



The Illinois Tollway's Use of Composite Concrete Pavements with Greener Concrete for Improved Sustainability

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Overview: About the Illinois Tollway

- ▶ 286-mile system comprised of four tollways
- ▶ Opened in 1958 as a bypass around Chicago to connect Indiana and Wisconsin
- ▶ Carries more than 1.4 million vehicles per day
- ▶ Largest open road tolling system in the nation
- ▶ User-fee system – no state or federal gas tax dollars



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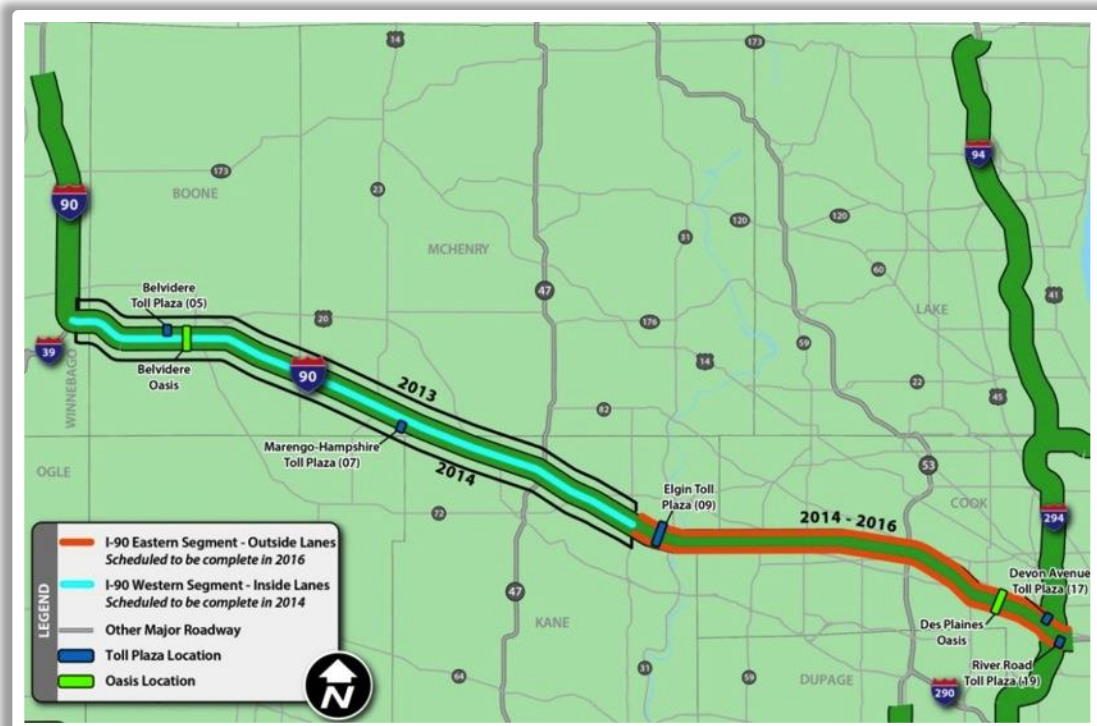
ILLIANA EXPRESSWAY



Jane Addams Memorial Tollway (I-90)

Rebuilding and widening I-90 as a 21st century, state-of-the-art corridor linking Rockford to O'Hare International Airport

- ▶ 62 miles of roadway improvements
- ▶ \$2.2 billion budget includes \$240 million to integrate transit in the corridor today, as well as future transit expansion plans



Implementing New Design Elements

- ▶ **“100-year” bridges**
 - ▶ **High-performance concrete decks**
 - ▶ **Stainless steel rebar**
 - ▶ **Jointless**
- ▶ **120,000 pound load capacity to roads and bridges**



Utilizing Recycled Materials

It starts from the bottom up

- ▶ Existing aggregate subbases recycled
- ▶ Subgrade undercuts eliminated
- ▶ Old concrete recycled as new porous base
- ▶ Old asphalt recycled for many applications



Innovative Pavement Designs

To provide long-lasting, smooth surface to customers...

- ▶ Life Cycle Cost Assessment
- ▶ 2-Lift concrete pavement with asphalt shoulders
- ▶ Incorporates various green initiatives





Pavement Type Selection Report Card

	West Rockford – IL-47	Center IL-47 to Randall	East Randall to O'Hare
2-Lift Composite Jointed Concrete	3.16 B	3.21 B	3.02 B
Continuously Reinforced Concrete	3.00 B	3.00 B	2.99 B-
Full Depth Asphalt	3.02 B	3.03 B	2.83 B-
Composite Asphalt/Jointed Concrete	2.43 C+	2.42 C+	2.38 C+
Composite Asphalt/Cont. Reinforced	2.34 C+	2.36 C+	2.34 C+

Two Lift Concrete Paving- A Forgotten Practice



**Popular back in the 50's, 60's and 70's when the
Tollway was originally built**



Tollway Requires 100% Recycling of Concrete and Asphalt Pavements with Reconstruction



In Base Aggregates



In New Asphalt Mixes



Milled RAP is Fractionated on Most All Tollway Projects



What is FRAP?

- ▶ Old asphalt pavement that has been milled and fractionated (graded)
- ▶ Coarse FRAP contains 2 to 3% asphalt binder
 - ▶ HMA has 5-6%
- ▶ Contains about 14% agglomerated particles (clumps of sand/asphalt)
- ▶ Sizes range from ½" to No. 4 size sieve.

Why use FRAP in Concrete?

- ▶ Sustainability
 - ▶ Disposal/hauling energy
 - ▶ Natural resource depletion
 - ▶ Carbon footprint
 - ▶ Economy!!!

Plenty of Coarse FRAP Left Over for Concrete



- Fine FRAP (<#4 sieve) used by the Tollway as a liquid binder replacement in new asphalt mixes with reclaimed asphalt shingles (RAS)
- Large stockpiles of coarse FRAP remain unused and take up space

Making Concrete Greener and Ultimately Cheaper For Both Lifts



Replace Virgin Aggregate with Recycled

Optimize gradation and reduce cement content



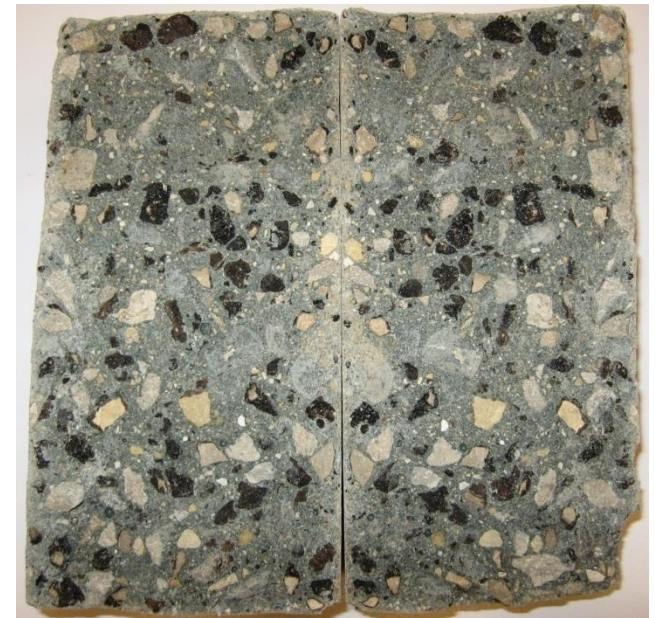
Replace portland cement with SCM's

“Green Concrete” Quandry

- ▶ Concrete today is made primarily with virgin materials.
 - ▶ Portland cement manufacturing creates 1 ton of CO₂ for every ton of cement produced.
 - ▶ Move Illinois:
Be the “cleanest and greenest” program in history
-

“Black Rock” in Concrete

- ▶ Coarse portion of fractionated RAP
- ▶ Minus ½-inch and plus #4
- ▶ Austria – standard practice in lower lift
- ▶ US Trial: Florida
- ▶ Tollway Trial: Milwaukee Avenue ramp - 2010



