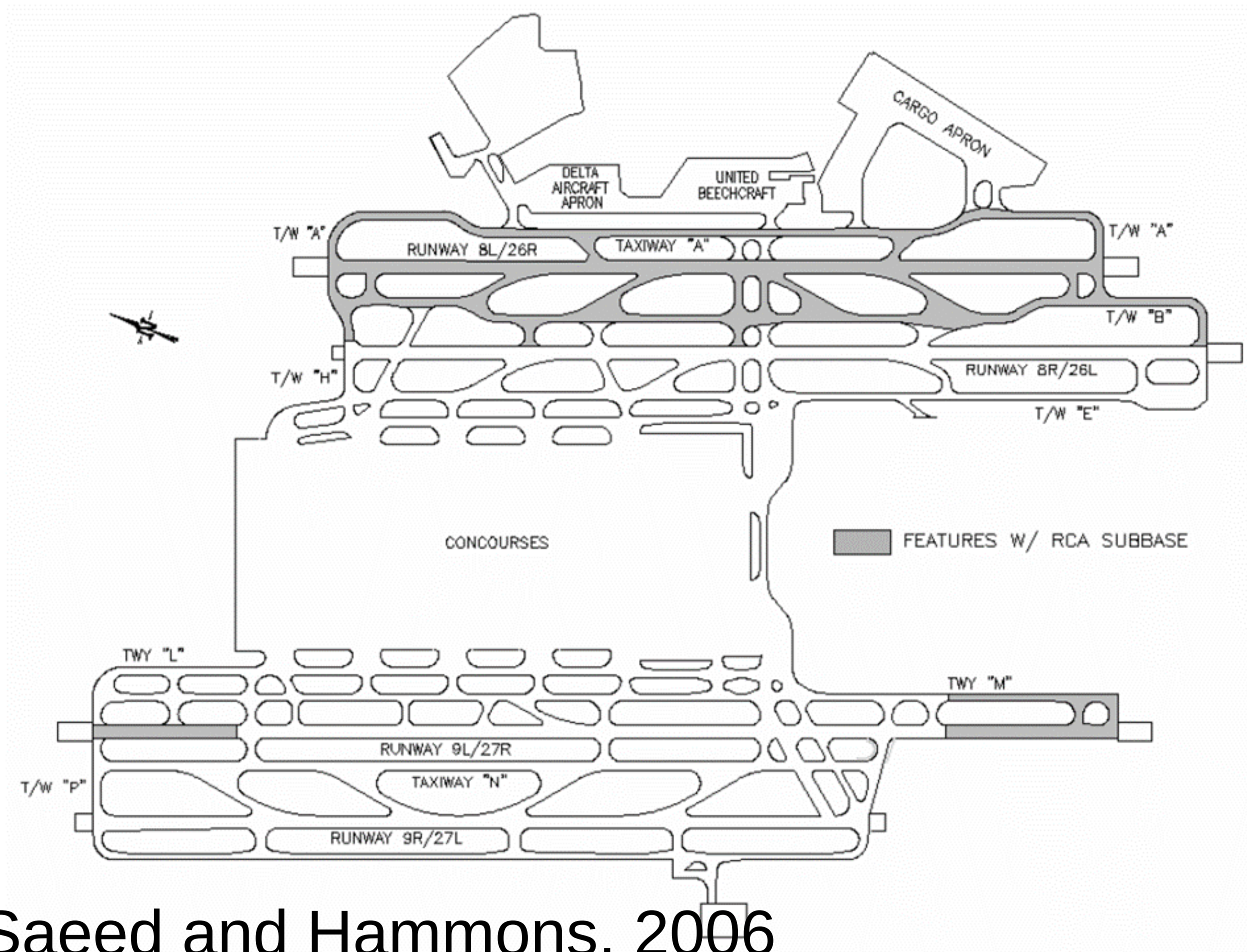
Use of RCA in Stabilized Base: Michigan DOT

- Special Provision for Cement-treated Perm Base Using Crushed Concrete
- Done, in part, to reduce precipitate from open-graded RCA drainage courses
- Mix Design:
  - 250 lbs cement, 100 – 120 lbs water
  - 1.5-in top size aggregate, 0 – 8% passing #8, <5% passing #200
  - F'c (7-day) = 200 – 700 psi
- Good performance reported for all sections

Source: Van Dam et al, 2011

Use of RCA in Stabilized Base: ATL Int'l Airport

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



Source: Saeed and Hammons, 2006

FHWA-Sponsored Research

Physical and Mechanical Properties of Recycled PCC Aggregate Concrete 1993 - 1999

PERFORMANCE OF CONCRETE PAVEMENTS CONTAINING RECYCLED CONCRETE AGGREGATE

Task B Draft Interim Report

Prepared For:

Federal Highway Administration

Prepared Under:

FHWA Contract DTFH61-93-C-00133,
Physical and Mechanical Properties of Recycled PCC Aggregate Concrete

Prepared By:

University of Minnesota
ERES Consultants, Inc.

December 1995

1994 Field Study Sections

Category	Location	Climatic Region	1994 Age, Yrs	Control Section	2 Way ADT, veh/day	Pavement Type (% long. reinf.)	Joint Spacing, ft	Dowel Diam., in
1 (Good)	CT 1, I-84 near Hartford	W-F	14	yes	56,000	9-in JRCP (0.10 %)	40	1.5 (I-beam)
	MN 1, I-94 near Brandon	W-F Transition	6	yes	8,170	11-in JRCP (0.06 %)	27	1.25
	KS 1, K-7 Johnson County	W-F	9	yes	7,310	9-in JPCP (n/a)	15	None
2 (Structural Problems)	MN 4, US52 near Zumbrota	W-F	10	yes	7,820	9-in JRCP (0.06 %)	27	1.0
	MN 2, I-90 Beaver Creek	W-F Transition	10	no	1,670	9-in JRCP (0.06 %)	27	1.0
	WI 1, I-94 near Menomonie	W-F	10	no	8,170	11-in JPCP (n/a)	12-13-19-18	None / 1.375
3 (Other Distresses)	MN 3, US59 near Worthington	W-F Transition	14	no	2,150	8-in JPCP (n/a)	13-16-14-19	None
	WI 2, I-90 near Beloit	W-F	8	no	22,622	10-in CRCP (0.67 %)	n/a	n/a
	WY 1, I-80 near Pine Bluffs	D-F	9 / 10	yes	4,410 (RCA) 4,280 (Con.)	10-in JPCP (n/a)	14-16-13-12	None

1994 Field Evaluation

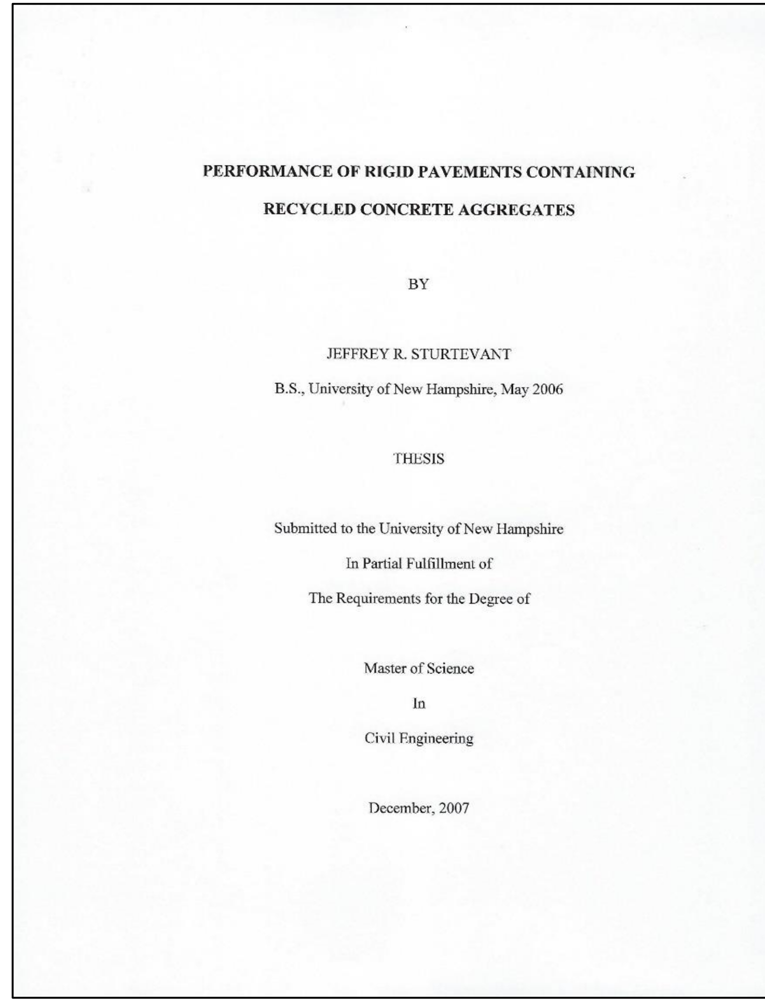
- Condition Survey
- Drainage Survey
- FWD
- Coring
  - Midpanel
  - Joints
  - Cracks
- Crack, Joint Width
- Faulting
- PSR
- Photolog

1994 Lab Testing

- Compression
- Split Tension
- Static E
- Dynamic E
- α
- Surface Texture
  - Sand Patch
  - Profilometer
- Freeze-Thaw
- Linear Traverse
- Petrography

FHWA-Sponsored Research

Performance of Concrete Pavements Containing Recycled Concrete Aggregate (2006)


PERFORMANCE OF RIGID PAVEMENTS CONTAINING

RECYCLED CONCRETE AGGREGATES

BY

JEFFREY R. STURTEVANT

B.S., University of New Hampshire, May 2006

THESIS

Submitted to the University of New Hampshire

In Partial Fulfillment of

The Requirements for the Degree of

Master of Science

In

Civil Engineering

December, 2007

2006 Added Field Study Sections

Category	Location	Climatic Region	2006 Age, Yrs	Control Section	2 Way ADT, veh/day	Pavement Type (% long. reinf.)	Joint Spacing, ft	Dowel Diam., in
3 (Other Distresses)	IA 1, US 75 near Rock Rapids	W-F	30	no	2,150	9-in JPCP (n/a)	13-16-14-19	None
	IL 1, I-57 near Effingham	W-F	20	no	4,410 (RCA) 4,280 (Con.)	10-in CRCP (n/a)	n/a	n/a

2006 Field Evaluation

- Condition Survey
- Drainage Survey
- Coring
  - Midpanel
  - Joints
  - Cracks
- Crack, Joint Width
- Faulting
- PSR
- Photolog
- [No FWD]

2006 Lab Testing

- Compression
- Split Tension
- Static E
- Modified ASTM C 1293 (ASR)
- ASTM C 856 (Uranyl Acetate)
- Volumetric Surface Texture
- Petrography

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
Aggregate Top Size, inches	1.0	1.5
Average VSTR, cm^3/cm^2	0.2902	0.3264
Total Mortar Content (New + Recycled), %	74	52
Coefficient of Thermal Expansion, F $degrees^{-1}$	6.9	6.6

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.

