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SOME PLEASANT SURPRISES ABOUT THE PERFORMANCE OF RECYCLED CONSTRUCTION MATERIALS

by

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Aged Material Properties of Cold In-Place Recycled Asphalt Roads

Sponsor: Iowa Highway Research Board

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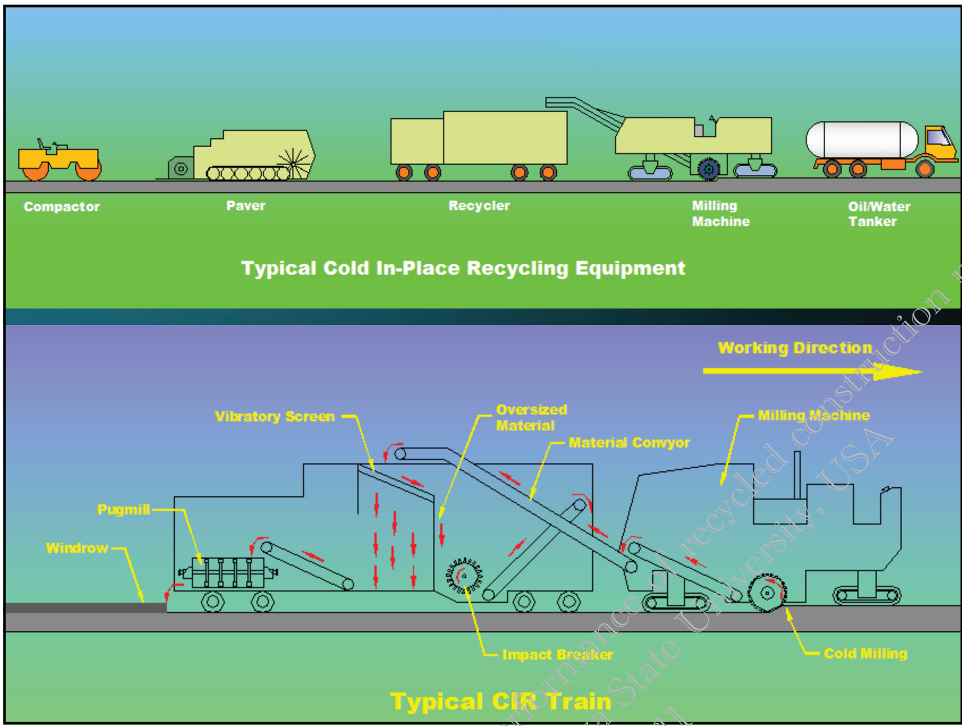
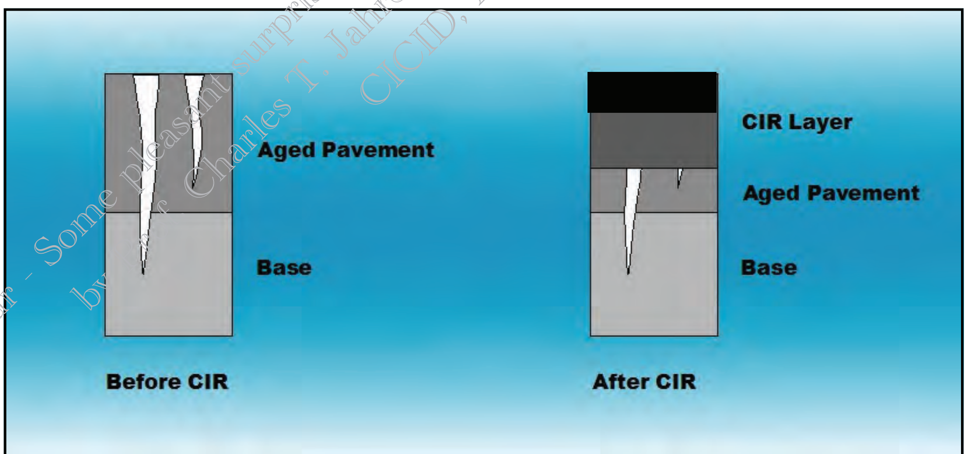

Compactor
Paver
Recycler
Milling Machine
Oil/Water Tanker
Typical Cold In-Place Recycling Equipment
Working Direction
Vibratory Screen
Oversized Material
Material Convyor
Milling Machine
Pugmill
Windrow
Impact Breaker
Cold Milling
Typical CIR Train



Reflective/Thermal cracks

- Affect ride quality when rolled down
- Cause the base to soften by allowing water penetration

Cold In-Place Recycling destroys the old crack pattern in the recycled layer, thus mitigating the problem.

Problem Statement

- Recycled roads have inconsistent performance
- Prominent factors:
  - Age of the recycled pavement
  - Traffic volume
  - Support conditions
  - Aged engineering properties of the CIR materials

Objectives

- To answer two questions:
  - How do aged engineering properties of CIR materials, traffic and subgrade conditions affect the pavement performance?
  - What changes should be made with regard to design, material selection and construction in order to improve the performance of future recycled roads?

