ABC's of CRACK-Less Bridge Decks

With Applications in

ACCELERATED

BRIDGE CONSTRUCTION

Sonny Fereira, PE California Department of Transportation
March 21, 2014
Bridge Contractors/ Caltrans Liaison Committee Meeting

Today's Program

- Background
- Formula for CRACK-Less Bridge Decks
- Specifying Drying Shrinkage values
- Plastic Shrinkage Control
- Caltrans' success over the past decade
- Applications in Accelerated Bridge Construction

A Tool of the Past

Deck Cracks Impact Service Life

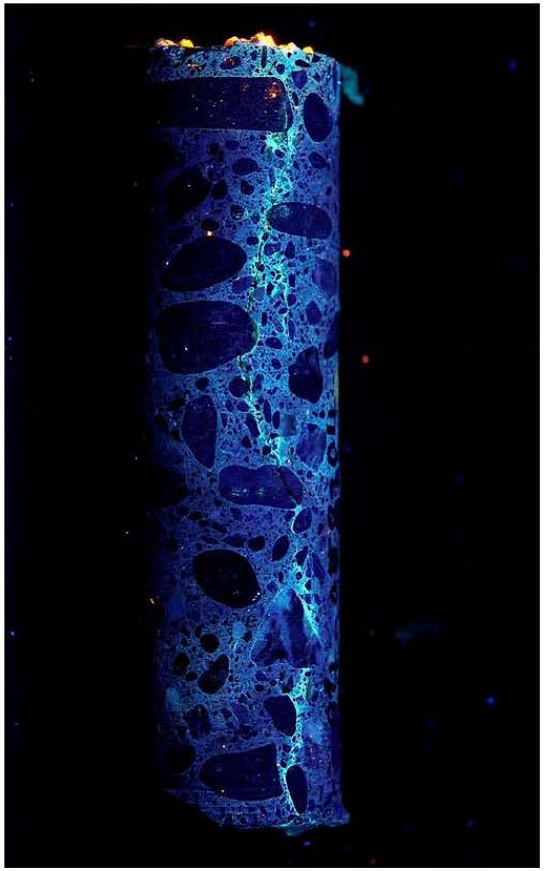
Deck Cracking has many causes, including those due to strains from:

- Drying Shrinkage
- Plastic Shrinkage
- Thermal Strain gradients
- Autogenous and Chemical Shrinkage

Drying Shrinkage and Plastic Shrinkage in Bridge Decks are the biggest sources of cracks

Autogenous, chemical, and thermal effects are relatively a minor contributor

Methacrylate “Fluoresces” under Black Light; indicates depth of penetration of crack in core



Early Age Deck Cracking Fact Sheet (March2013)

- Methacrylate deck treatment cost Caltrans

$50 Million Annually

- Over half of the State + Local bridge decks treated have been newer (less than 4 years old)
- About half of those were flagged for treatment in the first biennial inspection (~2 years old)

“Fixing” Deck Cracks is a costly solution Internationally

“Preventing” Deck Cracks is a better solution

Preventing Deck Cracks

- Modifying Procedures can result in reduced Plastic Shrinkage cracking

- Modifying the Concrete can result in reducing both Plastic and Drying Shrinkage cracking

Formula for the CRACK-Less Bridge Deck

A. Shrinkage Reducing Admixture*

B. Water Reducing Admixture*

C. Fibers*

*add to concrete mix

ABC's for CRACK-Less Bridge Decks

- By using off-the-shelf Shrinkage Reducing Admixtures, combined with Water Reducing Admixtures and Poly Fibers, CalTrans has been successful in producing CRACK-Less Bridge Decks experimentally across the State since 2002.
- Aggregates were from many different local sources
- Successful in a wide range of mixes using 0%-25% Flyash; air entrainment; accelerating admixtures, rich and lean mixes, w/c ratios from 0.36 to over 0.50