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!

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

Case Study: Recycling D-Cracked Concrete into US TH 59 in Minnesota

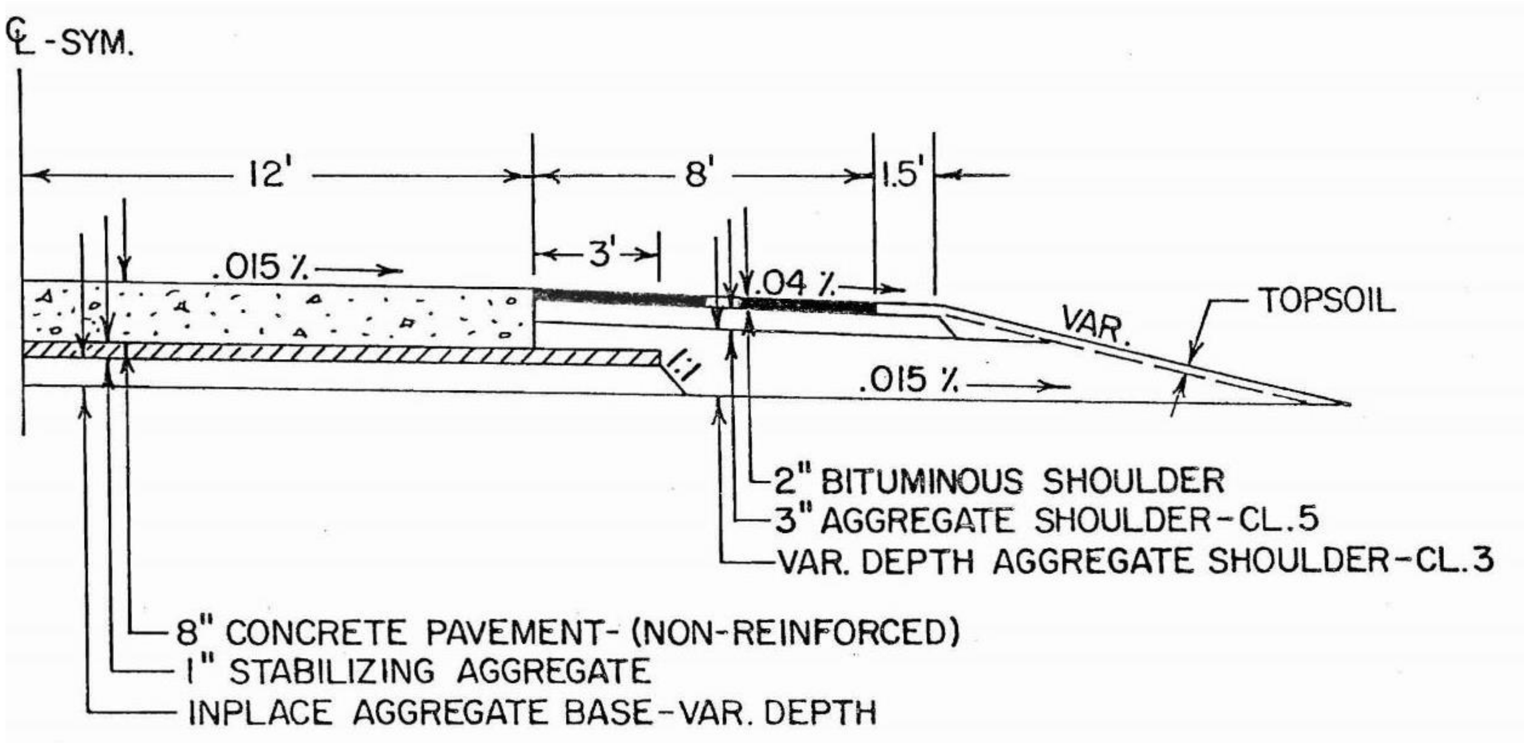
For additional information, see
presentation by Matt Zeller, Concrete Paving Association of MN
For Workshop 3: Recycled Concrete Aggregate
11th International Conference
on Concrete Pavements (ICCP)
San Antonio, Texas, USA
2016

Original Construction

- Mix Design???
- Coarse aggregate sources:
  - Hallett Edgerton
  - Hallett Luverne
- Both D-cracking gravel aggregates with >50% limestone
- Current MnDOT spec limit is <30%

1980 Reconstruction

- ~3000 vpd, ~8 percent heavy commercial
- 8-in thickness, 24-ft width, 16 centerline miles
- 15.5’ effective skewed, undoweled transverse joints
- 1955 base left in place, capped with 1”+ RCA fines
- Longitudinal edge drains added



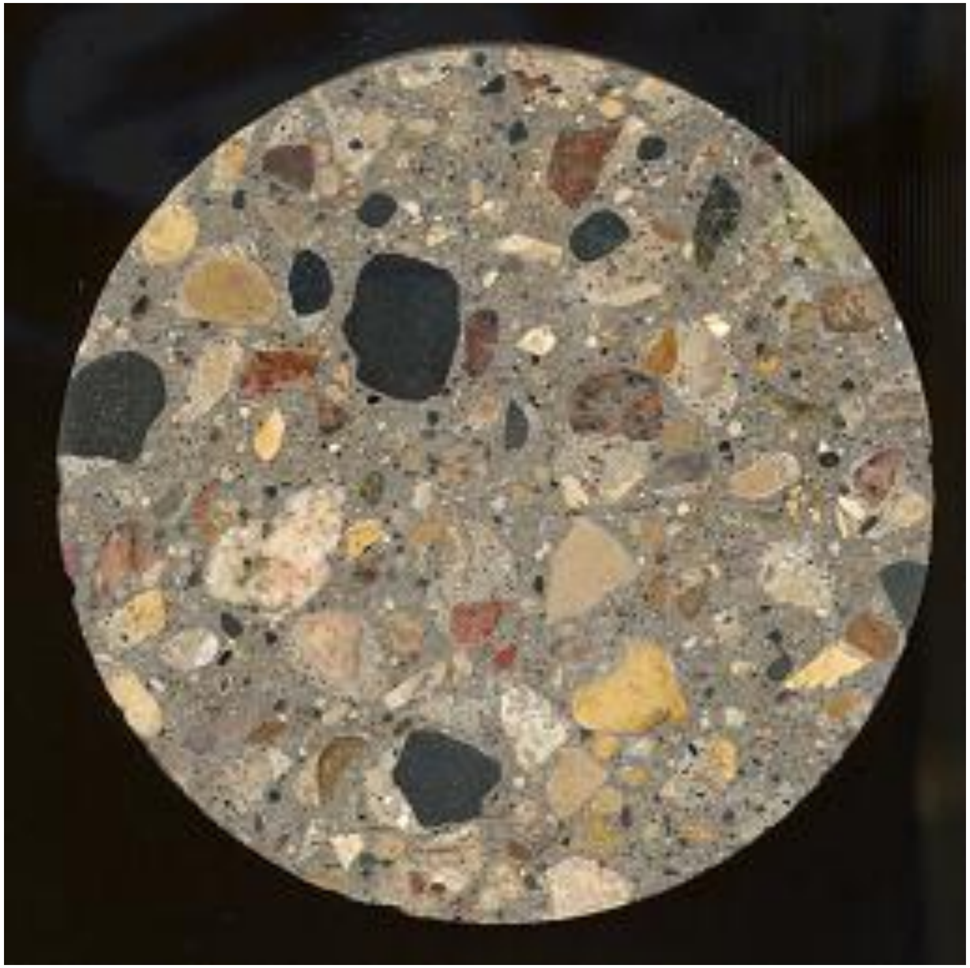
1980 Reconstruction – Procedures

- Remove asphalt overlay and joint seal material
- Break pavement with a diesel hammer
  - ~2-ft fragment size
- Primary crusher: jaw-type 36 in. x 48 in.
- Secondary crusher: 54-in. cone-type
- Products:
  - Coarse: 95 - 100 % passing ¾-in, 0 - 5% passing #4
  - Fine fraction used as stabilizer/cap for granular base

1980 Reconstruction

- Mix Design – 3A20R
  - 465 lb cement
  - 109 lb fly ash
    (465 lb cement + 109 lb fly ash = 574 lb total cementitous)
  - 255 lb water
  - 1198 lb sand
  - 1653 lb RCA (4.5% absorption)
  - 5.5% air
  - 14-day flex strength ~700 psi
- w/c = 0.44 (theoretical)
- *First major recycle of D-cracked PCC into new PCC!*
- RCA aggregate properties
  - 3/4" top size (for freeze-thaw durability)
  - Passing #4 sieve was used for base and shoulder
  - Not washed

MN 3 (US 59 Worthington-Fulda) Polished Section



Sturtevant M.S. Thesis - 2007

Estimated Cost Savings

MnDOT estimated savings due to use of recycled concrete aggregate of $600,000 – 700,000 (~27% of total project costs) and 150,000 gallons of fuel.