Selection of CIR Test Sections

- Eighteen 1,500-ft old test sections, which were surveyed in 1996 and 1997, were selected for re-evaluation in 2005.
- Eight 1,500-ft new test sections were surveyed in 2005.
- Test sections were categorized by:
  - Age
  - Traffic level
  - Subgrade support level

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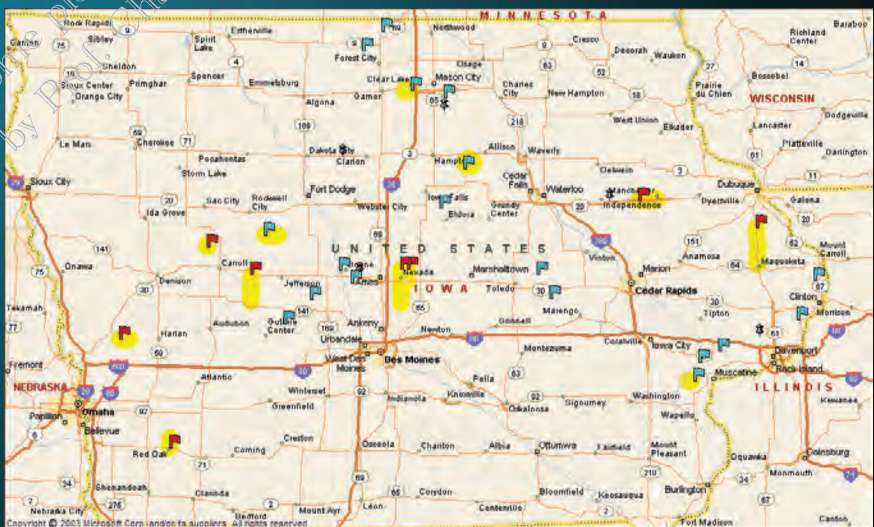
Locations of 26 Test Sections



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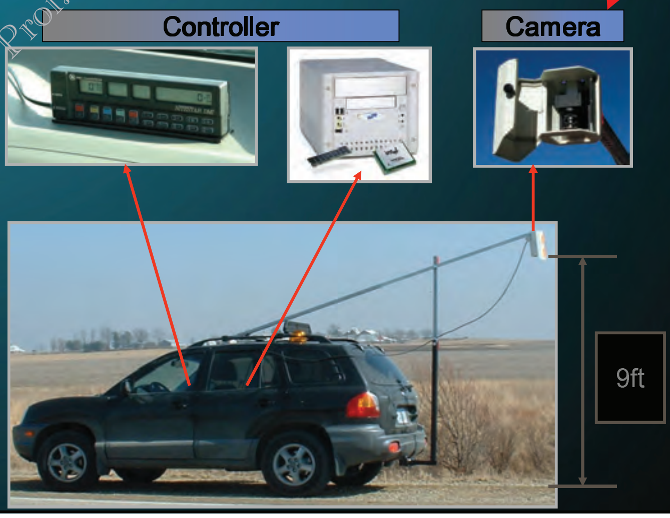
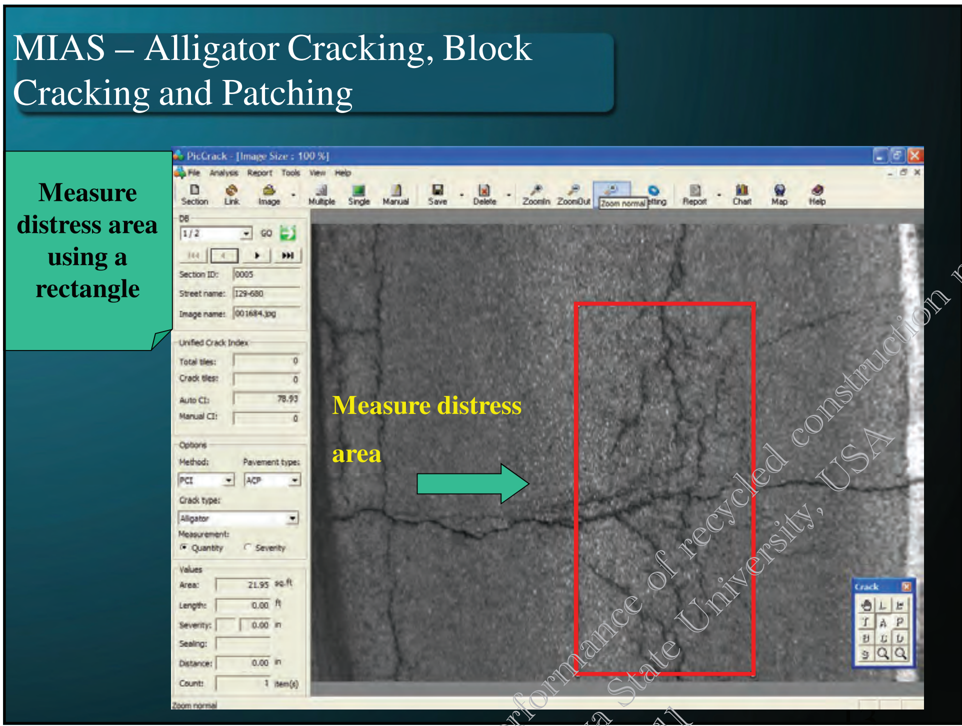
CIR Projects for Sampling Matrix