Role of Aggregate in Drying Shrinkage

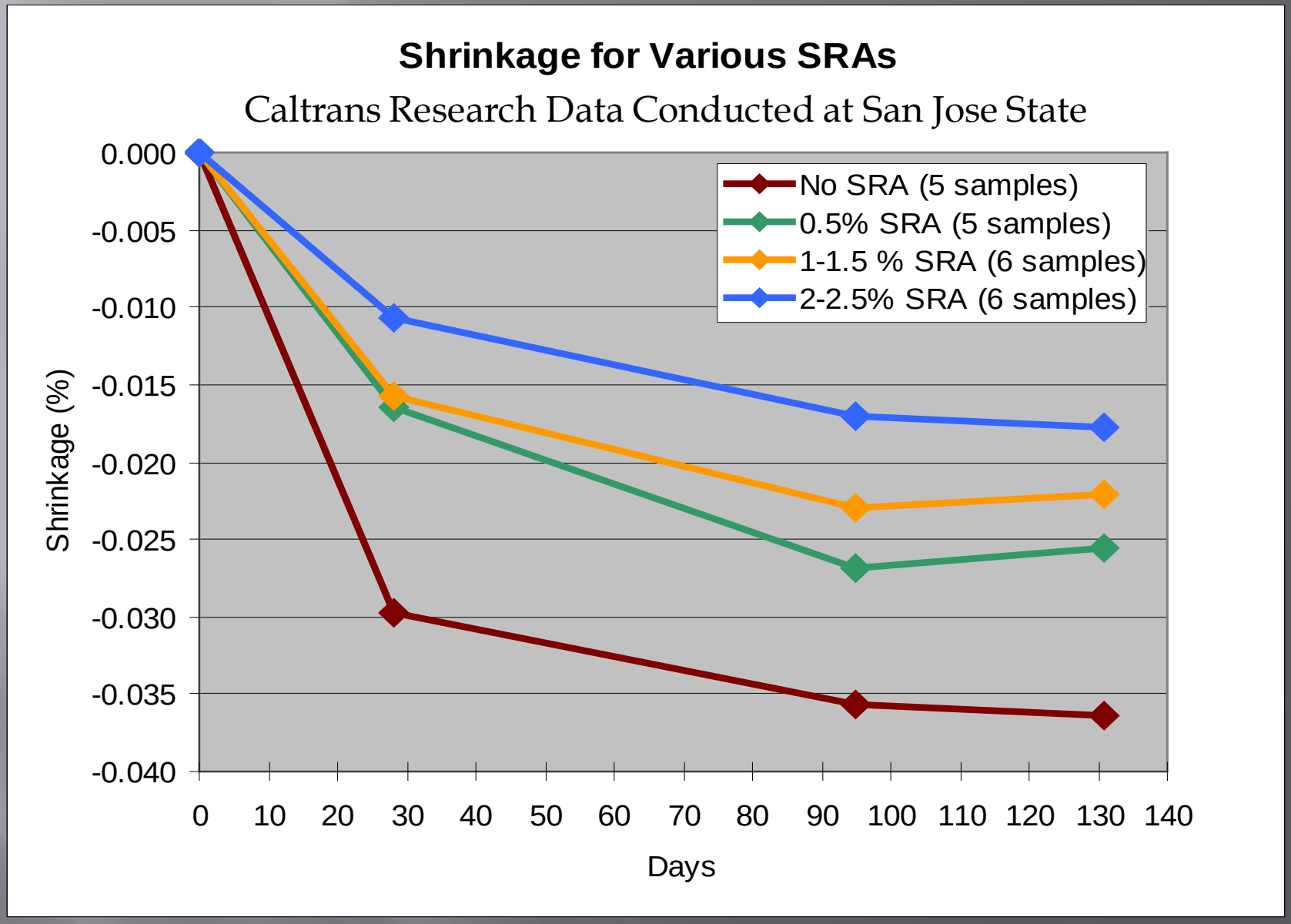
- Aggregates directly influence drying shrinkage by restraining shrinkage of the paste.
- Shrinkage is a function of the aggregate's stiffness (for a given aggregate size, concrete shrinkage will decrease with increasing aggregate modulus of elasticity).
- The size, shape, and gradation of the aggregates in a mixture also indirectly influence shrinkage by affecting water content and volume of paste in the concrete.