1994 Evaluation

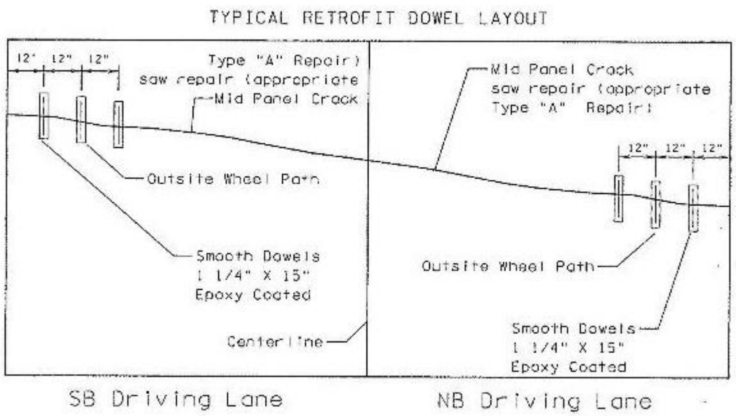
- No recurrent D-cracking observed after 24 years of service
- Primary performance-related problems due to excessive panel length, lack of dowels, lack of drainage
  - Longer skewed panels developed mid-panel cracks
  - Average faulting ~1/4 inch (maximum faulting >1/2 inch)
- Freeze-thaw testing of drilled cores (ASTM C666): DF<60

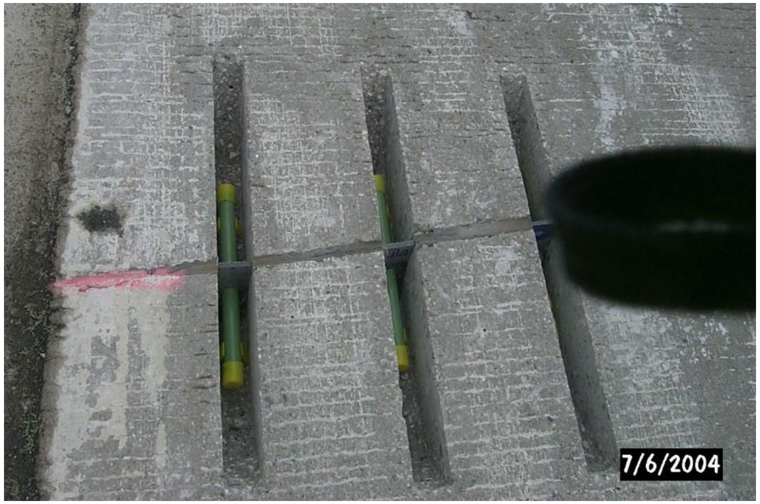
2004 Rehabilitation (CPR)

- Pavement ride quality becoming intolerable (faulting of joints and cracks)
- Concrete samples still failing freeze-thaw test
- Still no recurrent D-cracking
  - Apparently no critical saturation in the field
- MnDOT decided to proceed with CPR due to lack of deterioration

2004 CPR

- Retrofit 1.25” dowel bars at existing transverse joints as well as mid-panel cracks
- 3 bars only in the outside wheel paths (9’, 10’ & 11’ from centerline)
- Diamond grind 100% of mainline pavement
- CPR as necessary
- Reseal transverse joints only (silicone)





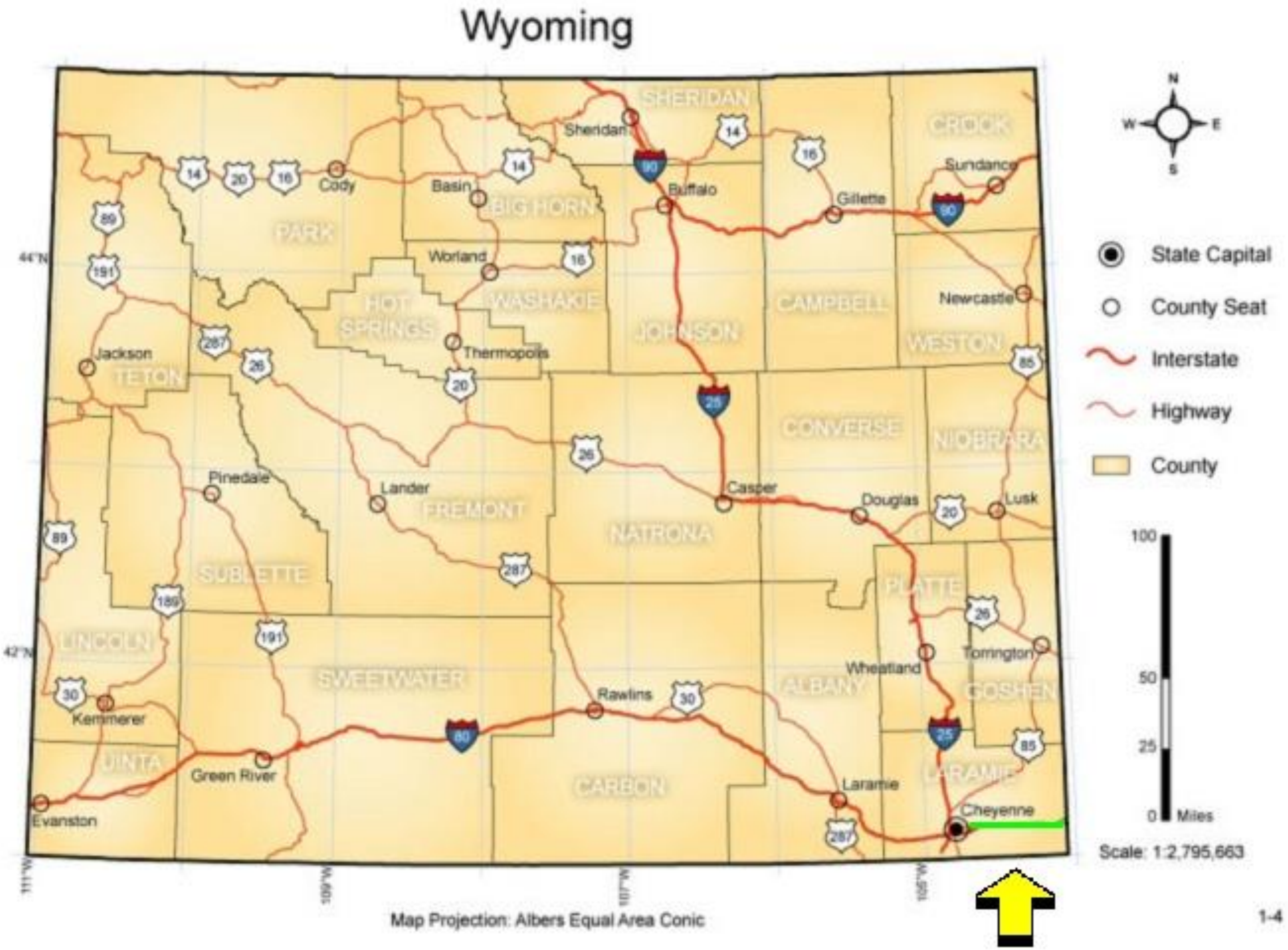
2006 Review

2015 Image

- Good performance after 35 years of service
- Indicates D-cracked pavement can be used to produce RCA for new PCC pavement with appropriate precautions
  - Prevent critical saturation (drainage)
  - Limit aggregate top size

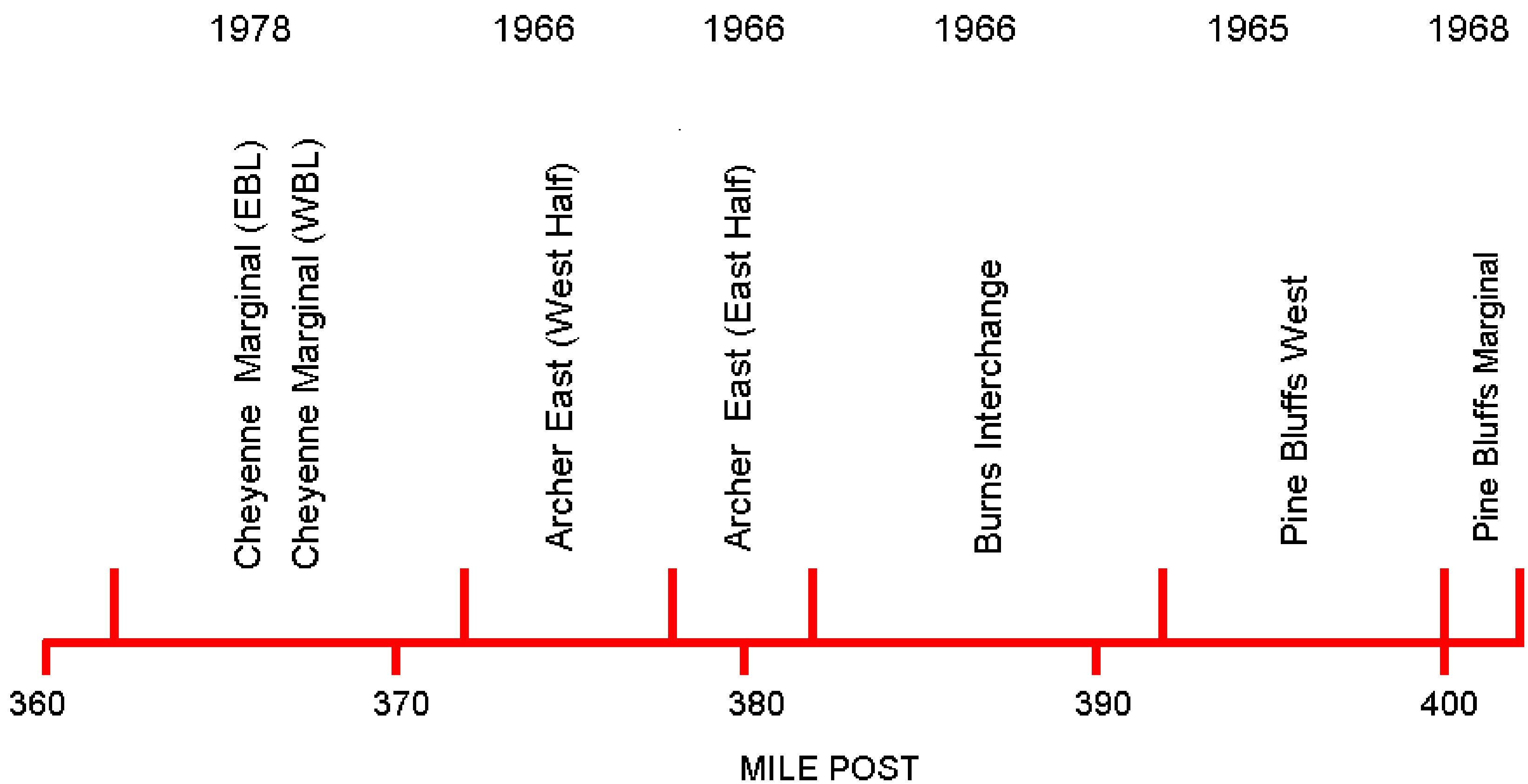
Case Study: Recycling ASR-Distressed Concrete into New Concrete on I-80 (Southeast Wyoming)

For additional information, see presentation by Bob Rothwell, Wyoming DOT
2017 Annual Concrete Pavement Workshop
ACPA CO/WY Chapter
Denver, Colorado



- 40 miles of PCCP constructed 1965 to 1978
- Early distress due to ASR

Original Construction (mileposts and dates)