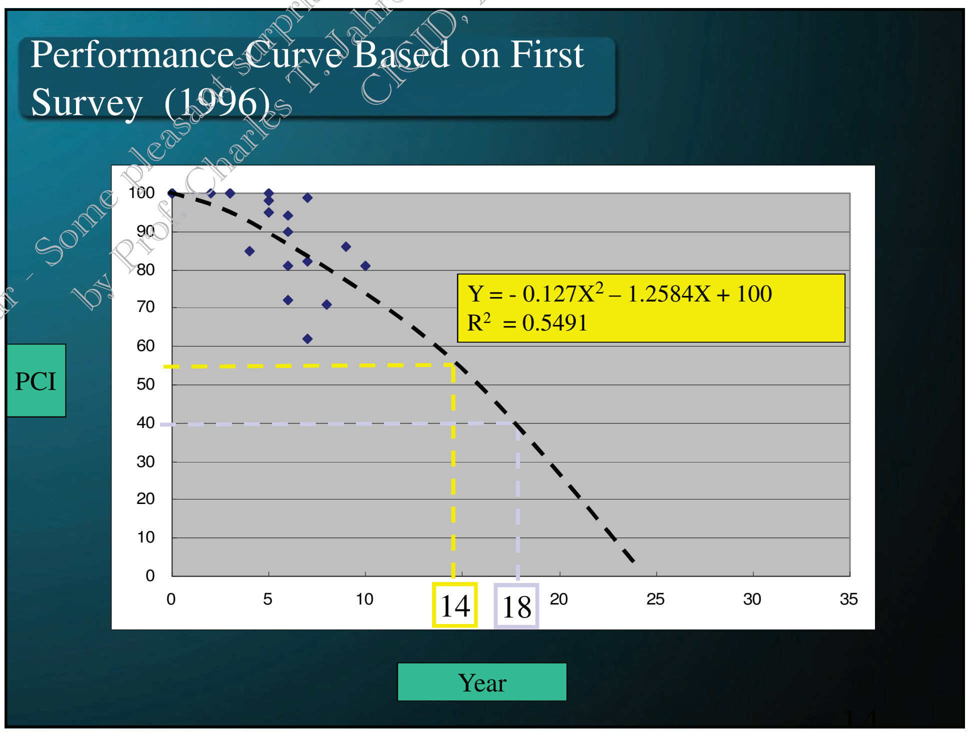
		Good Support (>Subgrade Modulus of 5,000 psi)		Poor Support (< Subgrade Modulus of 5,000 psi)	
		Low Traffic (0~800)	High Traffic (>800)	Low Traffic (0~800)	High Traffic (>800)
Age	Young (1999~)	IA-44, Harrison	US-20, Delaware US-61, Jackson IA-48, Montgomery	N-58, Carroll N. of Breda, Carroll S-14, Story	S-27, Story
	Medium (1992~ 1998)	-	IA-175, Calhoun IA-4, Guthrie F-70, Muscatine	V-18, Tama E-52, Boone T-16, Butler	G-28, Muscatine D-35, Hardin
	Old (1986~ 1991)	R-34, Winnebago B-43, Cerro Gordo R-60, Winnebago	S.S.L., Cerro Gordo Z-30, Clinton E-66, Tama	198th St., Boone E-50,Clinton	Y-14, Muscatine IA-144, Greene