The Target is Set

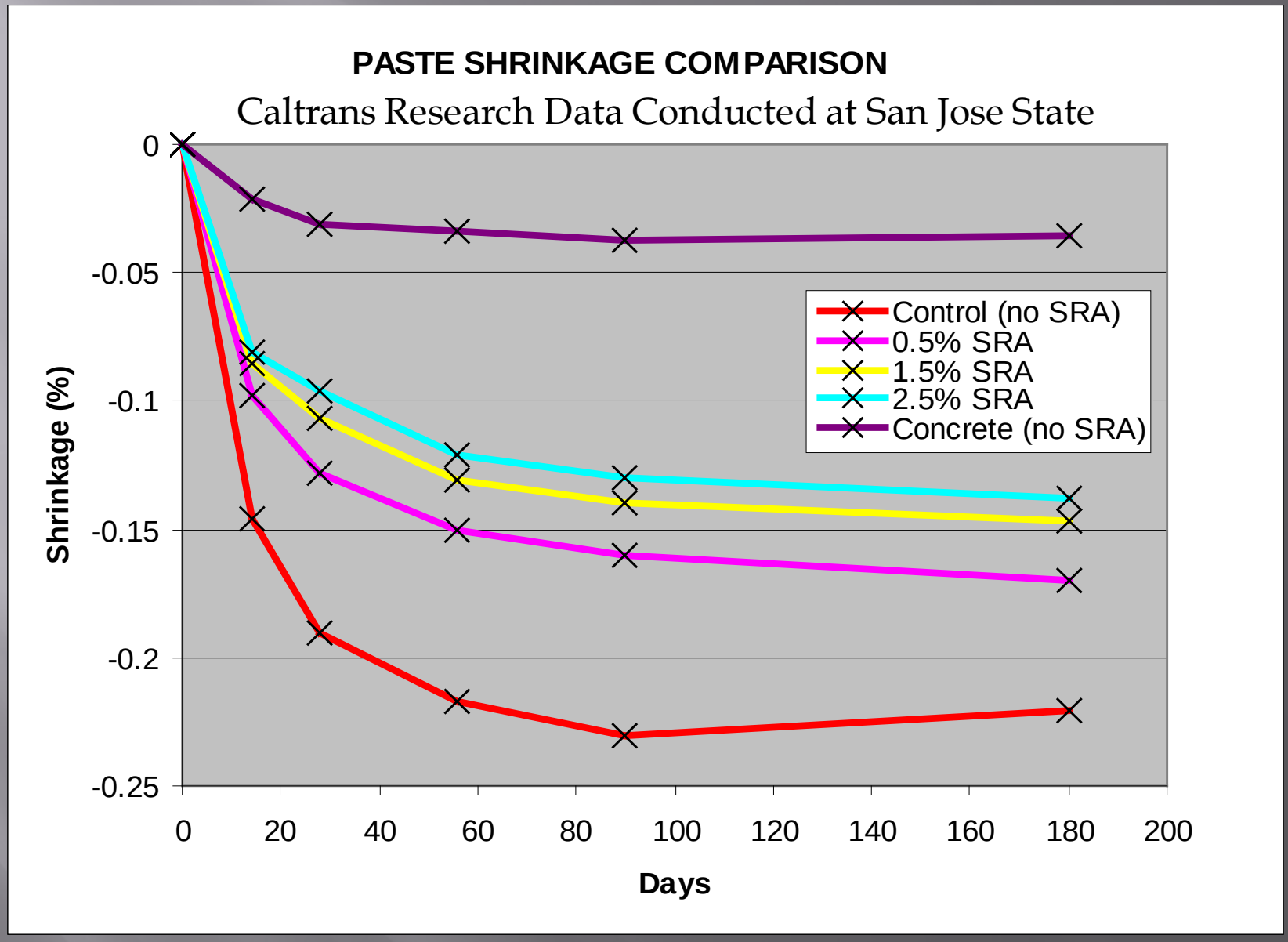
SPECIFYING DRYING SHRINKAGE VALUES

A target 28-day shrinkage value below 0.030% would significantly limit or eliminate early-age shrinkage cracking.

However, it would be difficult to achieve a 28-day shrinkage value below 0.030% without transporting specific aggregates to areas where they are not readily available.



22 concrete batches. Concrete had w/c ratio of 0.33, 631 lb/cy cementitious with fly ash at 20%, 25% or 30%, and 5% either Silica Fume or Metakaolin.



Of course it is the paste being controlled. Shown for comparison is a typical deck mix using low shrinkage aggregate (no SRA).

SRAs Achieve Target !

SRAs reduce capillary tension in the paste pore water, thereby decreasing shrinkage strains as paste dries.