Composite Pavement Field Trials Initiated in 2010 With SHRP 2 R21 Team's Help

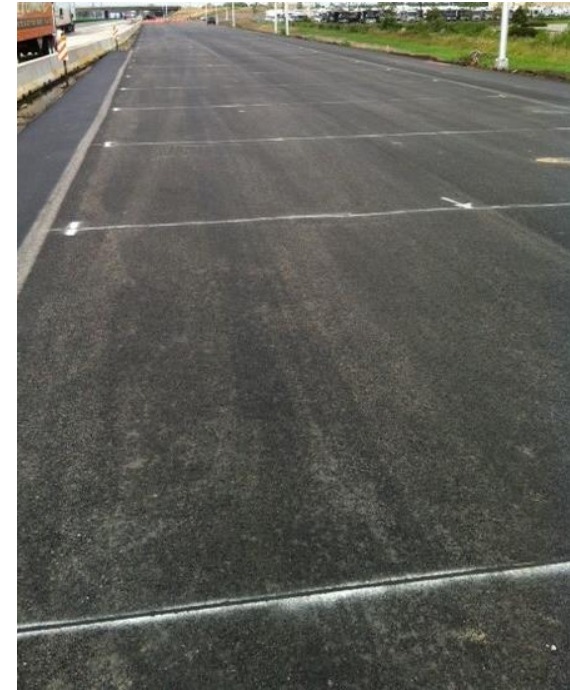


- ▶ **Asphalt-over-concrete composite ramps built**
- ▶ **Specifications for bottom lift concrete placement and for mix designs based on SHRP R21's MN Road Project**



I-294 Ramp first composite pavement

- ▶ Two HMA/JPC sections of I-94 ramps north of Chicago
- ▶ Constructed 2010 using 30% RAP & 20% fly ash in PCC, high quality WMA surface layer, & saw & seal joint over doweled JPC



“Black Rock” in Concrete Concerns

- ▶ Higher dust in RAP – washing RAP?
- ▶ “Agglomerated particles” – sand-asphalt pieces
- ▶ Lower Strengths
- ▶ Freeze-Thaw Durability



Black Rock Ternary Mixes Researched at The University of Illinois



- Phase I study focused on the physical properties and performance of black rock ternary concrete mixes
- Phase II study focused on the fracture properties and structural capacity of two lift pavements with recycled aggregates in the bottom lifts



Composite Pavement Research Performed at University of Illinois



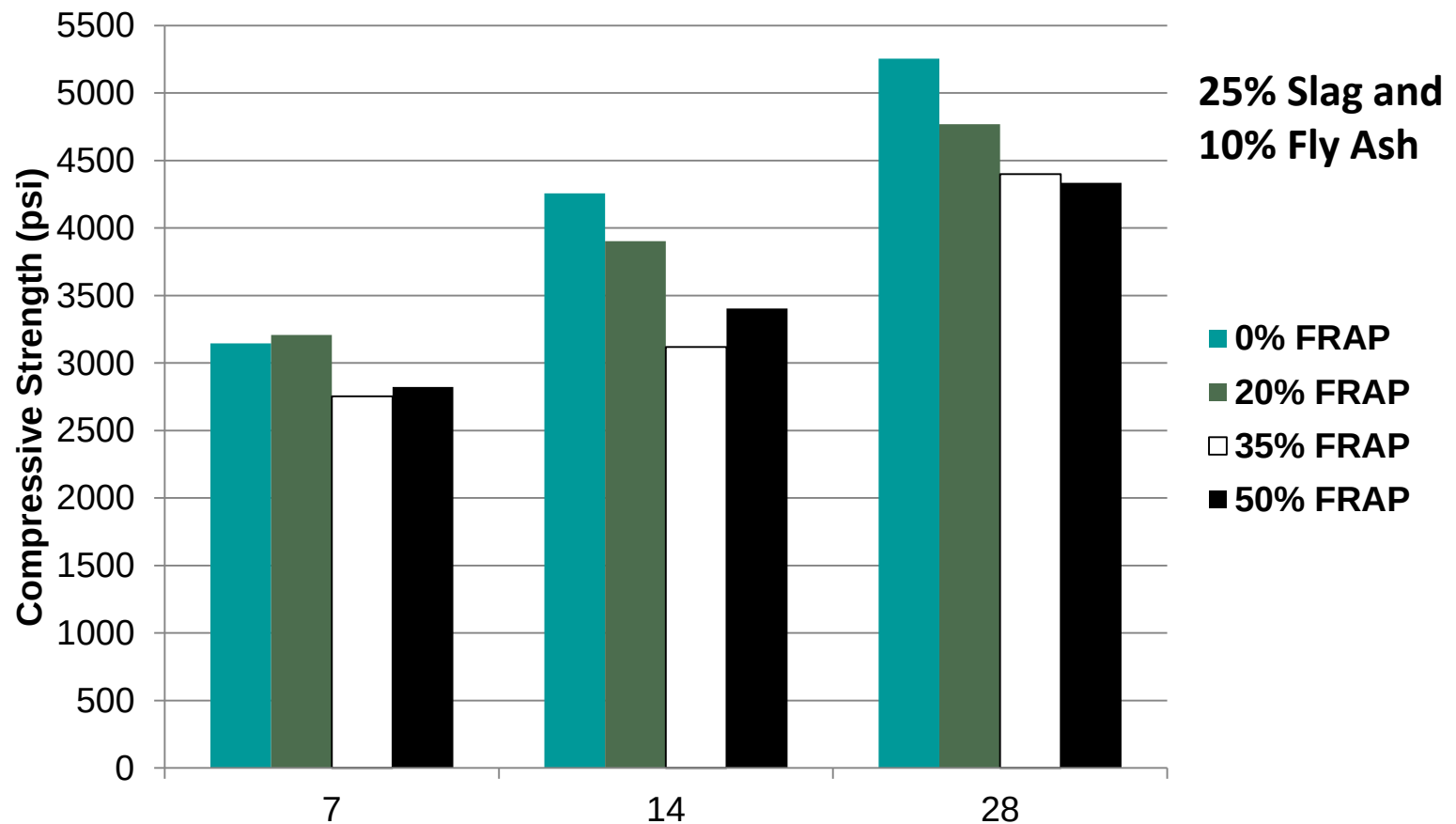
- Further evaluated black rock concrete mixes for fresh, hardened and durability properties
- Developed better predictive models of the field performance for 2-lift composite concrete pavements using recycled materials