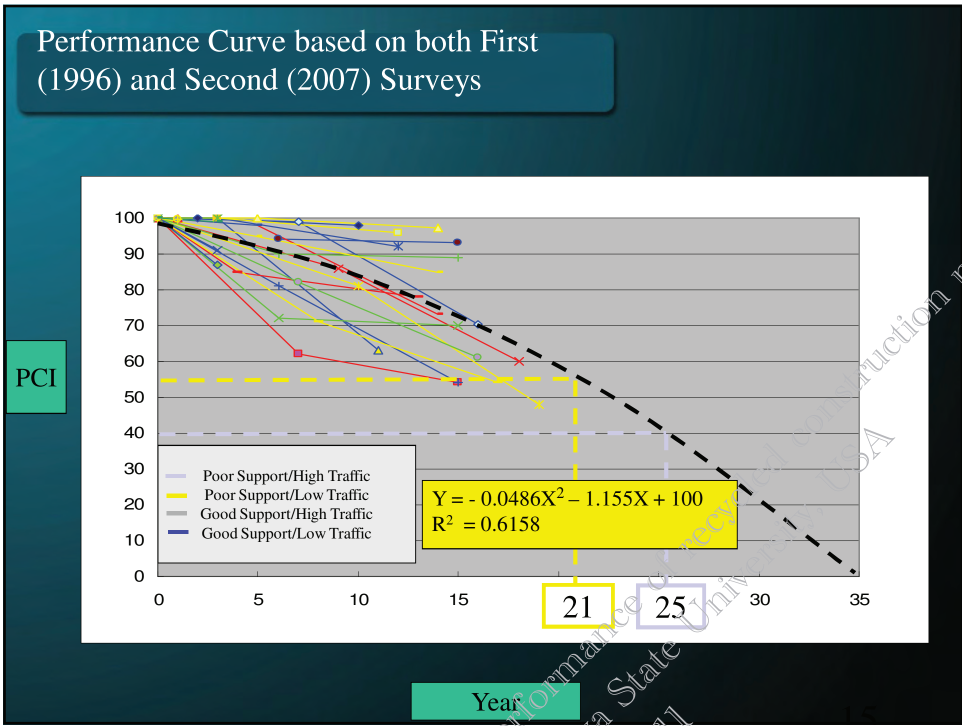
Test Program

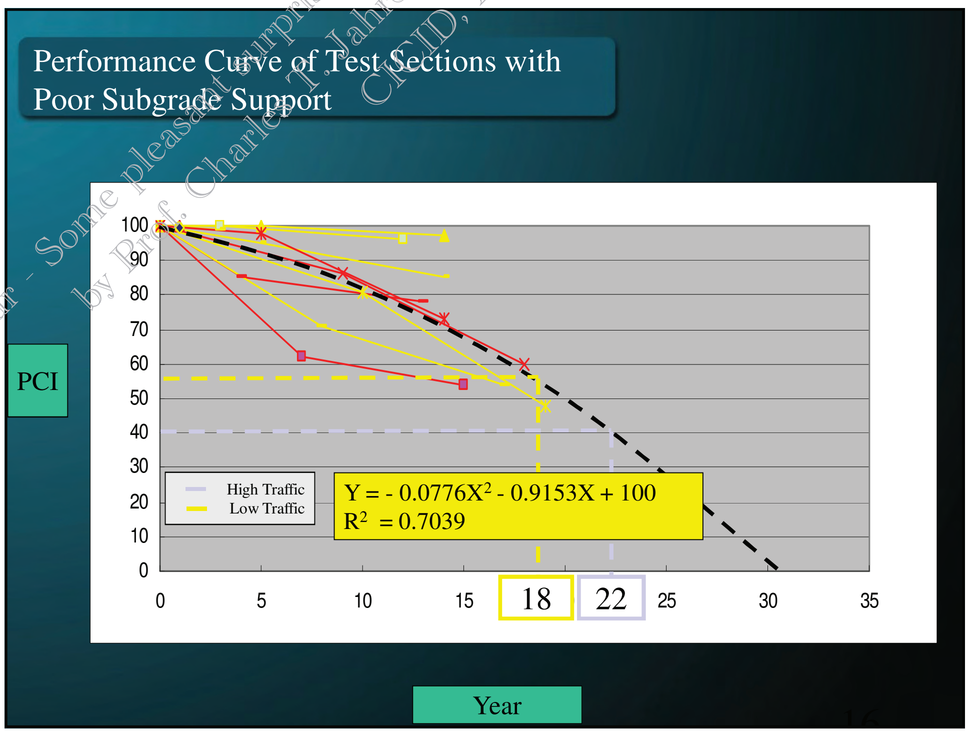
- Pavement distress survey

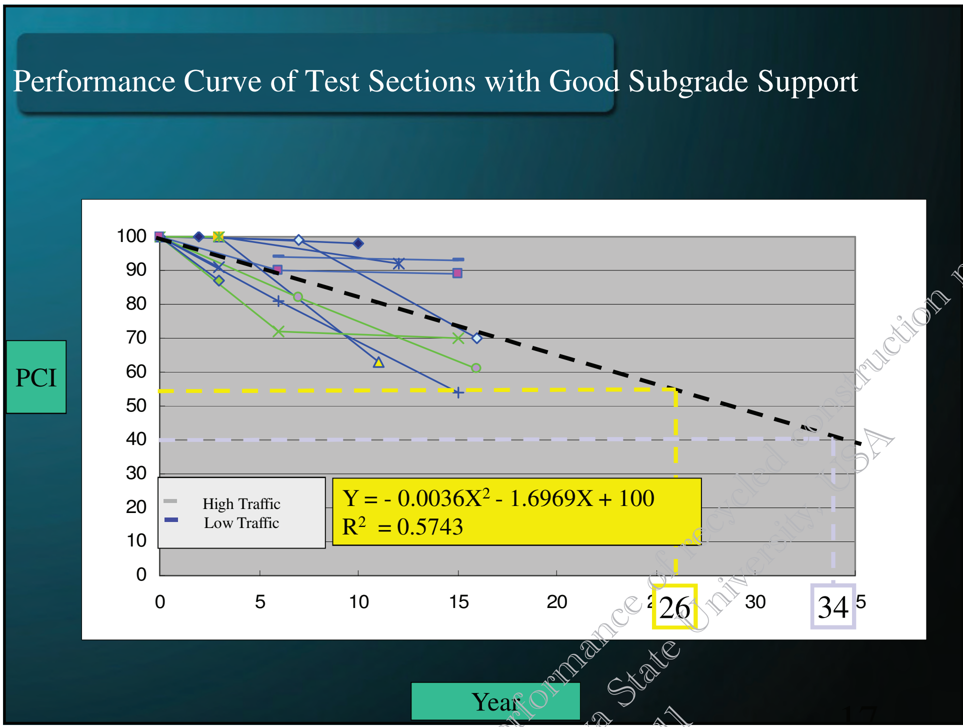



MIAS – Alligator Cracking, Block Cracking and Patching
Measure distress area using a rectangle
Measure distress area

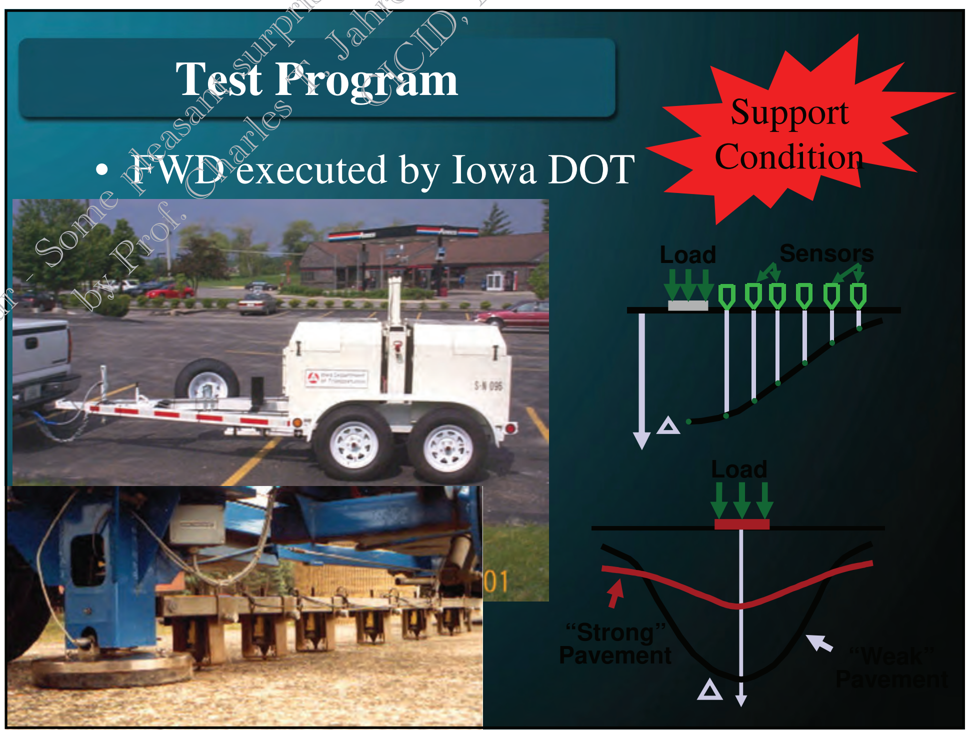

Performance Curve Based on First Survey (1996)
Y = - 0.127X² – 1.2584X + 100
R² = 0.5491
PCI
Year
14
18
0
5
10
20
25
30
35
100
90
80
70
60
50
40
30
20
10