Previously, controlling drying shrinkage to these low levels required use of low-slump mixtures and large, dense aggregates.

It is now possible to do so using SRAs, water reducers, and fibers.

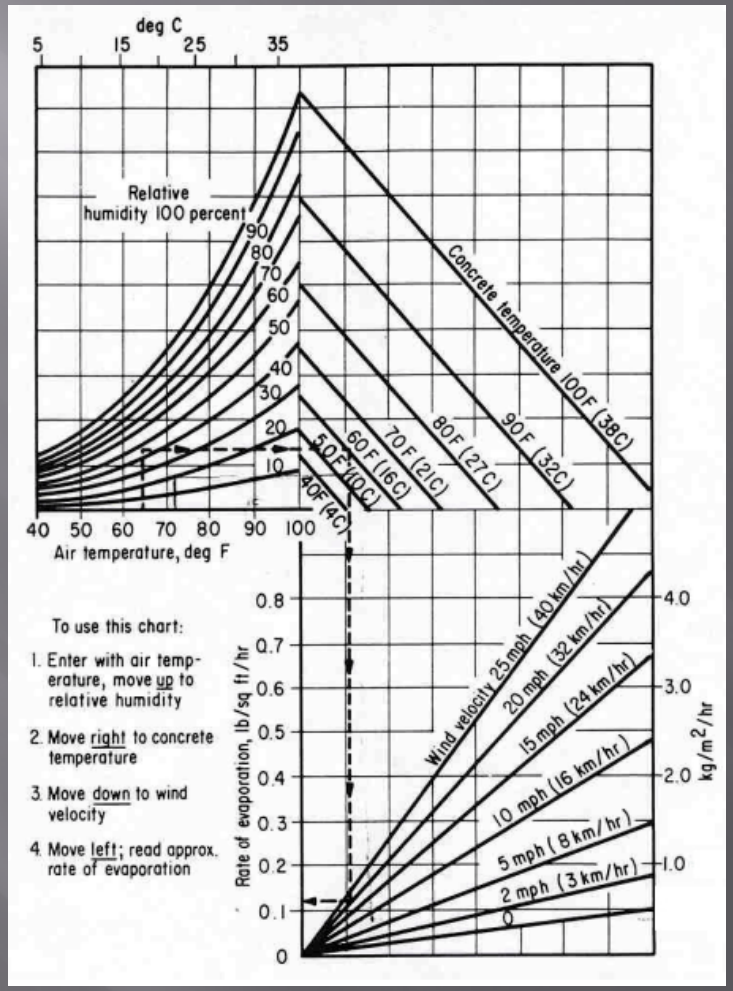
Workmanship Practices for Plastic Shrinkage Control

It is well established that eliminating evaporation of water from the plastic concrete as it sets up will control and prevent plastic shrinkage. Any neglect though will sabotage any effort to control early age shrinkage cracks.

Evaporation Rate Nomograph

From ACI 308

Precautionary measures are recommended when Rate of Evaporation is between 0.1 - 0.2 lb/sq ft/hr; Over 0.2 plastic cracking is expected.



Wind speed is taken 20" above surface.

Air Temp and Humidity are measured upwind 4-6' above surface, shaded from sun.

Concrete Temp is taken at wet surface

Commercial instruments are available (<$300 on Amazon)

Kestrel® 4300 Construction Weather Tracker

"Plastic Shrinkage Cracks are a costly problem for concrete professionals- they occur when the surface of the concrete dries quickly and shrinks before it is strong enough to resist cracking. Measuring relative humidity, ambient temperature and wind velocity at the pour site before the concrete is placed can help prevent this frustrating and expensive problem. Bluetooth® data transfer capabilities send minute by minute conditions during any pour straight to a laptop for easy jobsite documentation that conditions were within industry acceptable standards. The Kestrel 4300 Construction Pocket Weather Tracker is the perfect solution-accurate, quick response readings give concrete professionals the information they need to place concrete that won't crack."