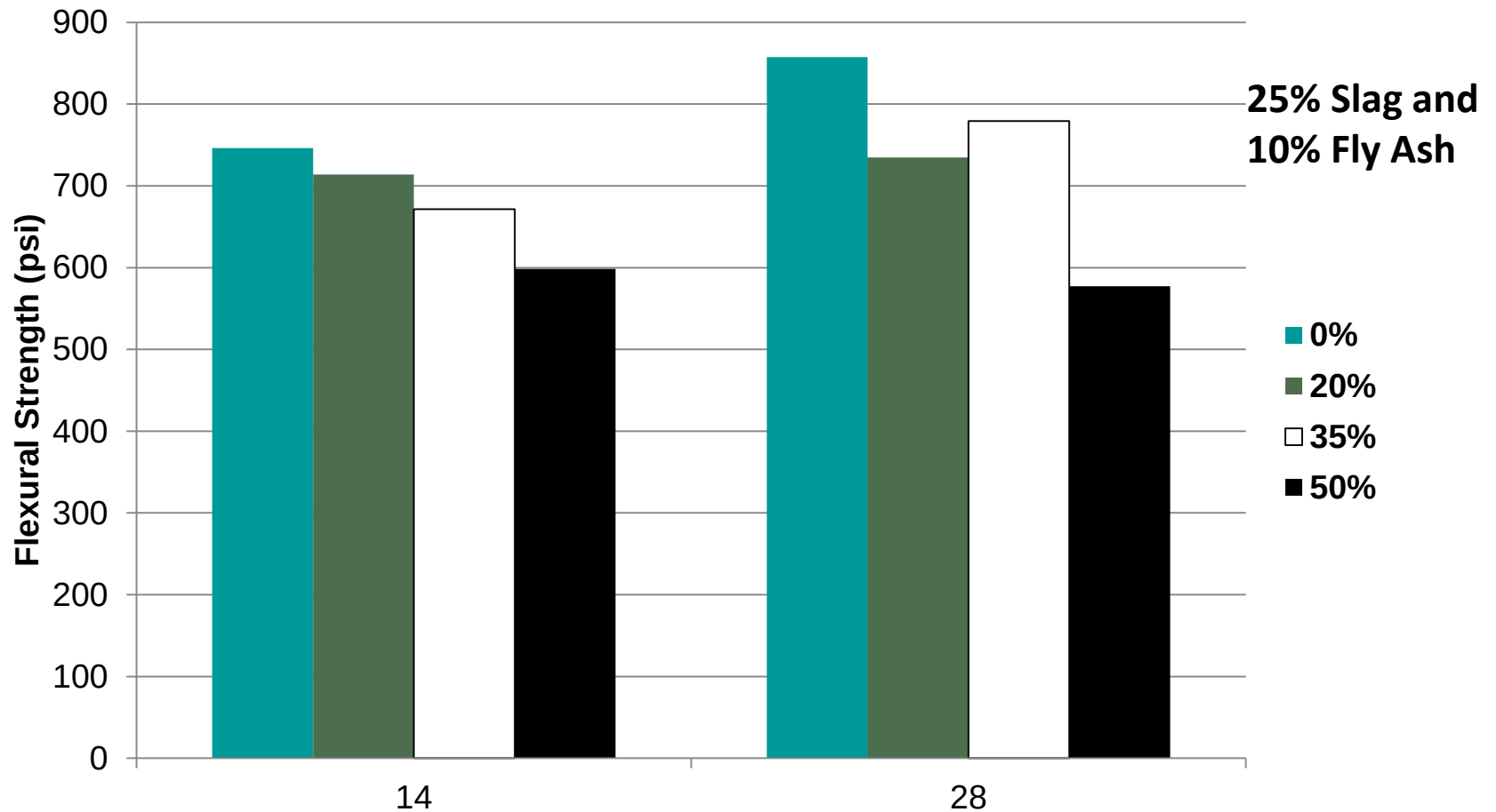
Research Mix Designs

Material	Virgin Mix	45% FRAP	100% RCA	45-55% FRAP-RCA
Total Cementitious	610.0	610.0	610.0	610.0
Cement 55%	335.5	335.5	335.5	335.5
Slag 35%	213.5	213.5	213.5	213.5
Type C Fly Ash 10%	61.0	61.0	61.0	61.0
Total Coarse Aggregate (SSD)	1867.9	1822.3	1696.2	1724.9
CA-11 Virgin Coarse Agg.	1307.5	1002.3	0.0	0.0
CA-16 Virgin Coarse Agg.	560.4	0.0	0.0	0.0
FRAP	0.0	820.0	0.0	776.2
RCA	0.0	0.0	1696.2	948.7
Virgin Fine Aggregate (SSD)	1216.9	1216.9	1216.9	1216.9
Water w/cm = 0.37	226.4	226.4	226.4	226.4

Compressive Strength



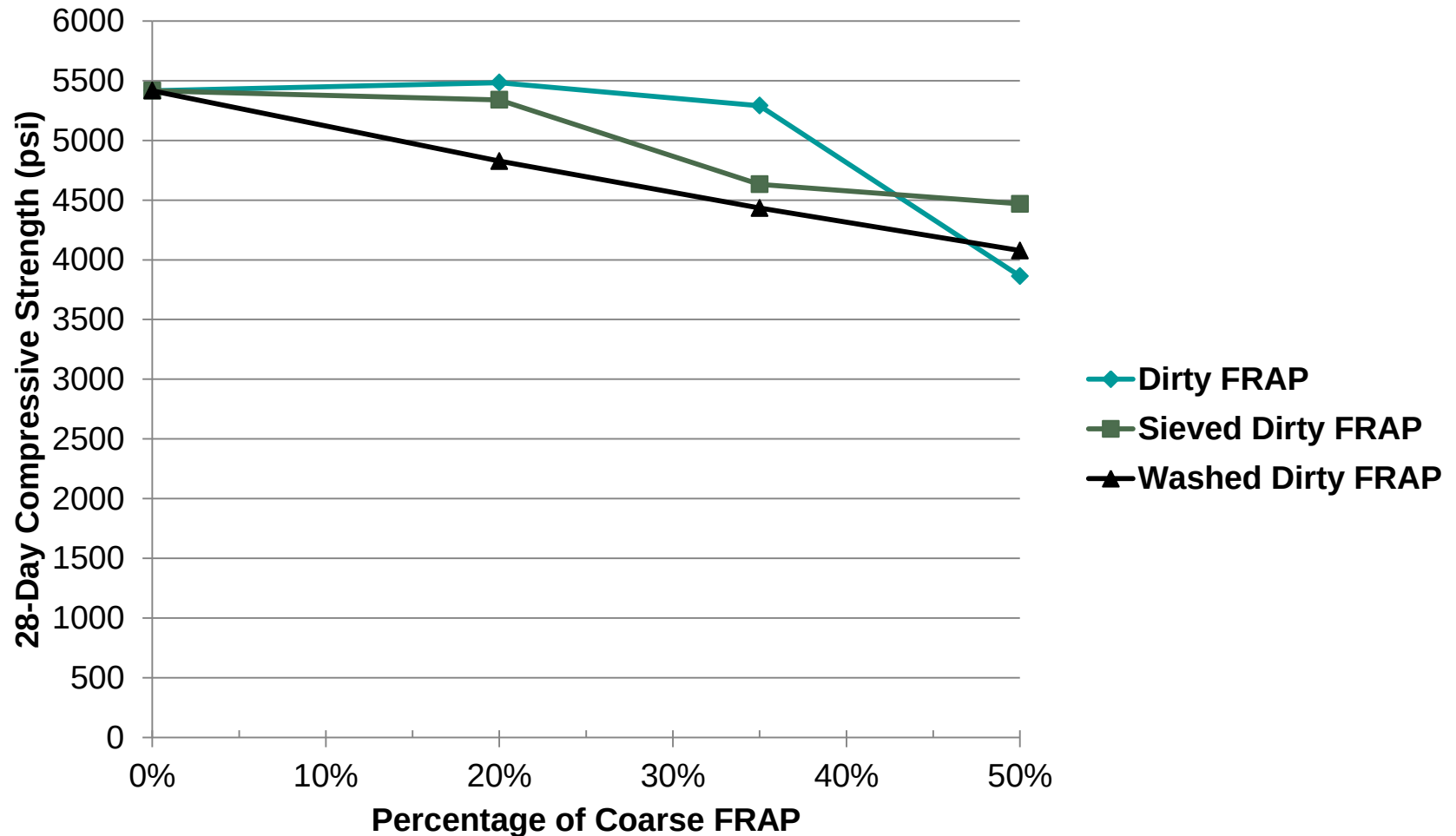
Flexural Strength



Is Washing the FRAP Necessary?

- **“Dirty” FRAP compared to washed FRAP**
 - **Four mix types:**
 1. **Control (0%)**
 2. **Dirty FRAP (20%, 35%, and 50%)**
 3. **Washed Dirty FRAP (20%, 35%, and 50%)**
 - **Fines (past #4) removed by washing**
 4. **Sieved Dirty FRAP (20%, 35%, and 50%)**
 - **Fines (past #4) removed by dry sieving**
 - **Tested for compressive and split tensile strength at 7, 14, and 28 days**
-

Compressive Strength – 28 Days



Phase I Research Conclusions

- ▶ **FRAP can used up to 50% to meet strength requirements for paving concrete**
 - ▶ **Compressive: 3500 psi at 14 days**
 - ▶ **Flexural: 650 psi at 14 days**
 - ▶ **Additional processing of the dirty FRAP does not appear beneficial**
 - ▶ **Concrete strength / modulus decreases as FRAP content increases, impacting cure times**
 - ▶ **Restrained shrinkage is slightly greater for control (0% RAP) mix**
 - ▶ **Chloride penetration is relatively unaffected**
-

Phase II Research Conclusions

- ▶ **Slab capacity is not accurately predicted by the beam flexural strength!**
 - ▶ Supports previous findings by other researchers.
 - ▶ Load capacity is under-predicted by a factor of 1.5 to 2.7.
 - ▶ Attributed to geometric / material size effect.
- ▶ **Despite a significant reduction in concrete beam / cylinder strengths, concrete with recycled aggregates can have similar slab flexural load capacities compared to virgin aggregate concrete.**
- ▶ **We don't need to increase the slab thickness for FRAP concrete!**

Research Developed Materials Specifications

Requirements for bottom lift concrete as currently specified:

- ▶ **Optimized gradations**
- ▶ **15% to 50% coarse FRAP (Black Rock)**
- ▶ **0% to 85% coarse RCA allowed**
- ▶ **Ternary mixes (35% to 50%) required**
- ▶ **Blended cements allowed**

Specifications For Composite Pavements

▶ *Materials*

- ▶ Top lift concrete designs either standard Class PV mix, or optimized ternary performance based mix with virgin aggregate. Only optimized mixes after 2014.
- ▶ Bottom lift concrete designs only with optimized ternary performance based mixes with black rock aggregate