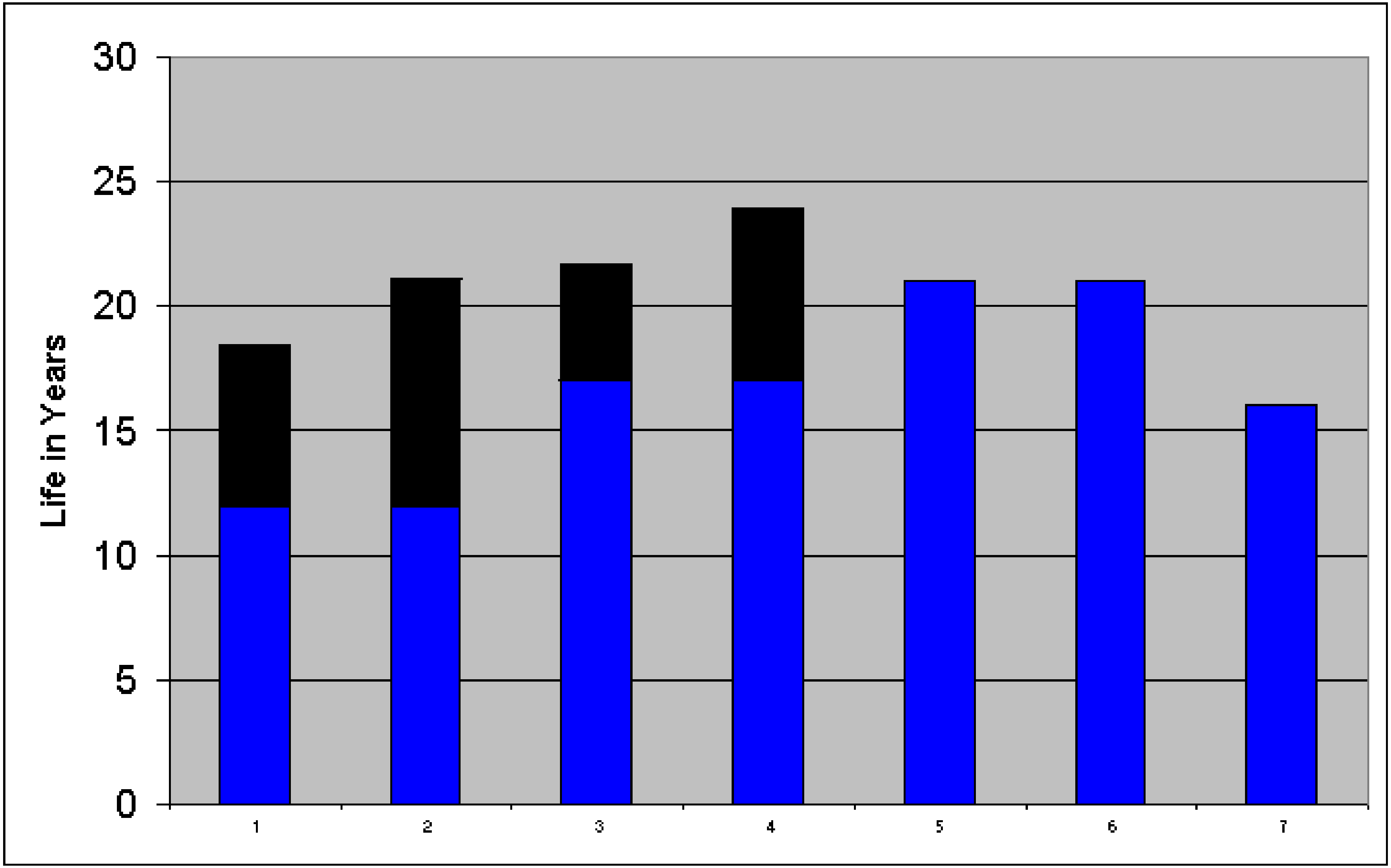


Alkali Silica Reactivity - MP 392 WB

1975

1978

Original Pavement Life



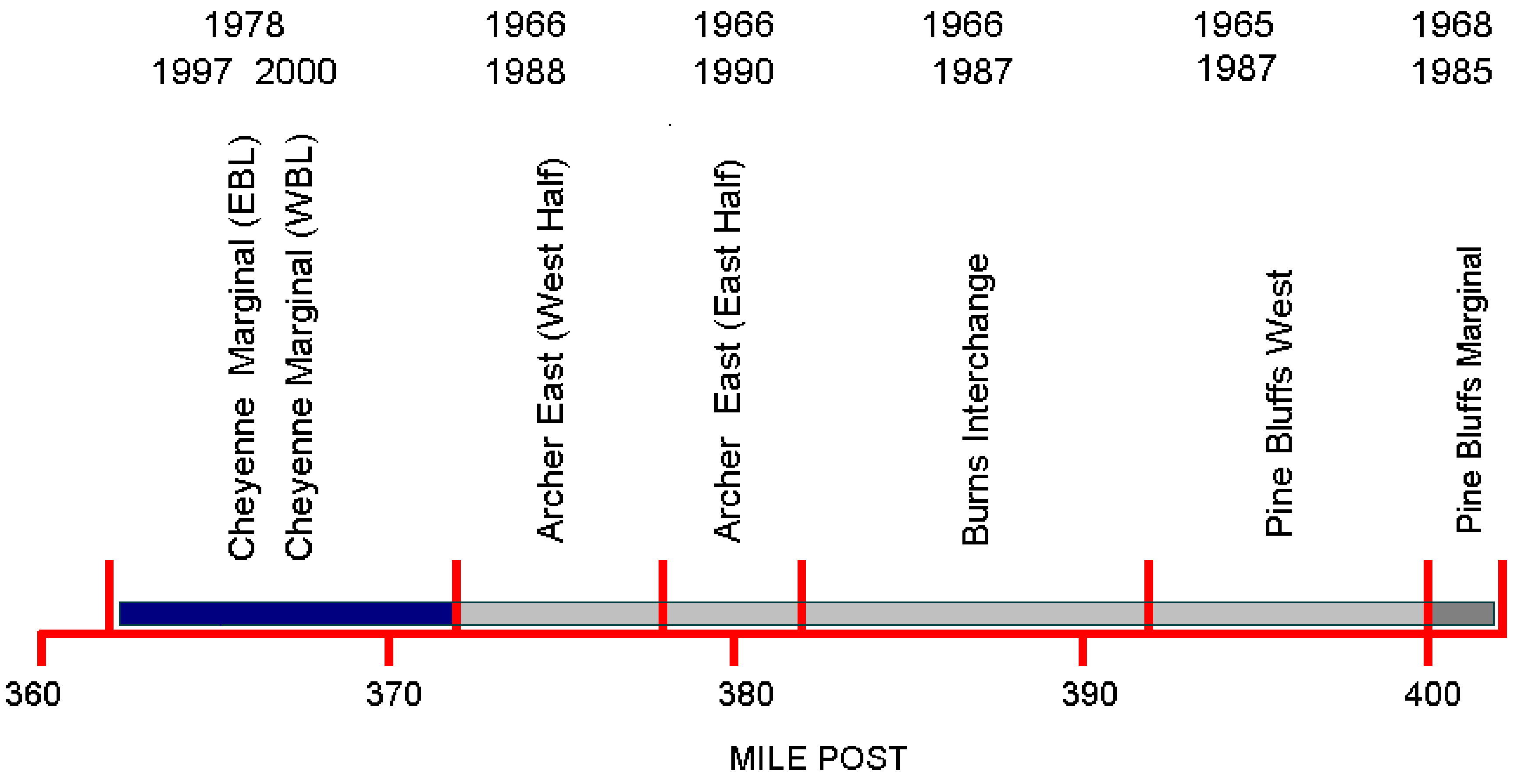
1985 Rehabilitation Options

1) Reconstruction with PCCP
   - Expensive
   - Lack of suitable local concrete aggregates
2) Reconstruction with Plant Mix
   - Rutting Problems of early 1980's
3) Crack-and-Seat with Plant-Mix Overlay
   - Rutting Problems of early 1980's
   - Expense in raising the grade and modifying structures
4) **Reconstruction with Recycled PCCP**
   - **Risk of continuation of ASR**

Reconstruction/Rehabilitation of Original Construction

- 2 miles reconstructed with conventional PCCP (1985)
- 28 miles reconstructed with RCA Concrete (1987 to 1990)
- 10 miles cracked-and-seated, overlaid with 4-inch plant mix, ¾-inch wearing course (1997 to 2000)

Reconstruction Dates



ASR Reconstruction Example: I-80, Pine Bluffs, Wyoming

- 1985 Reconstruction:
  - 65 percent coarse RCA, 22% fine RCA
  - Low-alkali (<0.5%) cement, 30% Class F flyash, w/c = 0.44
  - 4400 ADT in 1985 (30 - 40% heavy)

- 2004 Rehabilitation:
  - DBR, grind, joint reseal
- 2006 ADT: 8000 vpd (30-40% heavy)