Fogging

Best Practice to reduce Plastic Cracking in Decks

MODIFY PROCEDURES

- Conduct a Pre-Pour Meeting
- Ensure cure is applied timely
- Pre-wet curing blankets
- Use Fogging system
- Use windbreaks
- Place at night if required
- Use evaporation reducers
- Delay placement until environmental conditions are favorable
- Cure water T should be close to deck surface T to avoid ΔT stress

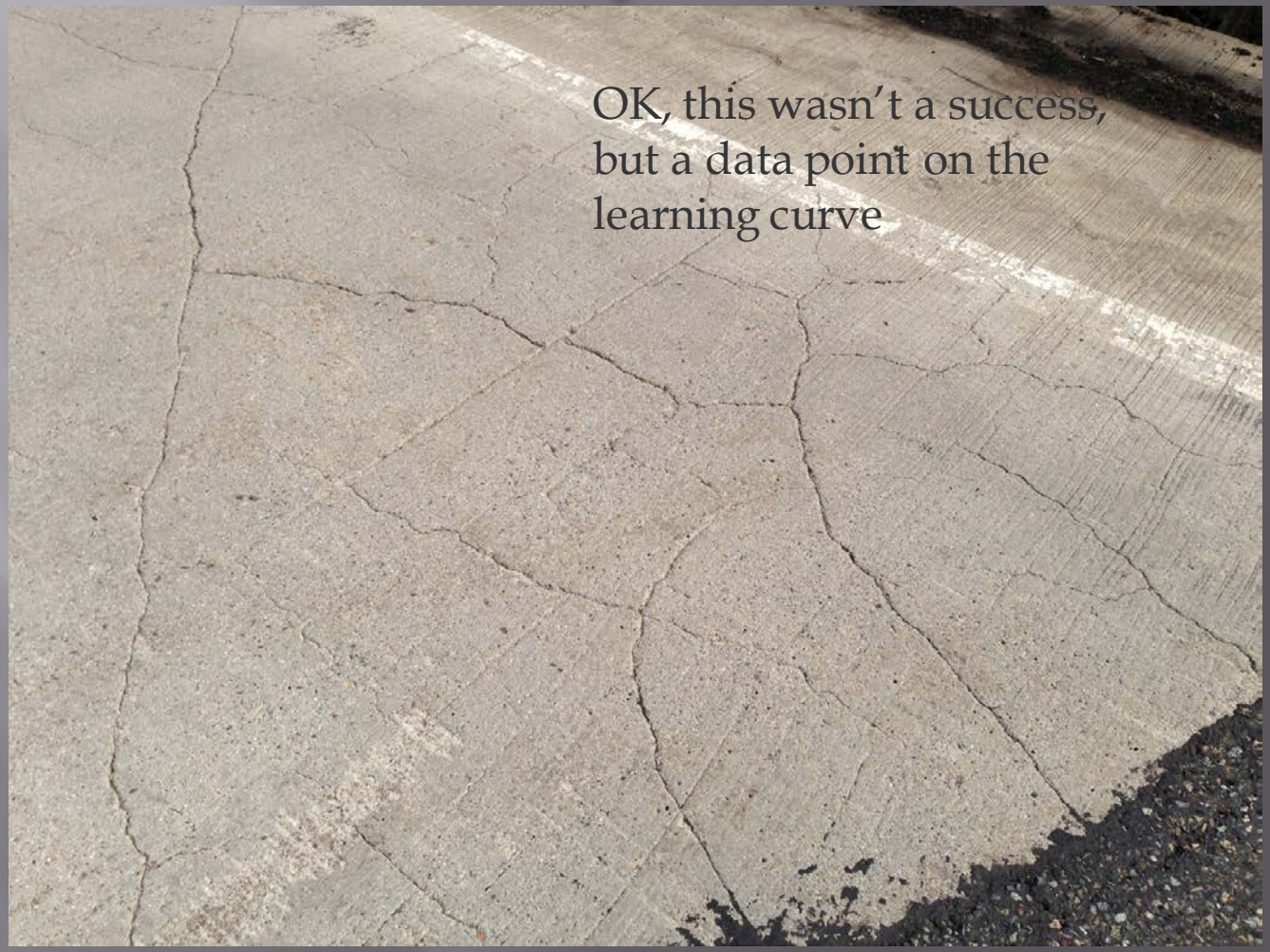
MODIFY CONCRETE

- Cool Concrete : T<80°F at placement: Ice, Nitrogen; wet down stockpiles days before need
- Use Shrinkage Reducing Admixture (mostly for Drying Shrinkage, however it may aid in cement hydration)
- Use Water Reducing Admixture and Fibers: micro and macro both help

CalTrans' Successes "Boca Bridges" - 2002 SRA

See Deck soffit – without SRA built 2001 ~ Note Efflorescence ~	Deck Concrete with SRA used after first stage 2002, this is also how it looks today!