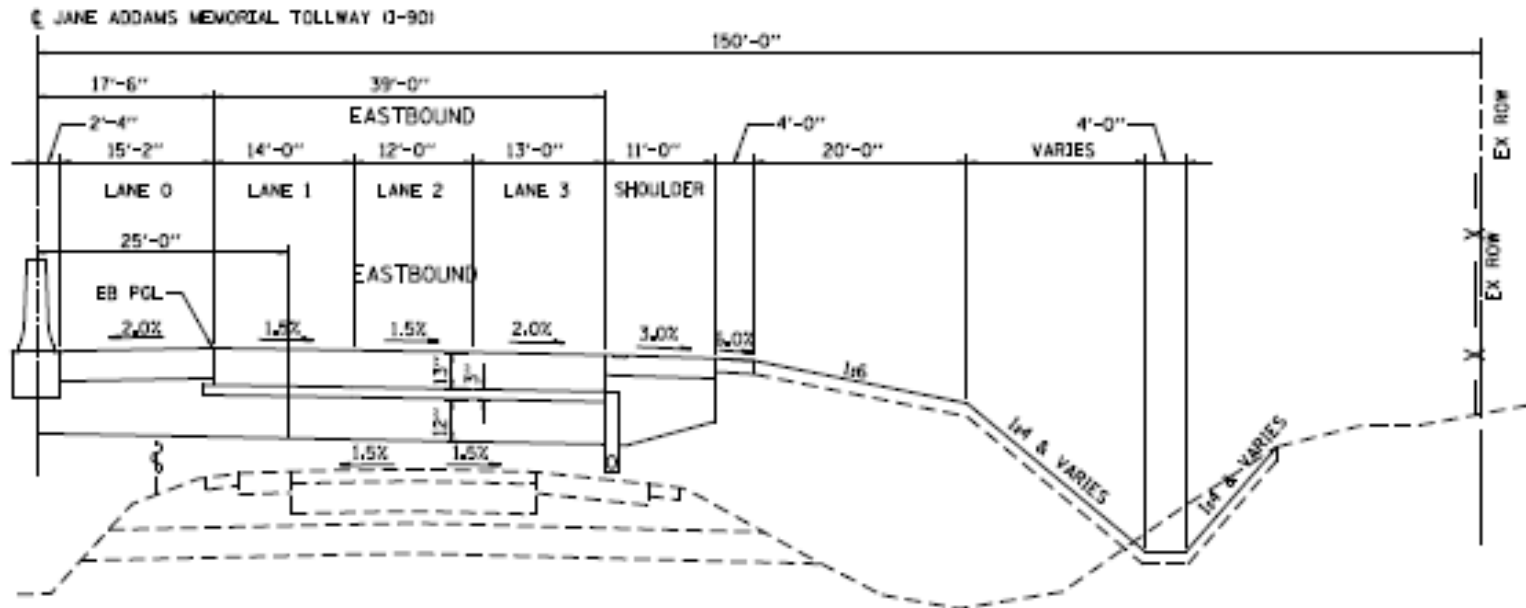
▶ *Curing*

- ▶ Opened to construction traffic at a min. flexural strength of 450 psi and 2,850 psi compressive strength no earlier than 3 or 4 days age for light trucks (< 20,000 single axle load) and no earlier than 4 or 5 days for heavy loaded trucks depending on FRAP content.
- ▶ Opened to public traffic at 650 psi flexural strength and 3,500 psi compressive strength, typically obtained in 7 to 14 days.

Placed 0.7 Mile Trial Reconstruction and Widening Project on I-88 in 2012



Composite Pavement Designs Fully Implemented for I-90 Construction in 2013



PROPOSED I-90 TOLLWAY
HIGH FILL SECTION

LCCA's Determine JPCP to be the Choice



$$C_{12} = C_1 + (C_2 * FR^{0.25})$$

$$C_{34} = C_3 + (C_4 * FR^{0.25})$$

$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right) \right]^{C_6}$$

$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^m DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$

$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$

$$C_8 = DowelDeterioration$$

- C1 - Cracking
- C2 - Spalling
- C3 - Faulting
- C4 - Site Factor

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$

$$CRK = \frac{100}{1 + C4 FD^{C5}}$$

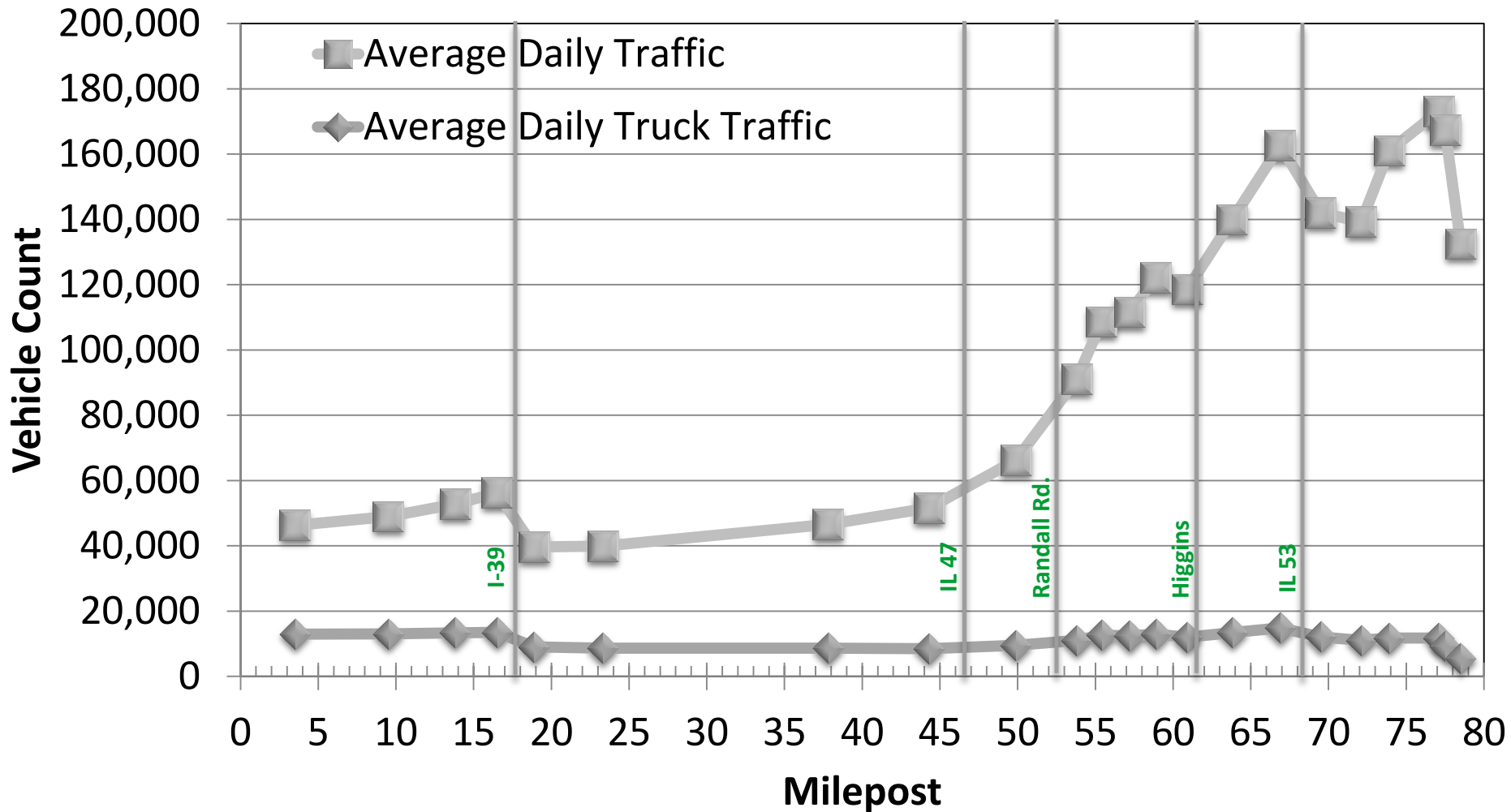
$$\log(N) = C_1 \left(\frac{MR}{\sigma}\right)^{C_2}$$