Performance Curve based on both First (1996) and Second (2007) Surveys
PCI
100
90
80
70
60
50
40
30
20
10
0
Poor Support/High Traffic
Poor Support/Low Traffic
Good Support/High Traffic
Good Support/Low Traffic
Y = - 0.0486X² – 1.155X + 100
R² = 0.6158
0
5
10
15
21
25
30
35
Year

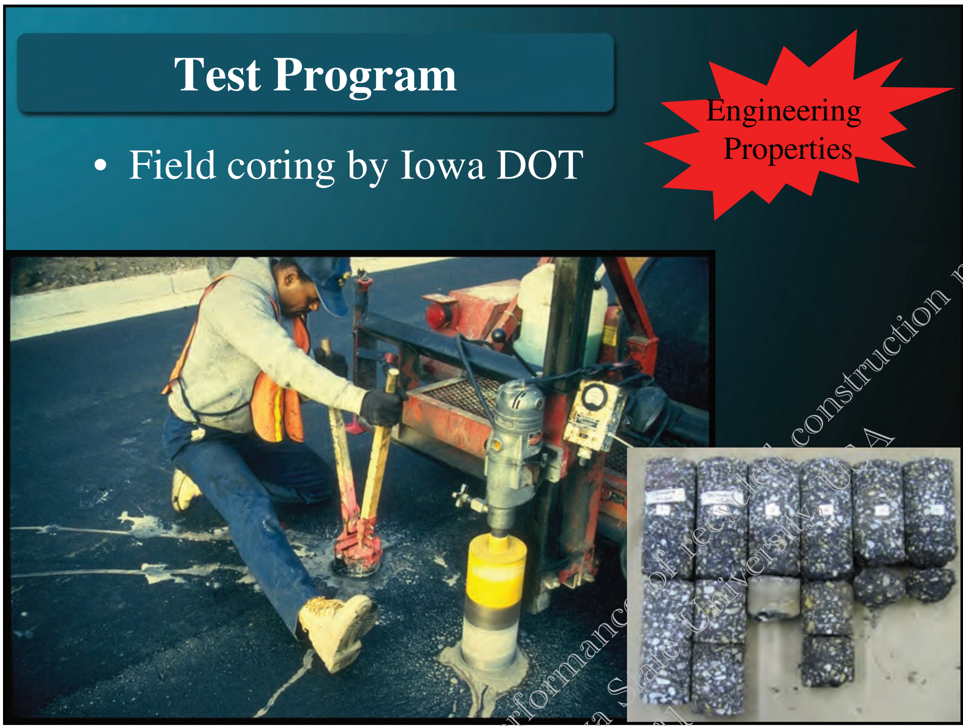

Performance Curve of Test Sections with Poor Subgrade Support
PCI
100
90
80
70
60
50
40
30
20
10
0
High Traffic
Low Traffic
Y = - 0.0776X² - 0.9153X + 100
R² = 0.7039
0
5
10
15
18
22
25
30
35
Year



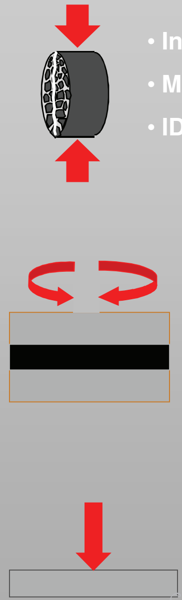
Performance Curve of Test Sections with Good Subgrade Support
PCI
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
26
30
34
High Traffic
Low Traffic
Y = - 0.0036X² - 1.6969X + 100
R² = 0.5743
Year



Test Program
• FWD executed by Iowa DOT
Support Condition
Load
Sensors
Load
"Strong" Pavement
"Weak" Pavement


Test Program
• Field coring by Iowa DOT
Engineering Properties


Lab Test Program
• Specimen Preparation



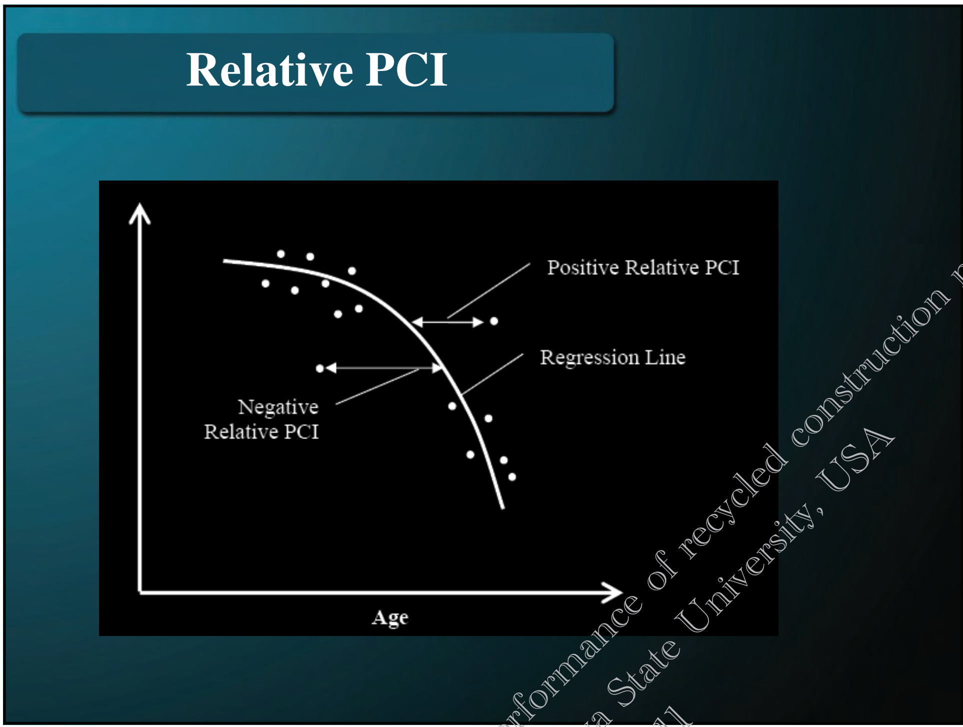
- Indirect tensile testing (IDT)
- Moisture sensitivity
- IDT_{wet} (psi)