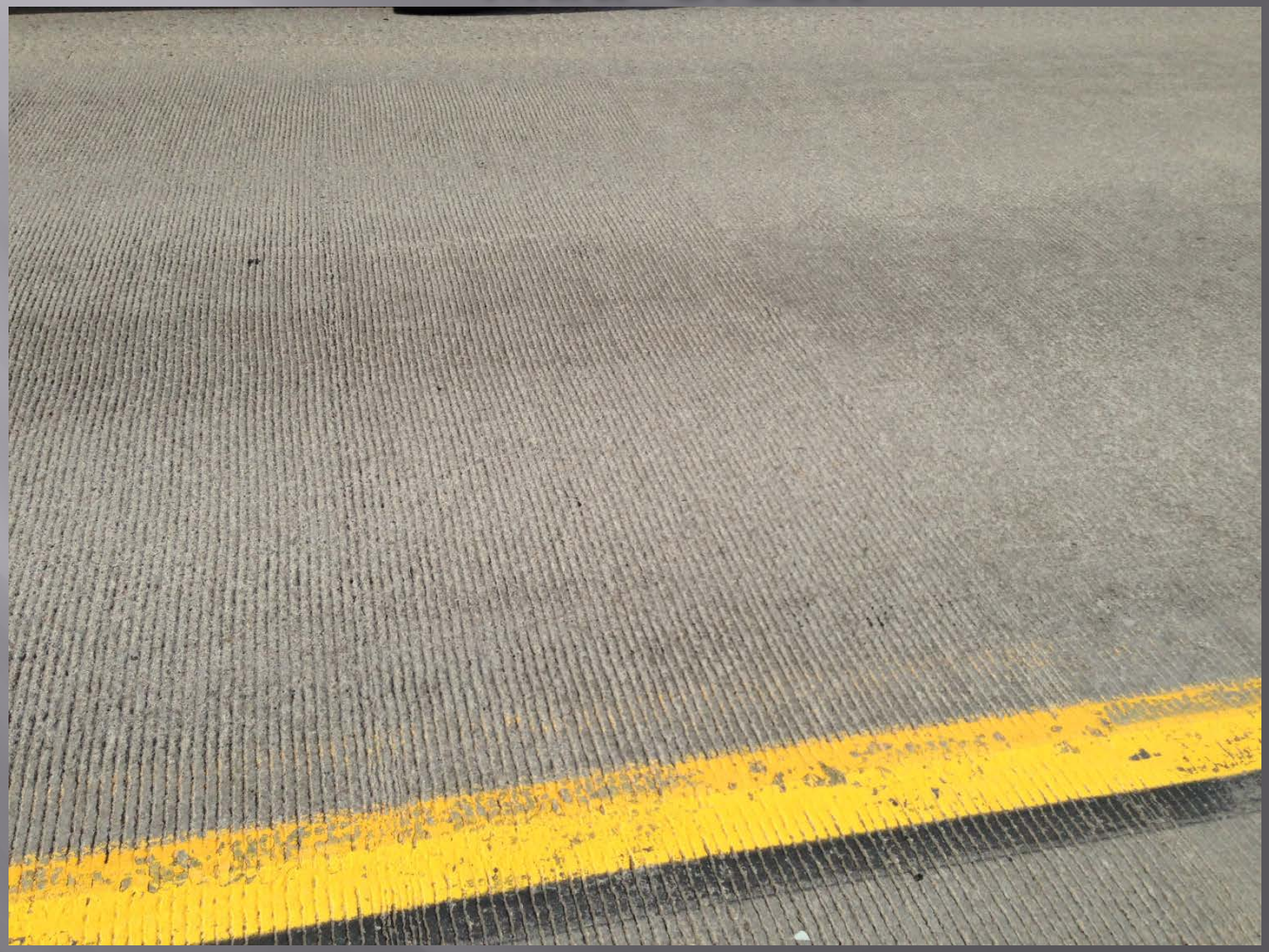
Mud Creek 2004 – Accelerated Mix and 3 day cure, No SRA