$$P.O. = \frac{C_3}{1 + C_4 Damage^{C_5}}$$

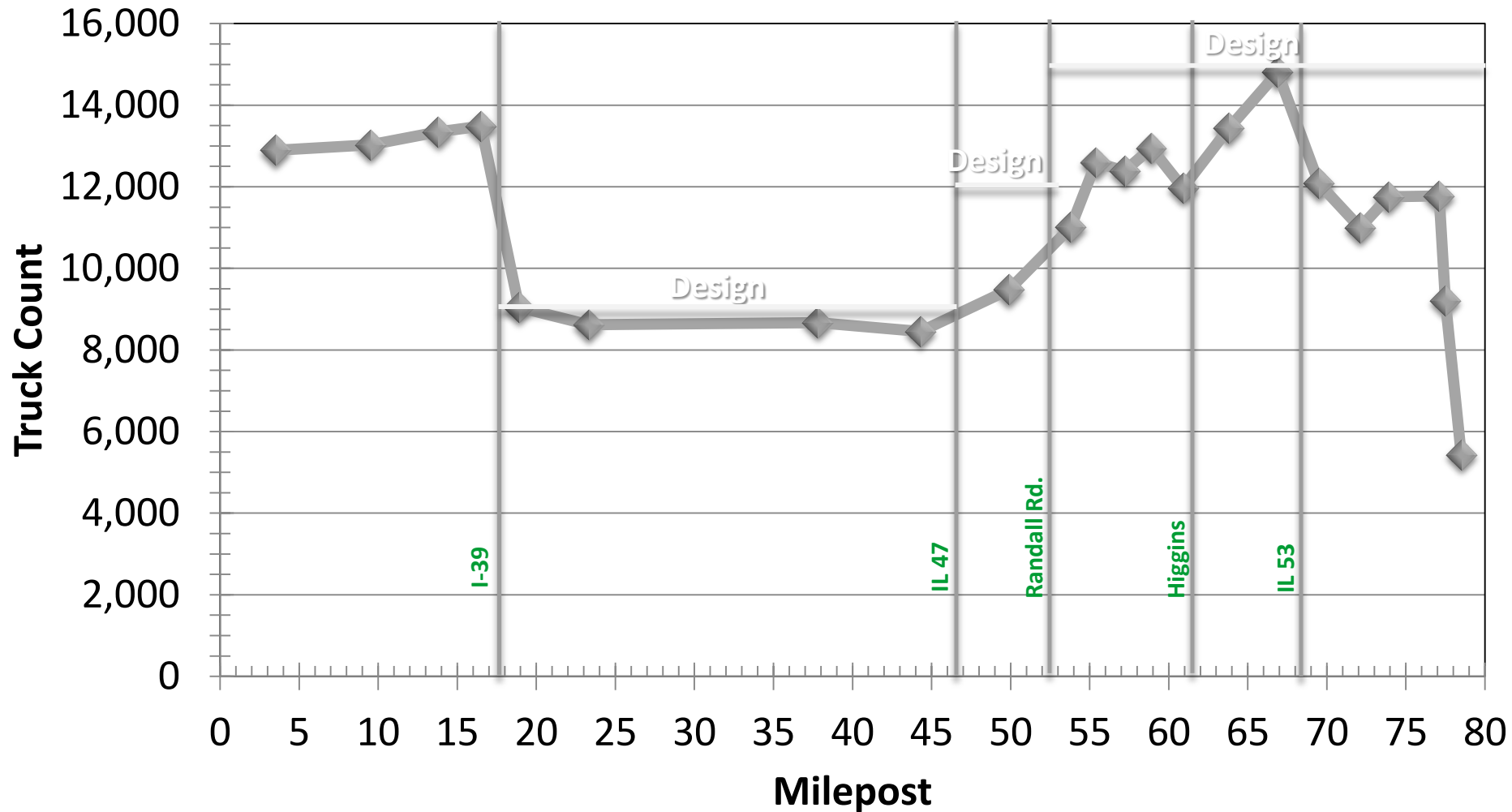
$$cw = C_6 (cw_i)$$

- C1 - Punchout
- C2 - Site Factor

Total Traffic and Truck Traffic Are Different



Truck Counts Split In 3 Segments



Major Traffic Inputs for Pavement Design

- ▶ Lane Distribution
- ▶ Traffic Volume
- ▶ Load Spectra

3-Lane

4-Lane

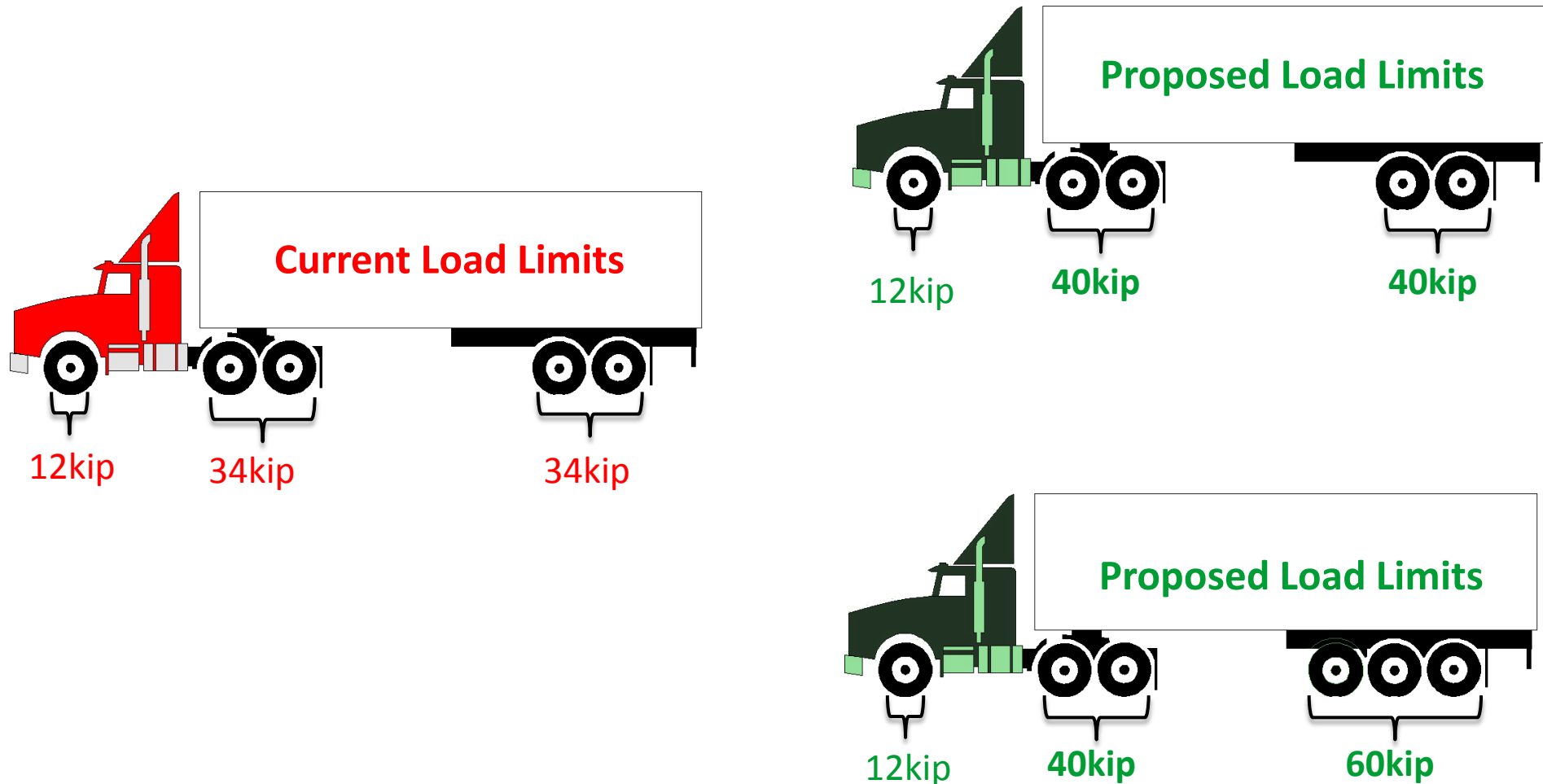
Tollway
70%

National
60%

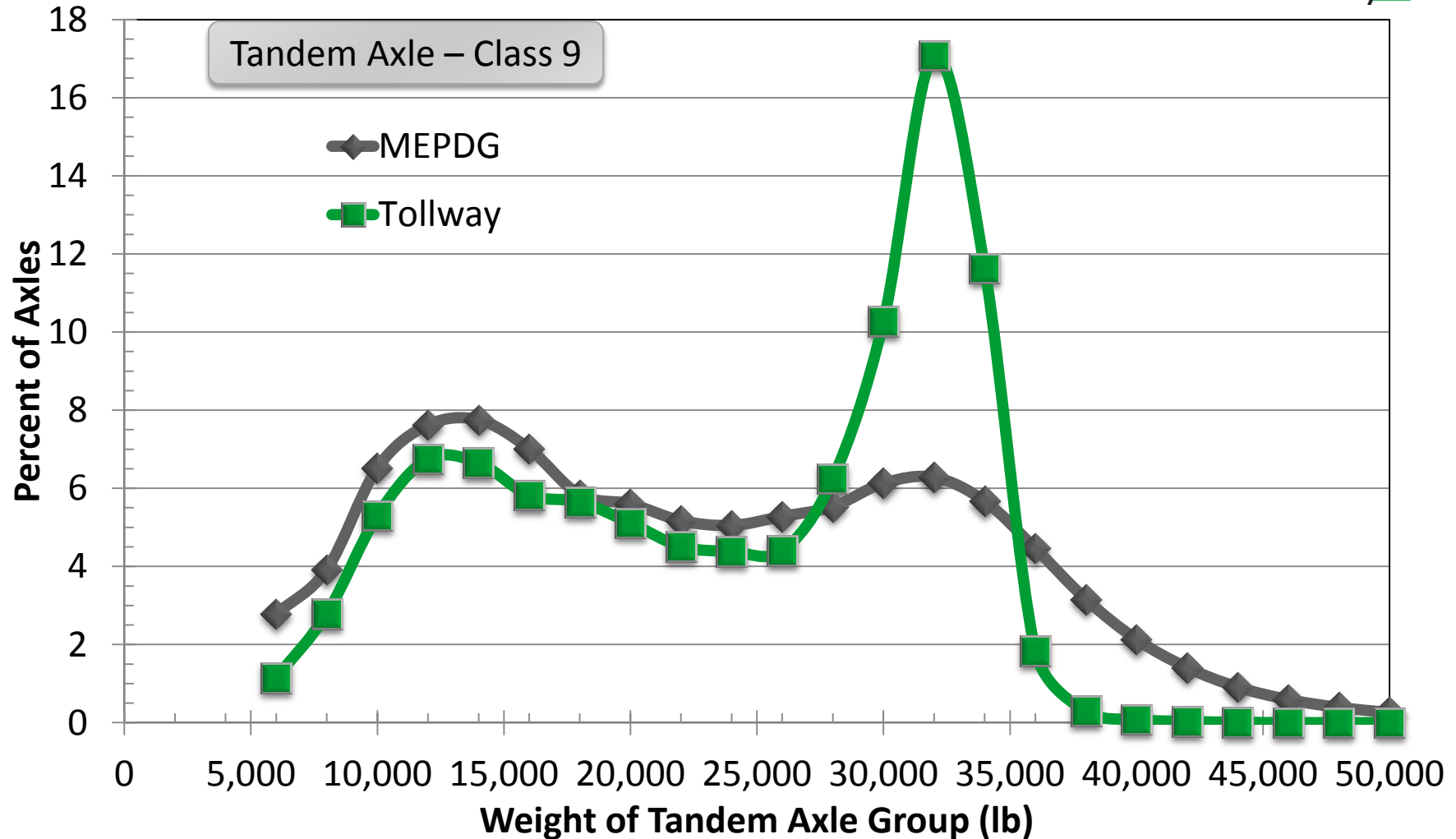
Tollway
70%

National
45%