RCA-Virgin Blend PCC Mix Design

Coarse Aggregate:
- 1080 lbs Recycled
- 600 lbs Virgin Limestone

Fine Aggregate:
- 280 lbs Recycled
- 800 lbs Virgin

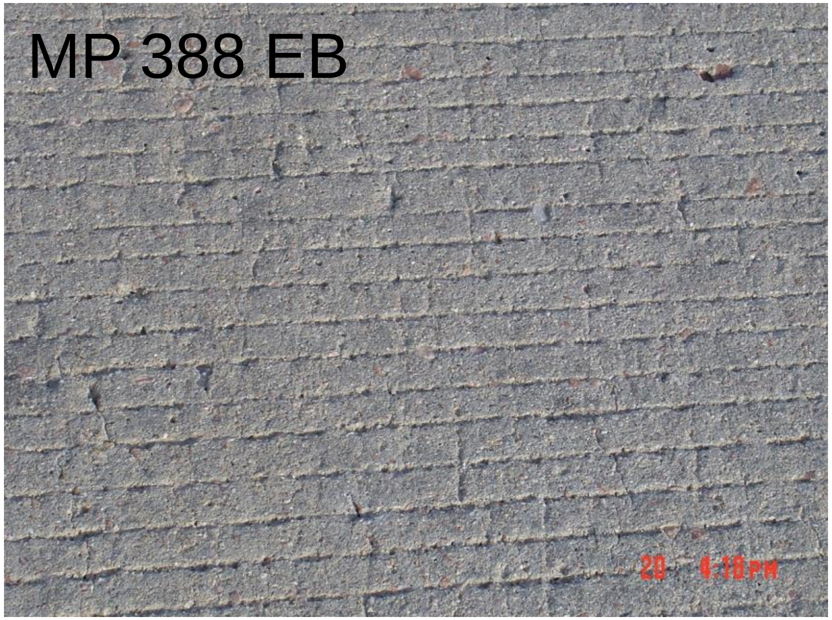
Low-Alkali Cement: 488 lbs

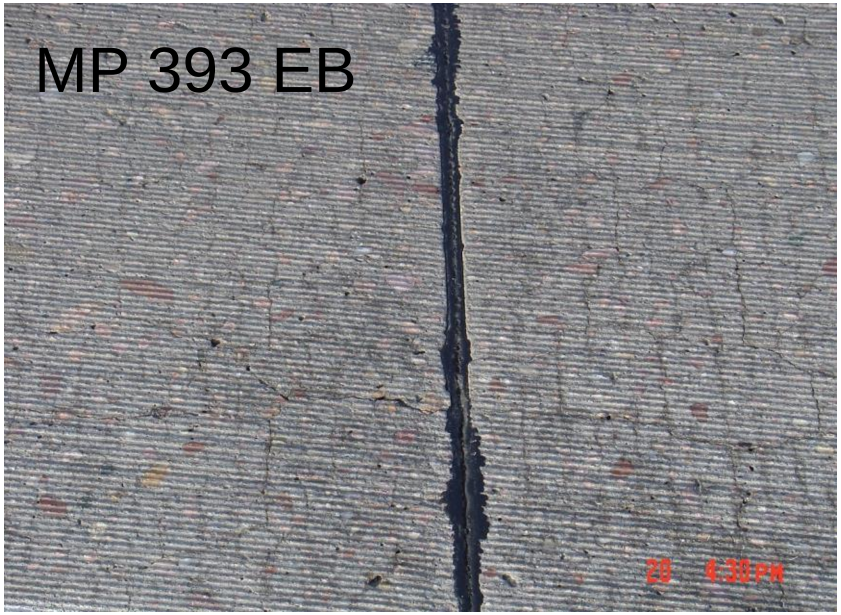
Class F Fly Ash: 133 lbs

w/cm: 0.38

1991 Memo from District Engineer

"It has been brought to my attention that the above referenced area [MP 382 to 393] on I-80 may be developing the reactive aggregate cracking that we experienced before the reconstruction."





Various Studies Followed …

- Dave Stark (CTL, 1991): cores showed "no evidence of new gel reaction product formation or microcracking."
- U-Mn/ERES (1995): small localized areas of recurrent ASR observed
- David Vollmer (CTL, 1997): "…cores submitted do not exhibit deleterious [ASR] … small amount of gel observed appears to be associated with the recycled concrete as aggregate … cracks are not typical of cracks induced by expansion from ASR and no crack is observed containing ASR gel."
- David Campbell (Campbell Petrographic Services, 1997): "An [ASR] reaction appears to be continuing in the recycled concrete and beginning in the host concrete, but neither of these relatively recent developments is beyond the earliest stages."

So What Is The Crack Mechanism?

- ASR
- Shrinkage
- Vibrator-Related
- All of the above?
- Other?

2004 REHABILITATION

Slab Replacement
Dowel Bar Retrofit
Diamond Grinding

DOWEL BAR RETROFIT

- Mixed success related to the integrity of the existing concrete
  - MP 392 to 400: Successful
  - MP 382 to 392: No DBR
  - MP 372 to 382: Many areas exhibiting concrete failures adjacent to dowels
    - No DBR in WB lanes from MP 375 to 377

Successful DBR (MP 393 to 400)

Failing DBRs (MP 372 to 382)

MP 376 EB

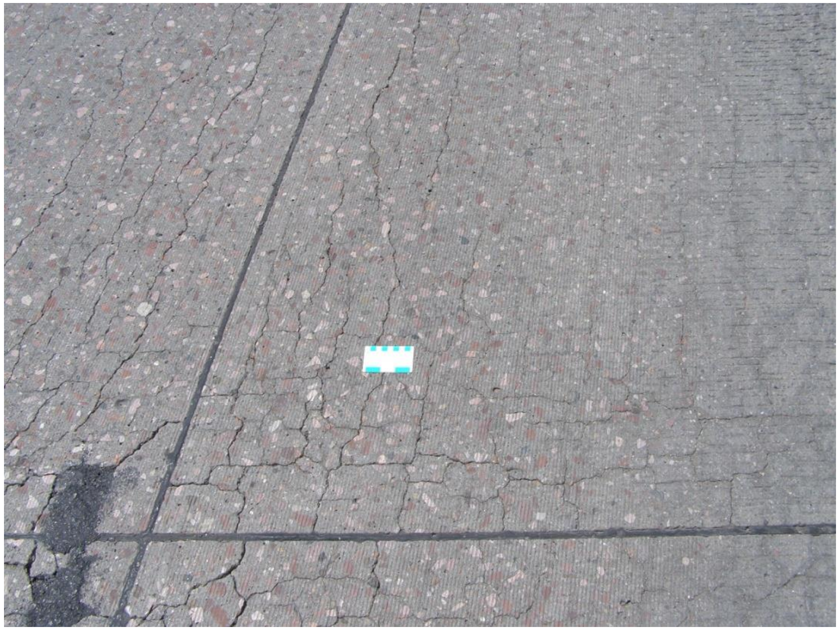
MP 380 EB

Failing/Failed DBRs (MP 372 to 382)

MP 378 EB

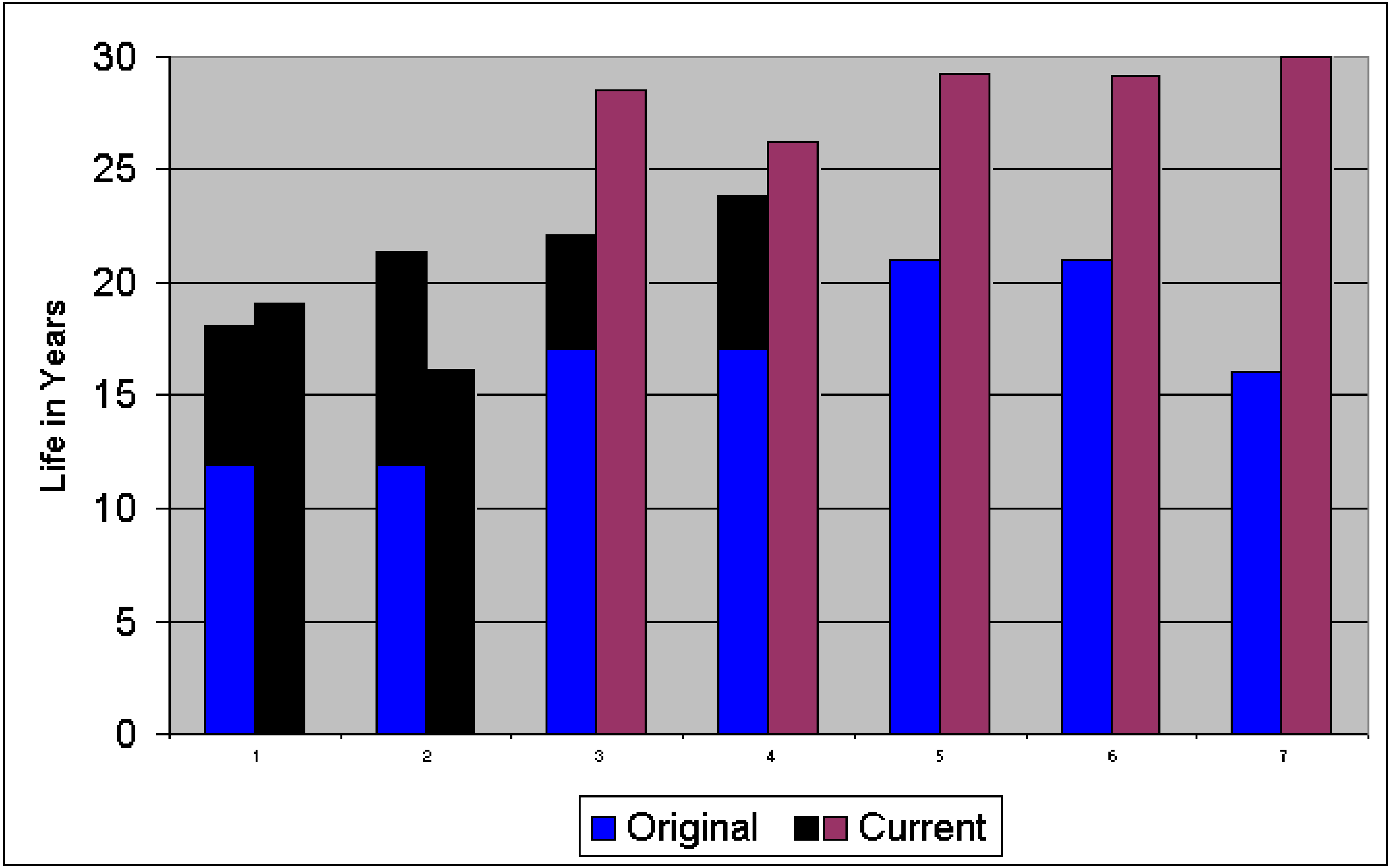
MP 372.4 EB

MP 375.3 to 377.3 WB No Dowels



MP 377 WBL

Reconstruction Pavement Life



Planned Future Rehab

CPR:

<u>Recycled Sections</u>

MP 382 to 393	2021
MP 393 to 400	2022

Plant-Mix Overlays:

<u>Virgin Reconstruction Sections</u>

MP 400 to 402	2015, 2016

<u>Crack and Seat and Overlay Sections</u>

MP 362 to 372	2017, 2019

<u>Recycled Sections</u>

MP 372 to 382	2020

Conclusions

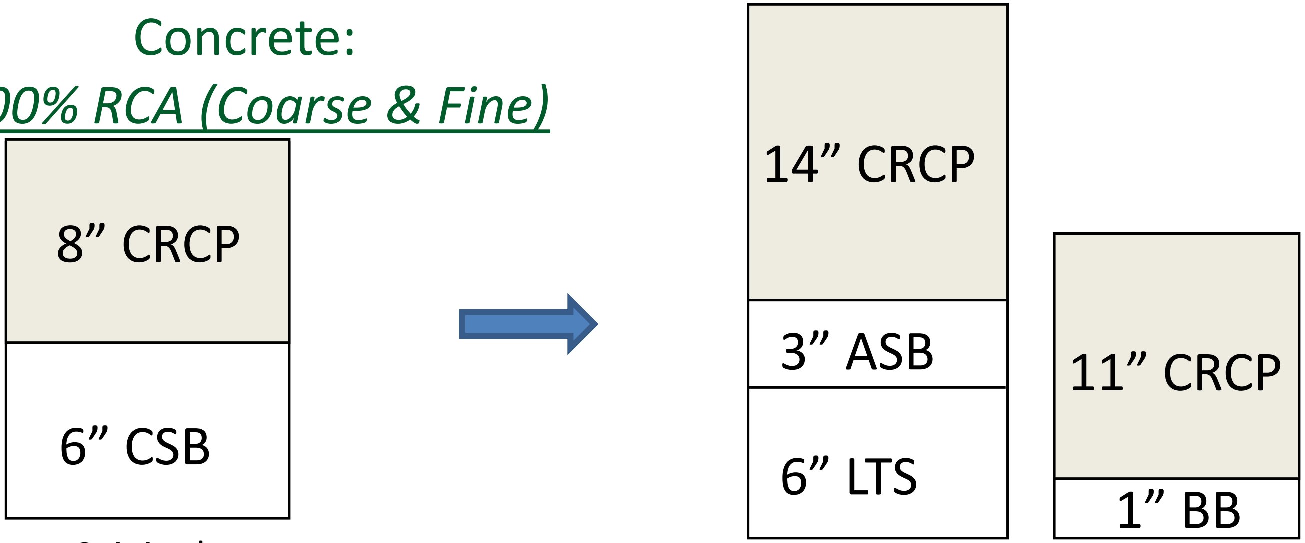
- Recycling of ASR-distressed pavement was successful
  - Continued progression of ASR distress, but at a slow rate
  - 30-year design life achieved
- RCA pavement life being extended with CPR and plant-mix overlays
- DBR pros and cons
  - Reduced faulting, improved ride
  - Increased susceptibility to distress

Case Study: 100% RCA in CRCP Reconstruction on Texas I-10

- Houston, TX between I-45 & Loop 610W
- 1995-98 Reconstruction – 5.8 CL miles
- Original CRCP built in 1968
- 10 Lanes + HOV

No Virgin Aggregates Used for New Concrete:

100% RCA (Coarse & Fine)

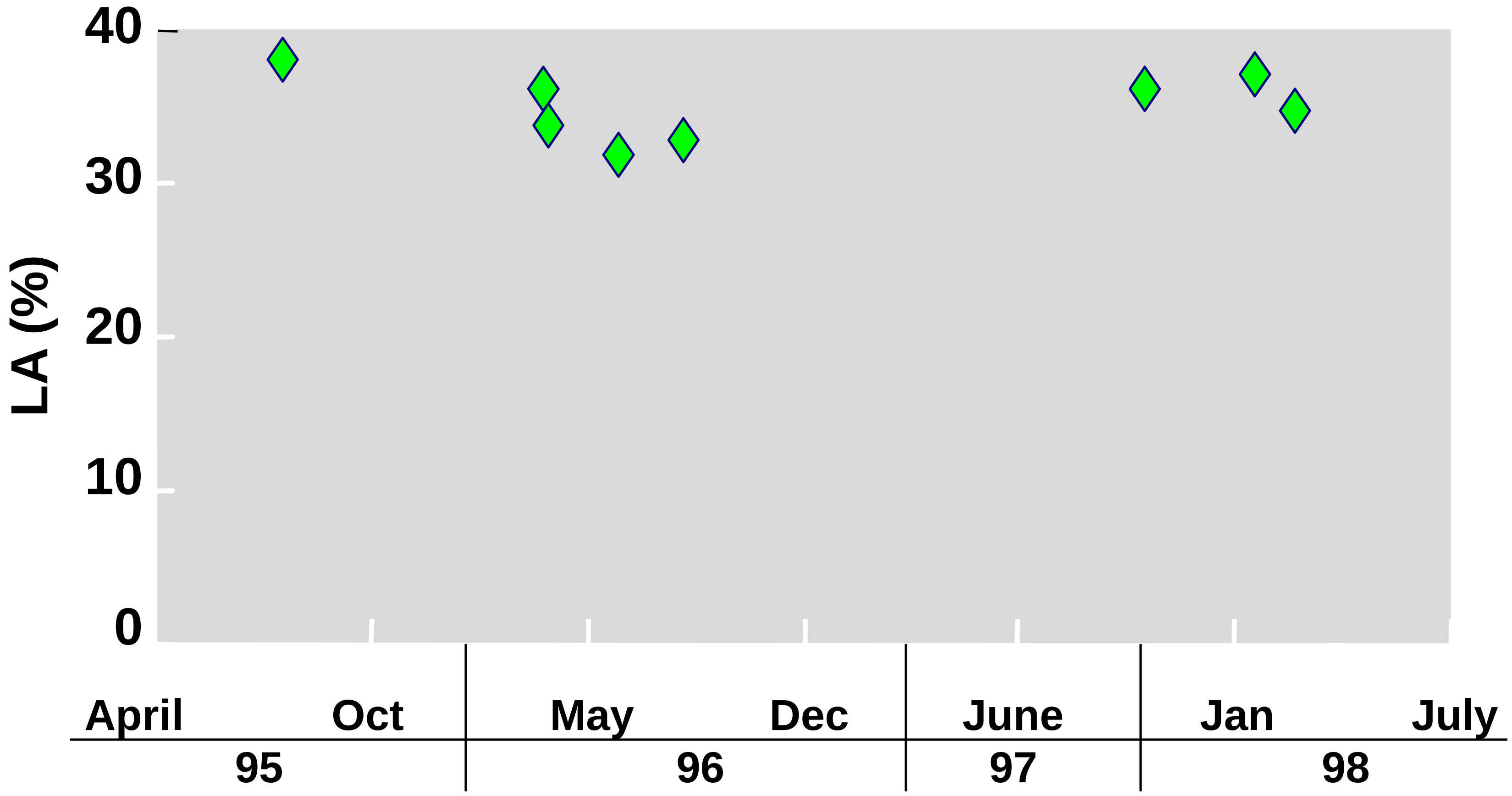


Original

Reconstruct and Unbonded Overlay

RCA Properties

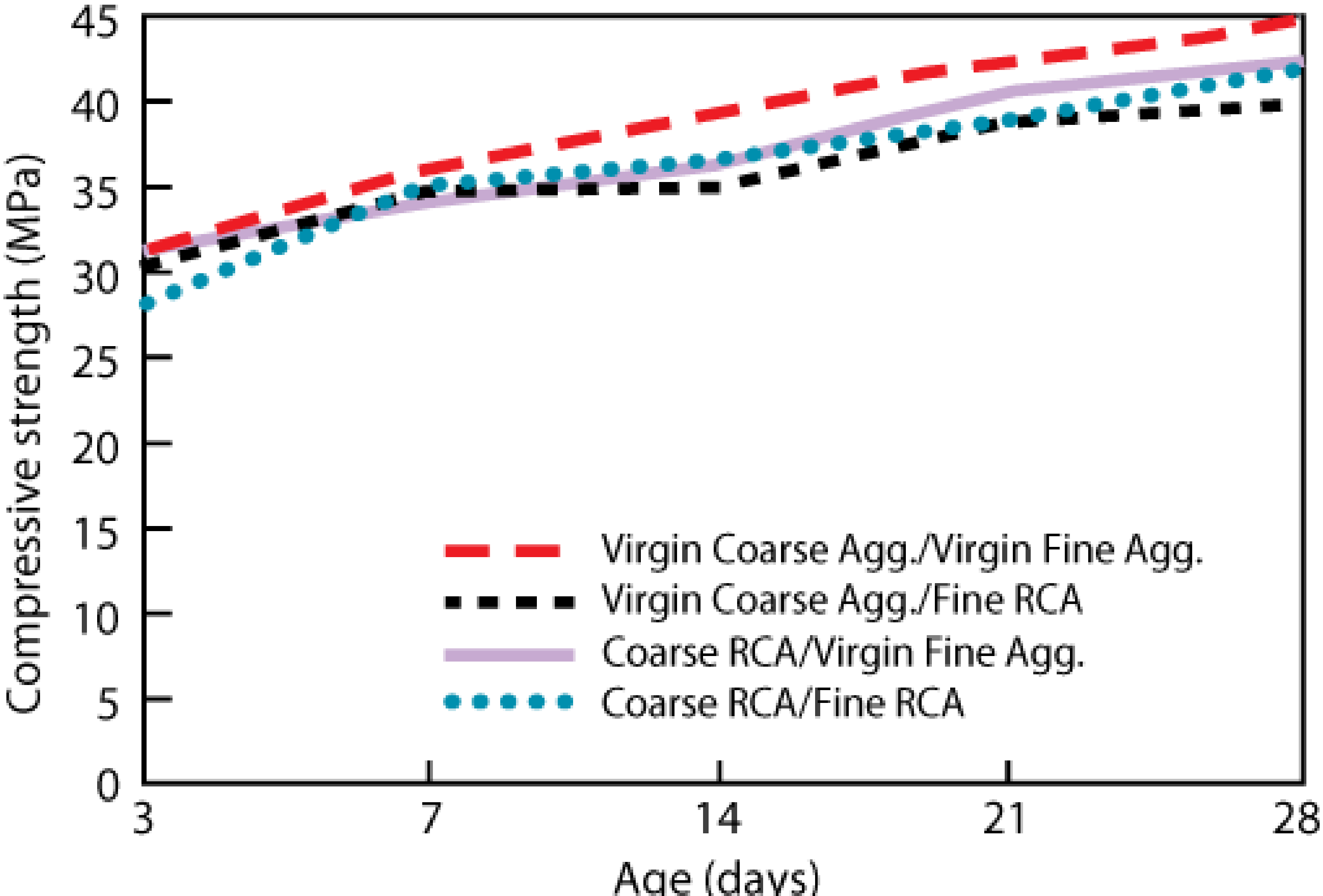
- Specific Gravity: 2.4 ~ 2.5 for CA & FA
- Water Absorption: CA - 3~5 % FA - 6~9 %
- Reclaimed Mortar Content
- Sulfate Soundness Loss
- LA Abrasion Loss
- Angularity