- Dynamic shear rheometer (DSR) testing
- Rutting and fatigue
- Complex modulus (G*, KPa)

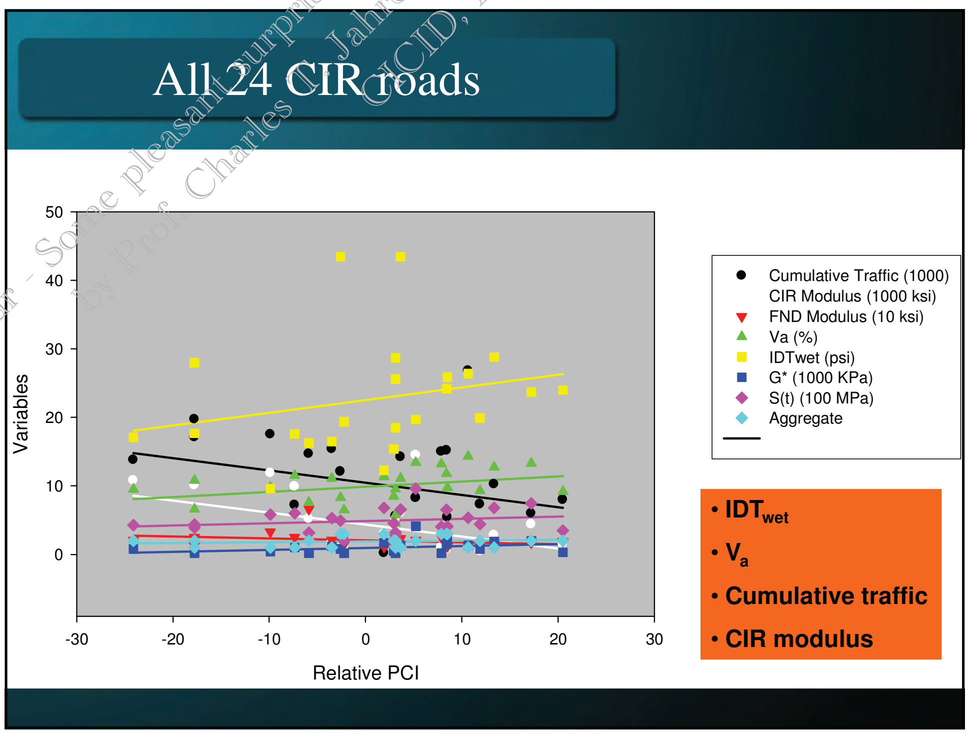
- Bending beam rheometer (BBR) testing
- Thermal Cracking
- Creep stiffness (S(t), MPa), m-value

Typical range of HMA/CIR properties

Type of Property	Property	Typical HMA	CIR in this study
Mix	V_a (field measured, %)	5 ~ 9	4.5 ~ 14.3
Binder	G*/sin(delta)	> 2.2	230 ~ 4,700
Binder	G*sin(delta)	< 5,000	170 ~ 3,600
Binder	Penetration (dmm)	20 ~ 30	0 ~ 30.3
Binder	S(t) (Mpa)	< 300	204 ~ 962
Binder	m-value	> 0.3	0.16 ~ 0.32
Pavement Layer Structural	Pavement modulus (ksi)*	100 ~ 6,000	200 ~ 4,400
Subgrade Layer Structural	Subgrade modulus (ksi)*	1 ~15#	3 ~ 16@



Relative PCI
Positive Relative PCI
Regression Line
Negative
Relative PCI
Age



All 24 CIR roads
Variables
Relative PCI
Cumulative Traffic (1000)
CIR Modulus (1000 ksi)
FND Modulus (10 ksi)
Va (%)
IDTwet (psi)
G* (1000 KPa)
S(t) (100 MPa)
Aggregate
• IDTwet
• Va
• Cumulative traffic
• CIR modulus

Results – all CIR roads

- R^2=0.5937
- R^2_{adj} = 0.5357

Term	Estimate	P-value	Significance at 0.05 level ?
$(V_a)^2$	2.45	0.0021	Yes
CIR modulus	-1.38	0.0027	Yes
(Cumulative Traffic)^2	-0.00026	0.015	Yes

** V_a is air void (%)*

** Air voids are voids between the aggregate particles in the compacted CIR layer that are filled with air*

Results – low traffic roads

- R^2=0.5213
- R^2_{adj} = 0.4256

Term	Estimate	P-value	Significance at 0.05 level ?
IDT_{wet}	0.361	0.008	Yes
(CIR modulus)^2	-1.28E-06	0.0845	No

Results – high traffic roads

- $R^2=0.5213$
- $R^2_{adj} = 0.4256$

Term	Estimate	P-value	Significance at 0.05 level ?
CIR modulus	-1.50E-03	0.0015	Yes
$(G^*)^2$	3.98	0.0914	No

Conclusions

- Predicted service life 21 to 25 years
  - Longer w/ good support (up to 34 yr)
  - Shorter w/ poor support (as little as 18 yr)
- Support more important than traffic
  - within range of analysis (< 2K AADT)
  - Traffic has little effect on roads w/ good support
- Longitudinal and alligator cracking increased… not transverse cracking
  - Rutting, patching and edge cracking associated with poor support