Design Trucks – Load Distributions

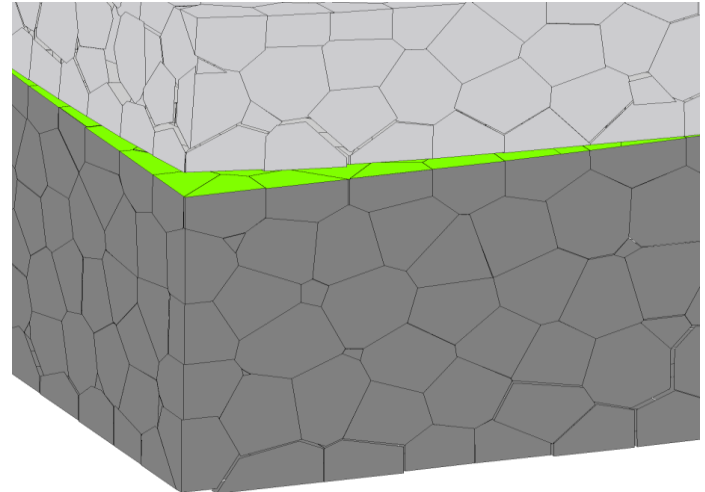


Tollway Axle Weight Distribution Does Not Follow National Data



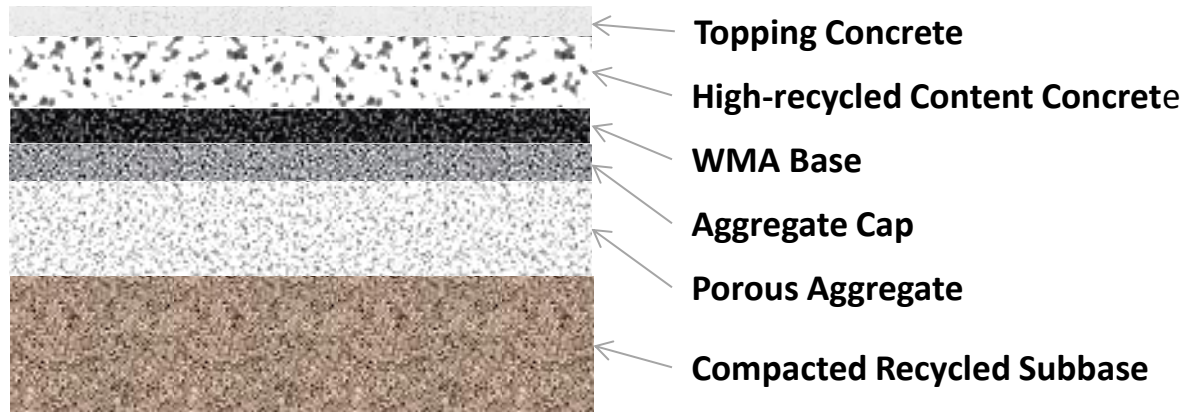
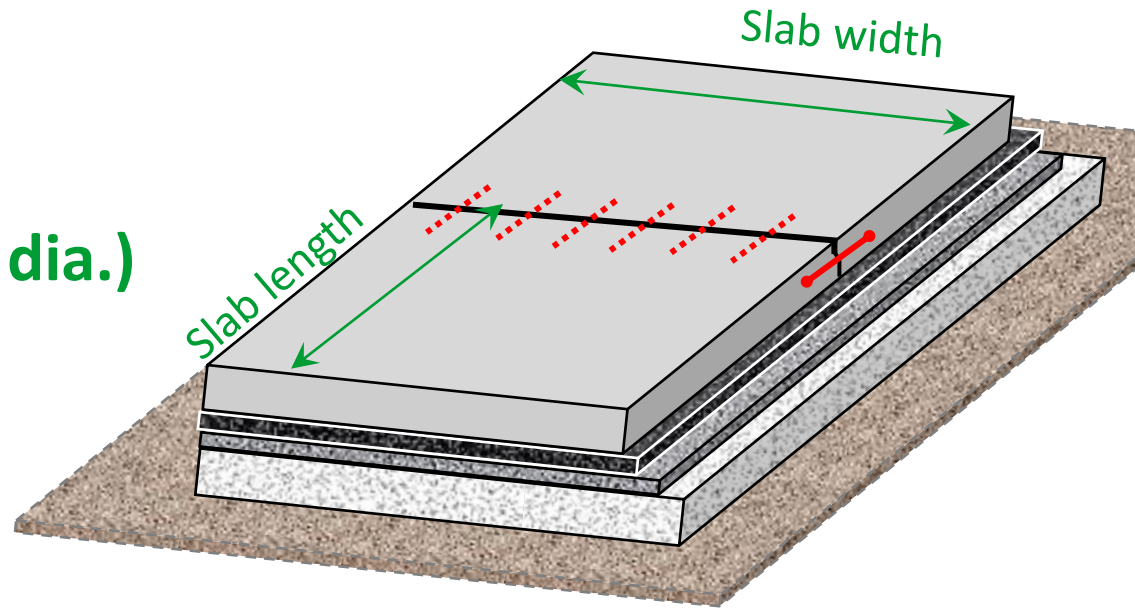
Understanding bonding is key

- ▶ **Lattice Model (PCC/PCC Debonding)**
 - ▶ R-21 work coupled lattice models with finite element models
 - ▶ Analysis concluded wet on wet paving had only very low chance if any to debond, matching field surveys & bond testing.