LA (%)
40
30
20
10
0
April
Oct
May
Dec
June
Jan
July
95
96
97
98

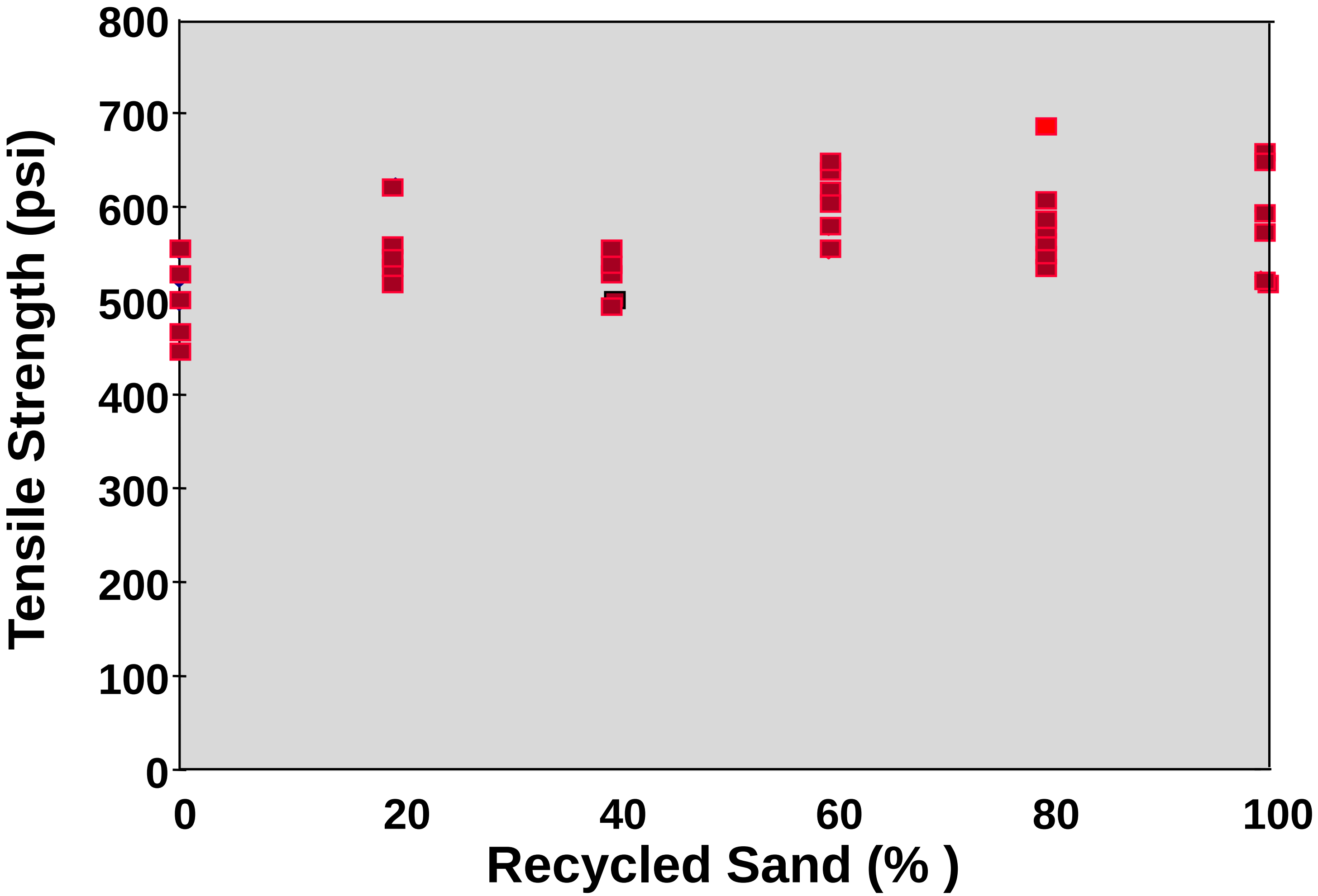
Concrete Properties

- **Strength**
- **Modulus of Elasticity**
- **Drying Shrinkage**
- **Thermal Coefficient**
- **Abrasion Resistance**

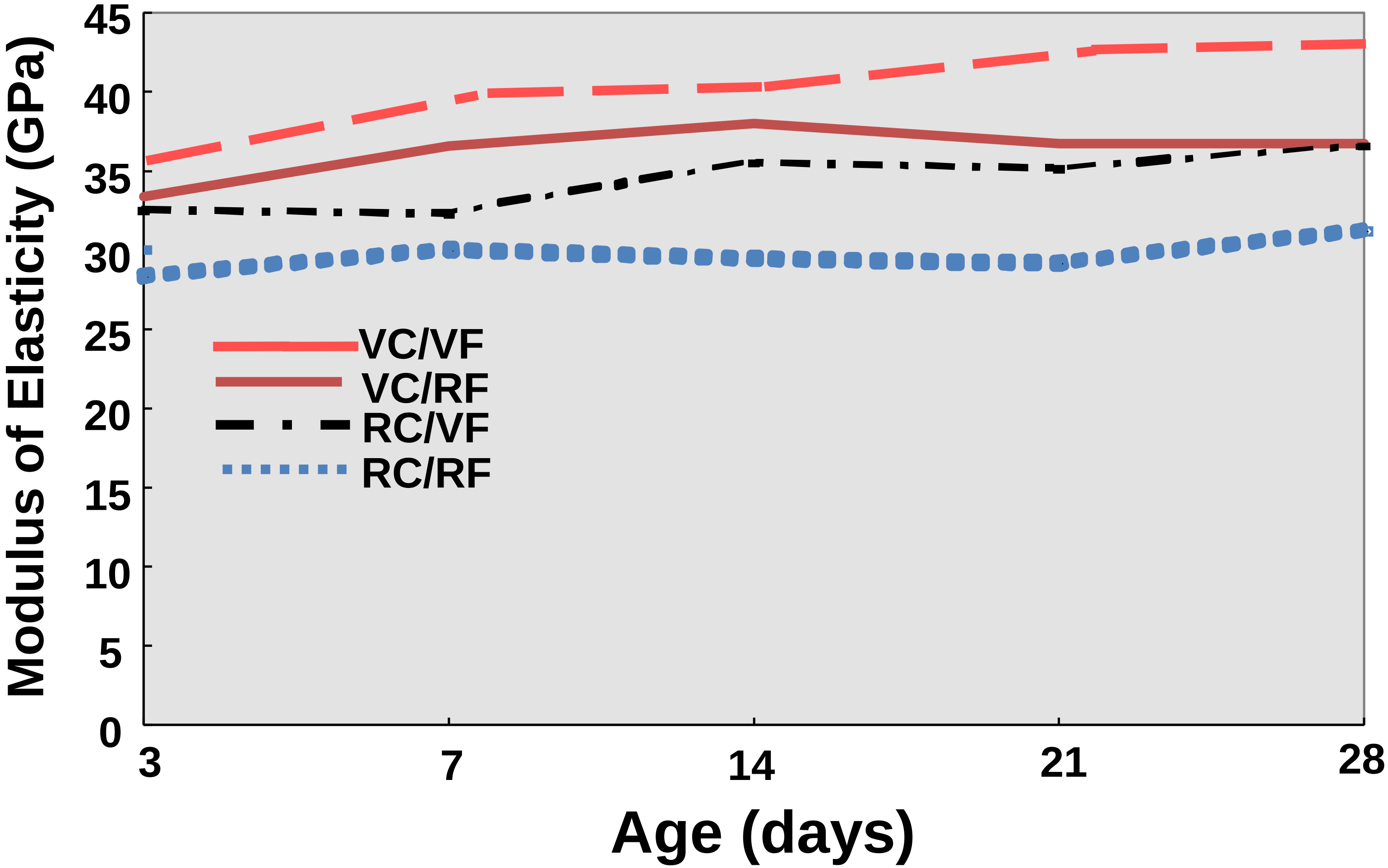
Compressive Strength of Various Concrete Mixtures

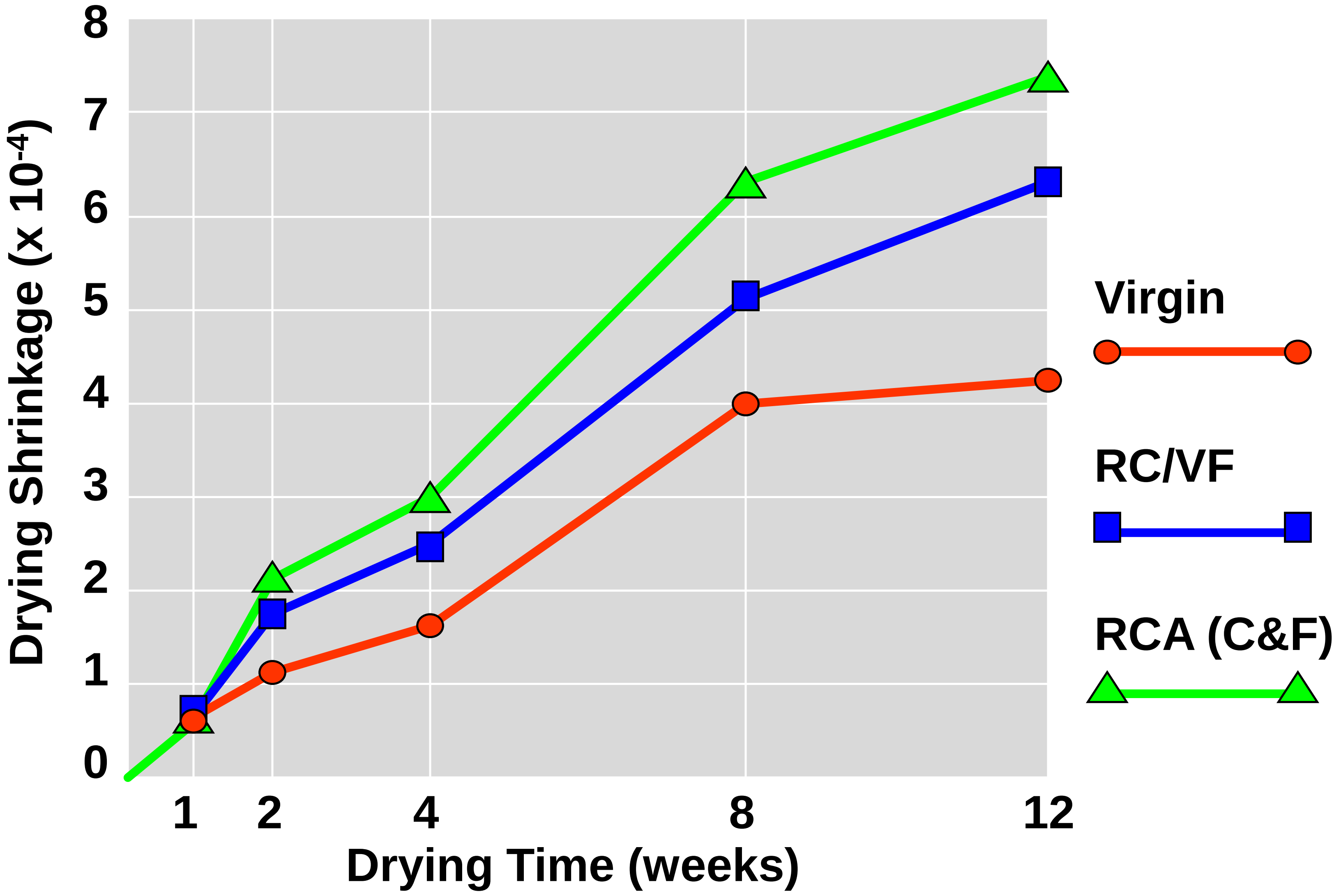


Effect of Recycled Sand on Tensile Strength



Modulus of Elasticity of Various Aggregate Mixes





Drying Shrinkage (x 10-4)
0
1
2
3
4
5
6
7
8
1
2
4
8
12
Drying Time (weeks)
Virgin
RC/VF
RCA (C&F)