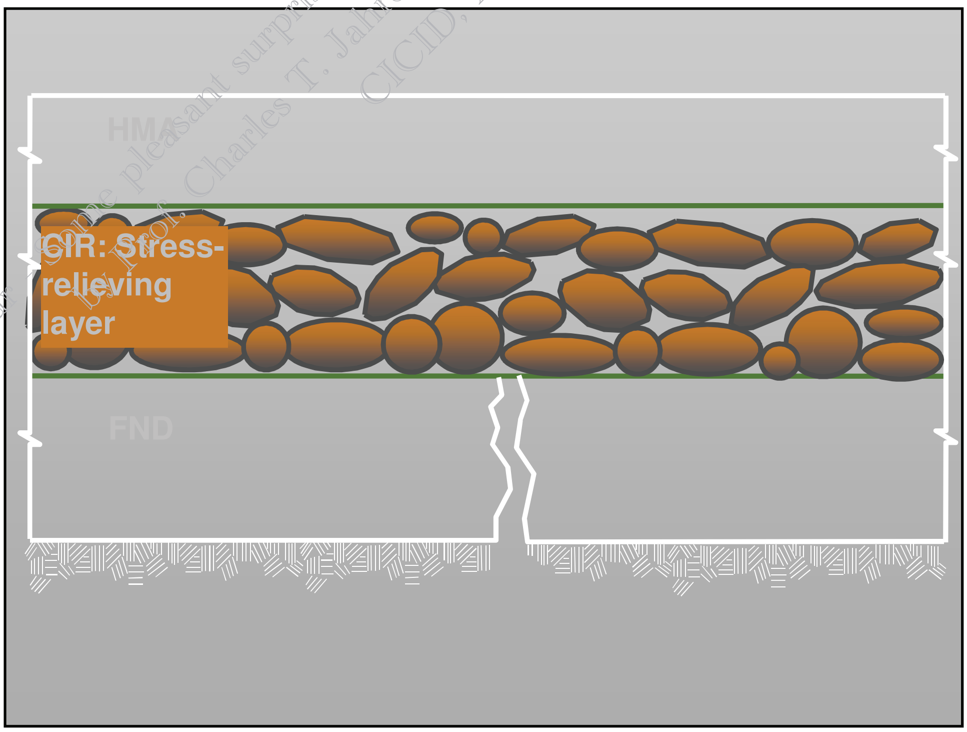
Conclusions

Better performance is associated with:

- V_a (air voids) is higher
  - Range: 6 to 12%
- CIR modulus is lower (more elastic)
  - Range: 200 to 4,400 ksi

-- within the range of the analysis

Poor Performance will result from higher V_a and lower CIR Modulus



Conclusions

- Within the range of the data analyzed, higher value of IDT_{wet} significantly and positively affected pavement performance of low traffic roads
- As would be expected, roads with higher cumulative traffic exhibited more distress

Performance Evaluation of Concrete Pavement Granular Subbase—Pavement Surface Condition Evaluation

Sponsored by
Iowa Highway Research Board
IHRB Project TR-554

Principal Investigators: David J. White, Ph.D., Halil Ceylan, Ph.D., Charles Jahren, Muhannad T. Suleiman, Ph.D., E. Tom Cackler, P.E.

Research Assistants: Thang Huu Phan and Sung Hwan Kim

Authors: David J. White, Halil Ceylan, Charles Jahren, Thang Huu Phan, Sung Hwan Kim, and Kasthurirangan Gopalakrisnan, Muhannad Suleiman

PGA Partnership for Geotechnical Advancement

ctre Center for Transportation Research and Education

Iowa State University of Science and Technology

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- Many people assisted the authors in identifying and locating projects for testing, controlling traffic, and refining research tasks.
- Reilly Construction is gratefully acknowledged for brainstorming the test locations of several old RPCC projects during a winter meeting.
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- Field team, including Heath Gieselman, Bryan Zimmerman, Bob Steffes, and Jeremy McIntyre with Iowa State University.
- John Vu allowed the authors to use the Iowa Department of Transportation field permeameter.

Introduction (continued)

What are the concerns of using RPCC for pavements?

- Recycled PCC aggregate reduces permeability, clog the drainage systems.
- High pH leachate corrodes metal drainage pipes, damages vegetation.
- Question on the stability of subbase layer using recycled PCC.

Literature Review - RPCC

- Experience breakage of particles, increase fines
- Reduce the freeze-thaw resistance and permeability
- High % fines & low permeability > pore water pressures develops under the pavement that reduce shear strength of base and subgrade layers
- High pore water pressures > cracks on pavement due to bulging of pavement and failure on the pavement surface under traffic load
- Cement hydration of the recycled PCC can reduce void ratio

Research Objectives

- Determine if RPCC pavement subbase is performing adequately.
- Evaluate subbase stiffness and permeability by performing multiple tests within a given test section using semi non-destructive methods.
- Determine the gradation of the subbase materials.
- Conduct crack and performance survey of pavement.
- Summarize projects used RPCC for pavement construction in Iowa.