I-90 Concrete Pavement Design Details

- ▶ 15' Slab length
- ▶ 1' Widened slab
- ▶ Doweled Joints (1 ½" dia.)
- ▶ 18" of base



Summary of I-90 Reconstruction - 2013

Test strips constructed for all types of placements (single and double lane)



Summary of I-90 Reconstruction - 2013

Two slip form pavers / two belt placers for double lane placements only



Summary of I-90 Reconstruction - 2013

One slip form paver / two belt placers for double lane and single lane placements



Summary of I-90 Reconstruction - 2013

Two slip form pavers / one belt placer for double lane placements only



Summary of I-90 Reconstruction - 2013

One slip form paver / one belt placer for single lane placements only



Summary of I-90 Reconstruction - 2013



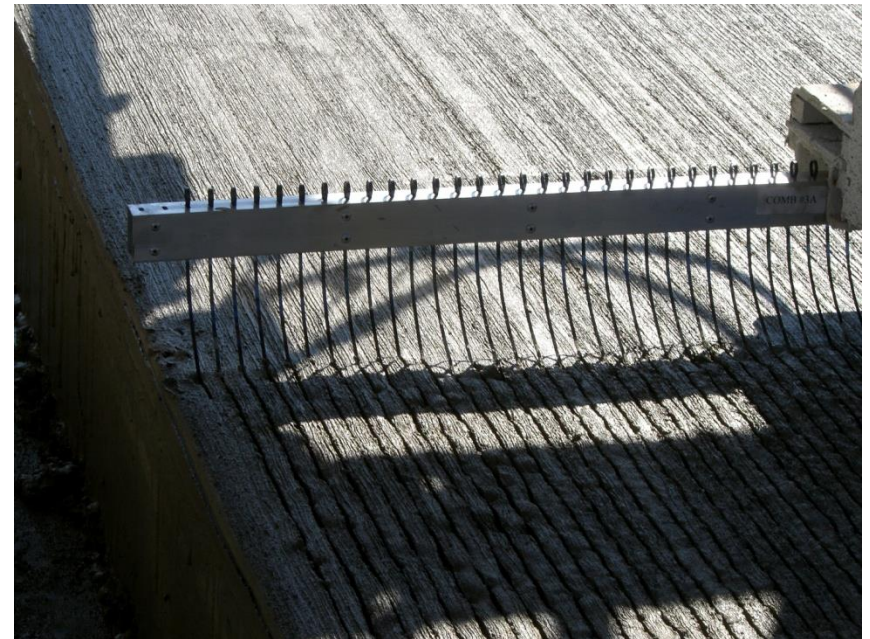
Envelope outside edges of bottom lifts



Summary of I-90 Reconstruction - 2013



Finishing / curing / opening to traffic



Summary of I-90 Reconstruction - 2013

*MIT Scan device to measure dowel bar alignment
used as a QA tool in 2013*



Summary of I-90 Reconstruction - 2013

Consolidation monitored with thickness cores



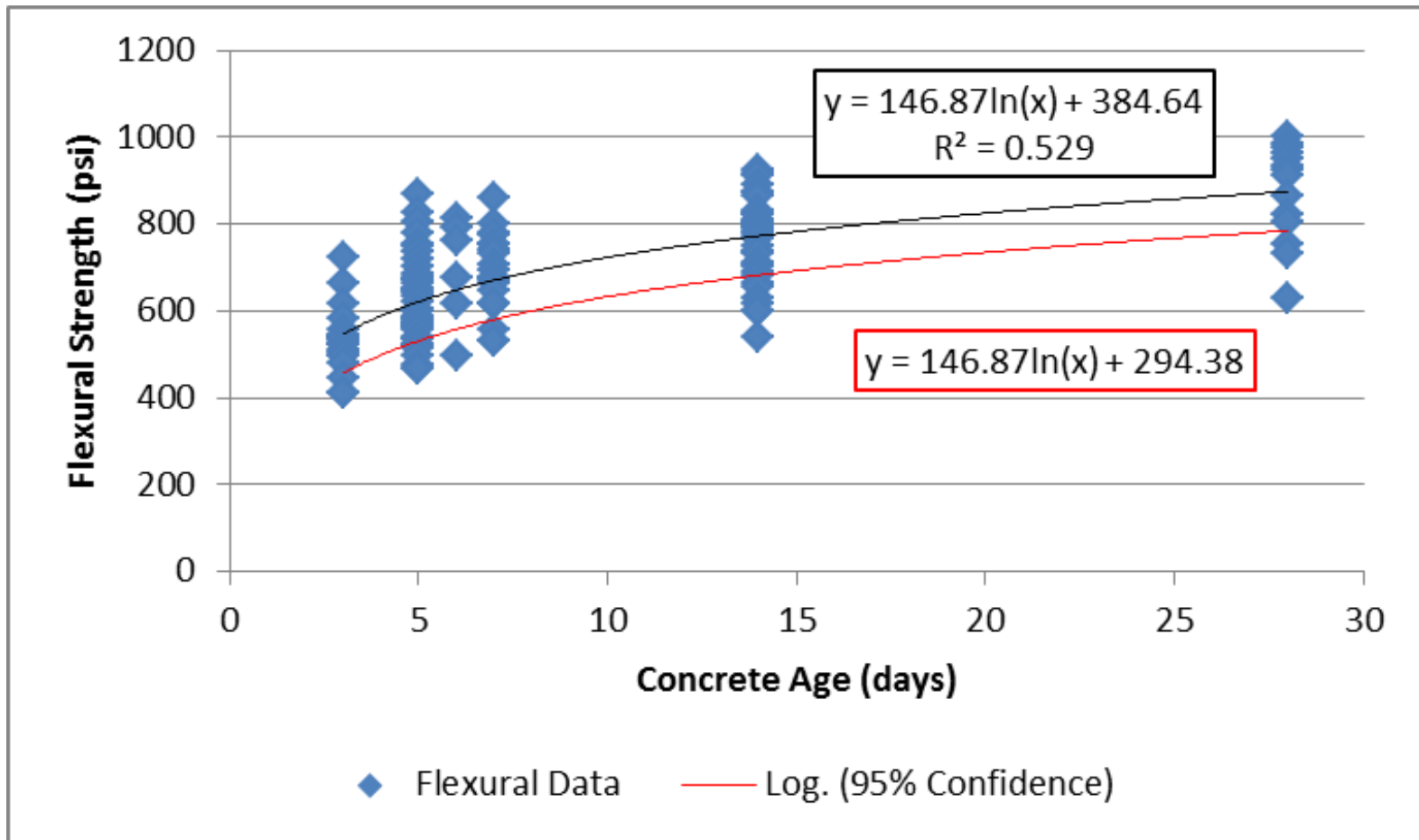
Typical Black Rock Mix Design Used in 2013

► *Typical Proportions:*

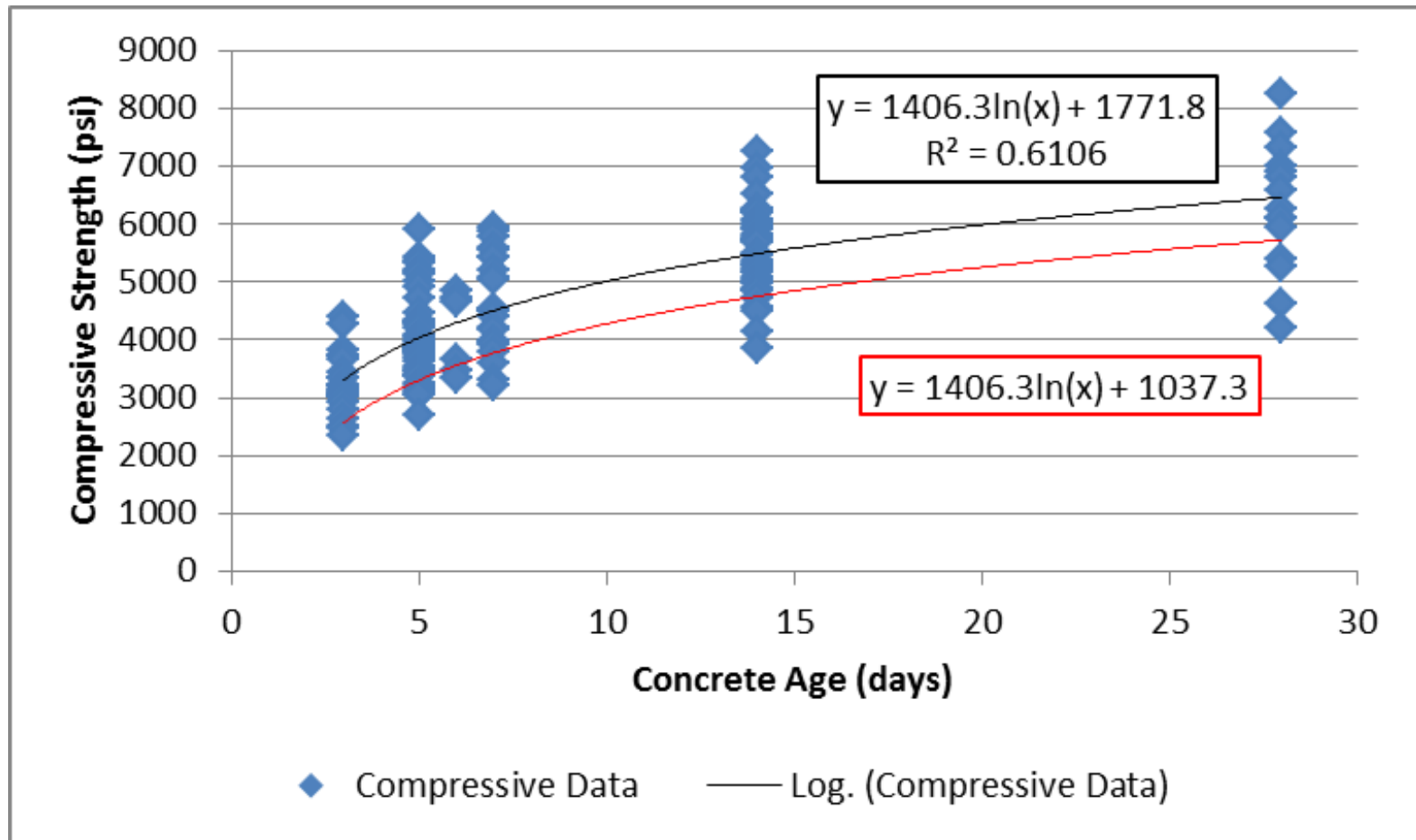
	Lbs/Cu Yd
Cement	375
Class C Fly Ash	145
Slag Cement	60
Coarse Aggregate*	1575
Black Rock	273
Natural Sand	1196