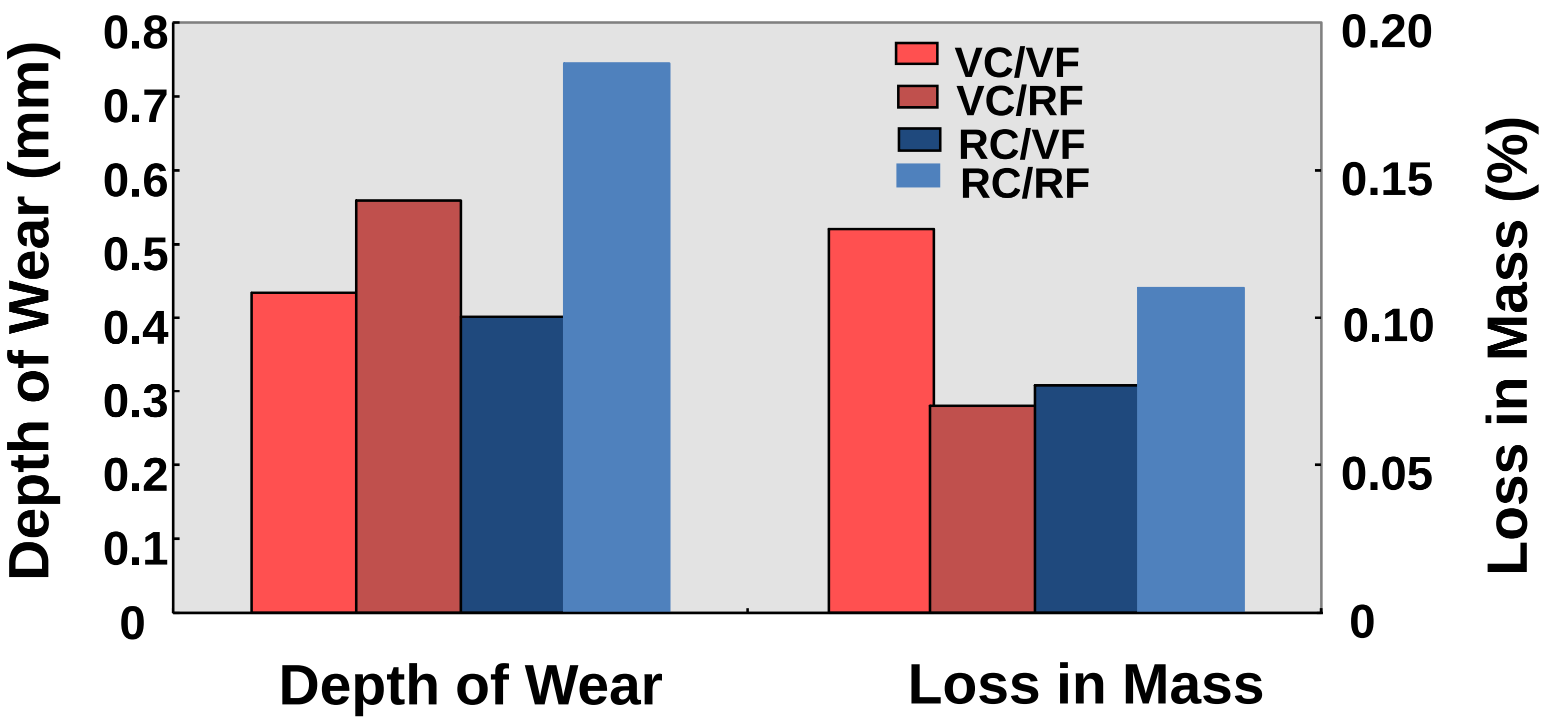
Concrete Properties

Coefficient of Thermal Expansion (COTE):

RCA: 15.8 $\mu/^{o}C$

Virgin: 10.6 $\mu/^{o}C$

Abrasion resistance of various aggregate mixes



Findings & Conclusions-cont'd

•Concrete Properties

- Recycled fine aggregate has an adverse effect on strength.
- The use of both recycled coarse and fine aggregates reduces modulus of elasticity of concrete substantially.
- Thermal coefficient of concrete with 100% RCA is higher than that of virgin aggregate concrete.
- The effect of recycled aggregate on the abrasion resistance of concrete is inconclusive.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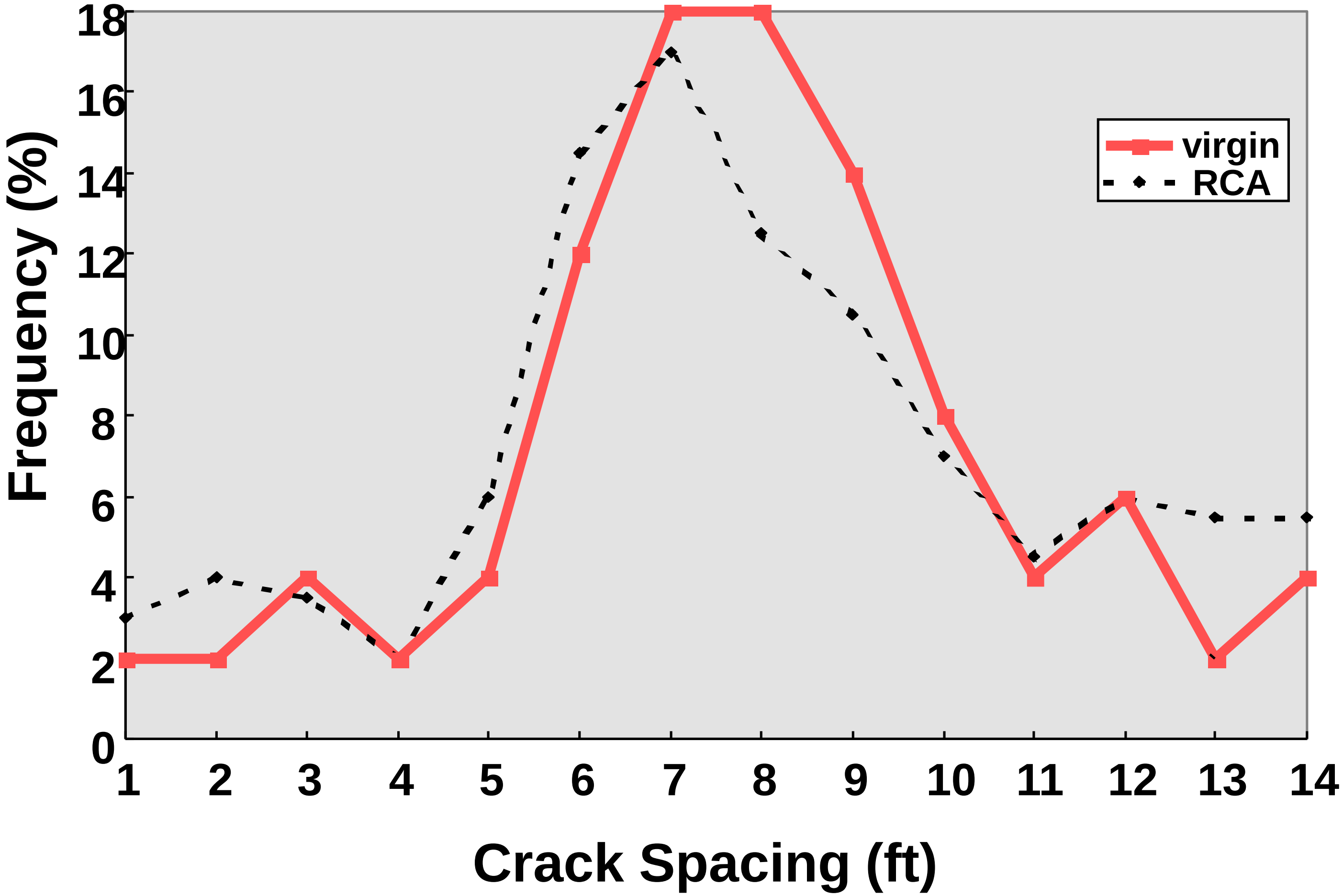
Crack Spacing Distribution of Virgin & Recycled Sections



Findings & Conclusions-cont'd

•Paving Operations/Pavement Performance

- **CRCP utilizing 100% recycled coarse & fine aggregates has performed well.**
  - **Possible exception: skid performance, which needs to be monitored.**
- **The large amount of old mortar in RCA does not appear to have adverse effect on CRCP performance.**
- **Moisture control of recycled aggregate is critical in producing consistent and workable concrete.**
- **No significant adjustment is necessary in paving operations due to the use of 100% RCA.**

Findings & Conclusions-cont'd

Spec Changes

- *1993*: Coarse aggregate shall be washed and shall consist of durable particles of gravel, crushed blast furnace slag, crushed stone, or combinations thereof.
- *2004*: Provide coarse aggregate consisting of durable particles of gravel, crushed blast furnace slag, recycled crushed hydraulic cement concrete, crushed stone, or combinations thereof.

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

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Thank You!

Questions/Discussion?

U.S. Department of Transportation
Federal Highway Administration

National Concrete Pavement Technology Center

Upcoming Webinars

Developed in cooperation with and sponsorship by FHWA.

Case Studies in Concrete Pavement Recycling

Offered again: July 12: 10:00 a.m. Central