Research Plan

- Visit 26 locations: 21 recycled and 5 virgin material sites
- At each site, conduct: LWD, Clegg hammer, DCP, permeability, sampling, and pavement crack survey.
- Compare and correlate performance of recycled PCC with virgin materials.
- Develop guidelines and specifications for pavement design using recycled PCC aggregate materials

Field Investigations

LWD Test

Clegg Hammer Test

DCP Test

Mn/DOT Permeability Tests

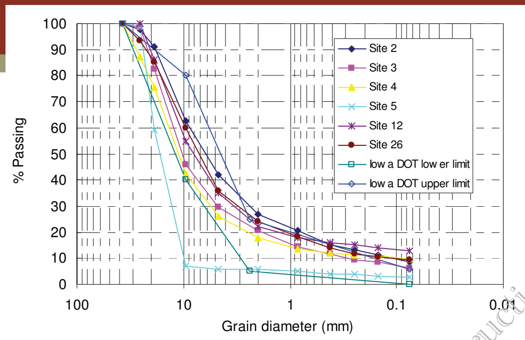
Virgin and RPCC Poperties

Property	**Natural aggregate**	**Recycled concrete aggregate**
Specific Gravity	2.4 - 2.6	2.2 - 2.3
Estimated loss based on the modified Micro-Deval test (%) (*)	11 - 32	16 - 65
USGS	GP-GM	Variable

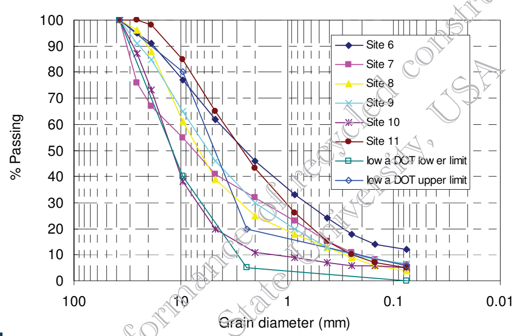
*: Maximum loss for coarse aggregates recommended by ASTM D6928-06 is 30%

Virgin and RPCC Gradations

Virgin Samples



RPCC Samples



Summary of Modulus of Elasticity, CIV, and CBR

	E_{LWD} (Mpa)		Subbase		
	Subbase	Subgrade	CIV	CBR[a]	CBR[b]
Max value	2126	150	638	100*	100*
Min Value	43	33	17	21.5	18
Average	535.3	66.1	89.4	73.0	66.9
STDEV	553.5	39.3	119.4	27.1	28.4
COV (%)	103.4	59.5	133.6	37.0	42.5

a: CBR estimated from CIV values of Clegg Hammer

b: CBR estimated from PI values of DCP

*: converted value is higher than 100

Estimated k-composite values from LWD

	Subbase			
	LWD measurements		Composite modulus k	
	Stress, kPa	Deflection, mm	MPa/m	pci
Max value	386	659	21093	77706
Min value	217	16	329	1210
Avg	262	142	4991	18386
STDEV	29	156	5359	19744
COV (%)	11	110	107	107

Permeability of Virgin Materials

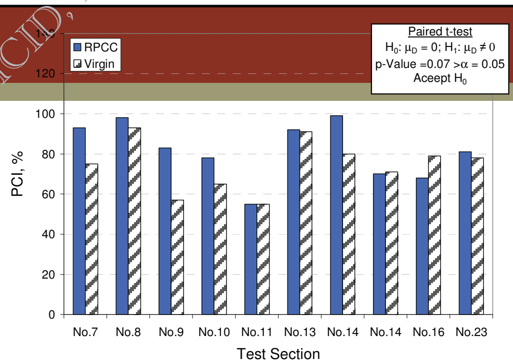
Subbase material	$k_{1\,(5\,cm)}$ (ft/day)	$k_{2\,(10\,cm)}$ (ft/day)
Max values	8.1	19.09
Min values	0.01	0.01
Average	2.73	6.39
STDEV	4.65	11.00
COV (%)	170.7	172.1

Permeability of RPCC Materials

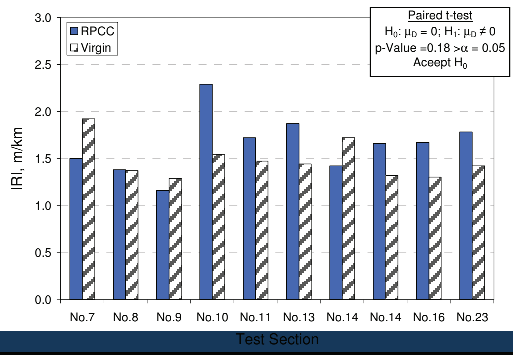
Subbase material	$k_{1\,(5\,cm)}$ (ft/day)	$k_{2\,(10\,cm)}$ (ft/day)
Max values	3.31	5.14
Min values	0.02	0
Average	0.90	1.03
STDEV	1.03	1.51
COV (%)	114.0	146.3

Paired *t*-test results for the RPCC and the virgin aggregate sections

a) PCI



b) IRI



Summary of Findings -- Lab and Field

- Modulus of elasticity of RPCC subbase materials is high and variable from one project to another.
- CIV obtained from Clegg hammer tests are high.
- RPCC subbase layers normally have low permeability.

Summary of Findings -- Distress Survey

- The current pavement surface condition of RPCC subbase sections is comparable to that of virgin aggregate subbase sections in terms of the Pavement Condition Index (PCI) and the International Roughness Index (IRI).
- Based on the evaluation of representative RPCC subbase pavement sections with comparisons to virgin aggregate subbase sections, it can be concluded that the RPCC pavement subbase is performing adequately.

General Conclusions

- Recycled materials behave differently from non-recycled materials.
- In some cases these behaviors seem to render the recycled materials as inferior to their non recycled counterparts
  - CIR has higher voids % and less stiffness in comparison to non recycled hot mix asphalt.
  - RPCC has less permeability in comparison to crushed rock

General Conclusions

- Recycled material properties may provide advantages.
  - Lower stiffness and higher air voids in CIR apparently mitigate crack reflection
  - Higher stiffness in RPCC layer may increase structural effectiveness and make up for lack of permeability.

Recommendations

- Investigate properties of recycled materials fully and on their own merits
  - Avoid considering them to be inferior versions on non recycled materials.
- Consider including recycle materials in a way that takes advantage of their desirable characteristics.
  - Crack mitigation layer for asphalt overlay projects from CIR
  - Strengthen pavement base with RPCC in a manner similar to that of asphalt or cement treated base.

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Thank You!