*** - IDOT CM-11 Crushed Stone (~ AASHTO #6 Stone)**

Summary of Flexural Strength Data Received on 2013 Ternary Black Rock Mixes



Summary of Compressive Strength Data Received on 2013 Ternary Black Rock Mixes



Bid Prices for 2013 and 2014 Composite Pavement Construction



- **Bid prices for 2013 construction of 11.25" JPC composite (637,429 Sq. Yds. – 5 contracts)**
 - **\$40.30 / Sq. Yd. average of all bids (24 total)**
 - **\$38.43 / Sq. Yd. average of all low bidders (5)**

- **Bid prices for 2014 construction of 11.25" JPC composite (685,243 Sq. Yd. – 5 contracts)**
 - **\$40.42 / Sq. Yd. average of all bids (15 total)**
 - **\$38.15 / Sq. Yd. average of all low bidders (5)**

Extra Costs Are Not An Issue With Composite Pavements



- **Approximately 1,188,086 Sq. Yds. of 12" JPCP Placed on I-294 and I-88 Reconstruction / Widening Projects**
- **Average Low Bid Price = \$56.37 / SY**

Lessons Learned From 2013 Placements

- ▶ Cure times can be reduced with low FRAP %
- ▶ Two slip form pavers are not to be mandated with black rock mixes
- ▶ Adequate spacing and time between paving operations is important
- ▶ MIT Scanning can be time consuming
- ▶ Two concrete plants must be required
- ▶ Two lift paving is not at a higher cost
- ▶ Don't use limited resources for recycled agg.

Next Step for Future Tollway Composites

- ▶ Samples taken from IDOT's mountain high stockpiles of RAP proven by CTL Group to be suitable for freeze thaw durability
- ▶ Supply of Black Rock on Tollway projects will no longer be constrained

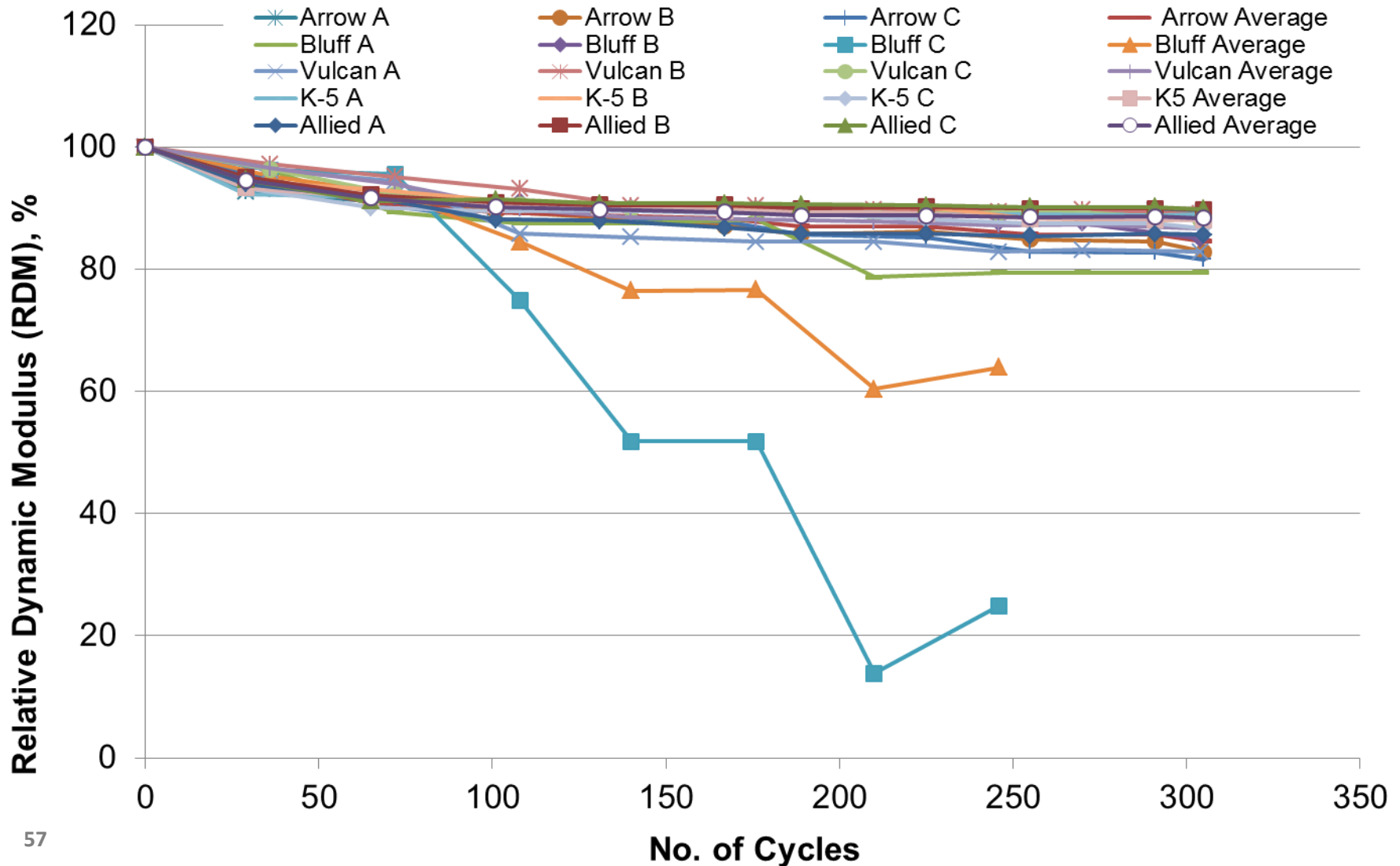


FRAP and B Quality Ternary Mixes

ASTM C192 Mixture Summary

	B1	B2	Frap A	Frap B	Frap C
Material	lb/yd ³ (SSD)				
Cement	370	370	370	370	370
Fly Ash	85	85	85	85	85
Slag	115	115	115	115	115
Coarse Aggregate	1880	1916	647	637	640
Coarse Aggregate	0	0	1240	1240	1240
Fine Aggregate	1190	1190	1190	1190	1190
Water	238	238	228	228	228
<i>w/cm</i>	0.42	0.42	0.40	0.40	0.40
fl. oz./cwt (100 lbs of cementitious material)					
Air Entraining Agent	1.41	1.02	1.02	1.02	1.02
Water Reducer	4.00	4.00	4.00	4.00	4.00
Measured Fresh Properties					
Slump, in.	0.75	2.25	1.5	2.5	2.25
Air Content, %	6.5%	8.0%	7.0%	8.5%	8.0%
Temperature, °F	72.8	71.2	72.3	73.7	73.8
Fresh Density, lb/ft ³	145.0	143.6	144.3	141.3	142.8

Freeze-Thaw Performance with FRAP and B-Quality Aggregates was Satisfactory



Current Research For Future Pavements

- ▶ Use of aged/oxidized steel slag FRAP in bottom lift
- ▶ Use of carbonate waste fines (screenings) in bottom lift





THANK YOU