Crag View Drive Deck-on-Deck 2006

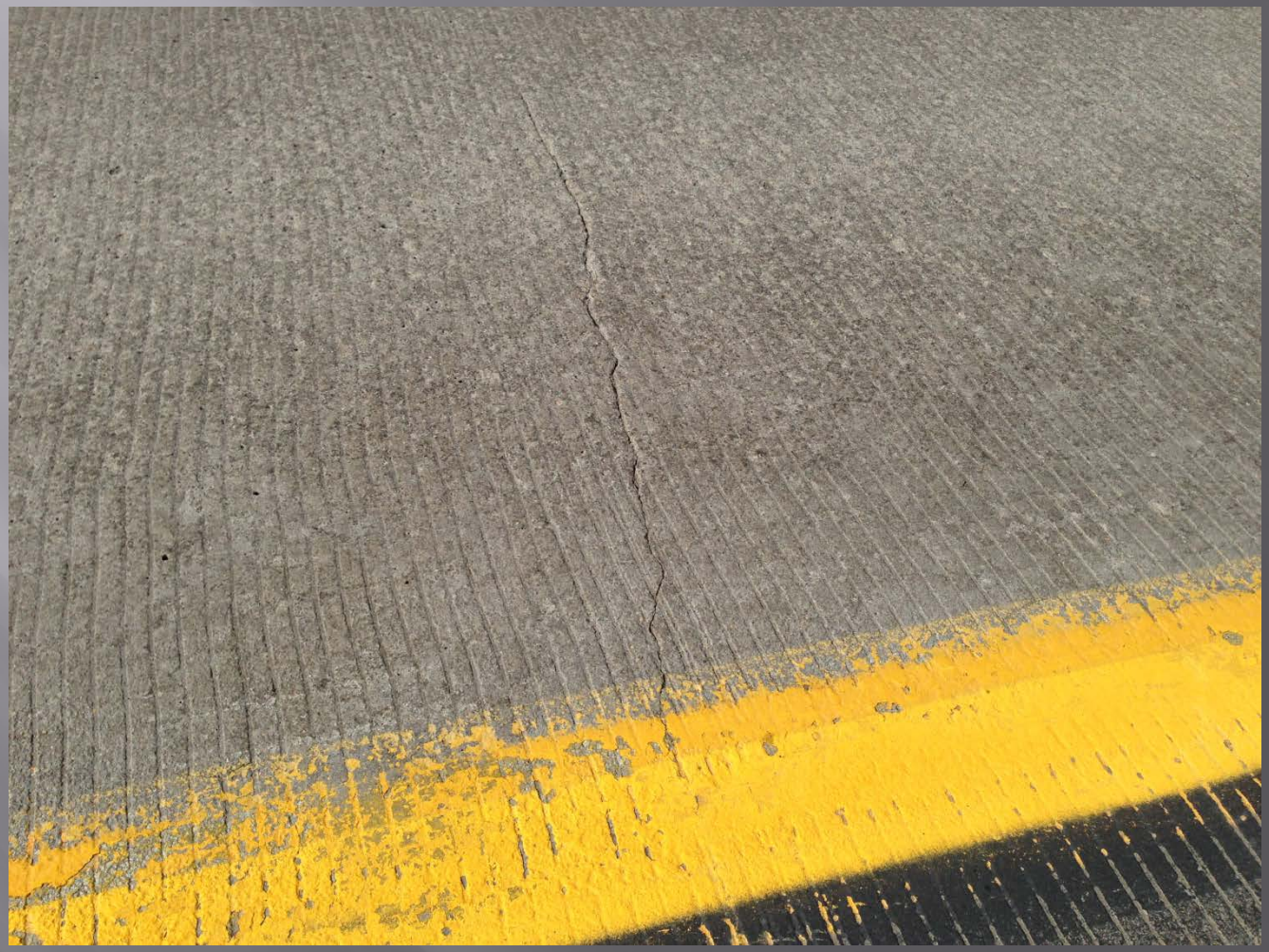
Crag View Drive UC Today

Same Mix (but w/ SRA) and Contractor as Mud Creek



Single Crack – Crag View

6 ½ years after placement over existing ASR deck



Pit River Bridge over Lake Shasta 2007
Side-by-Side comparison opportunity
SRA + Fibers

Countering Cracks from Drying Shrinkage

Pit River Mix Design

Shasta Redi-Mix
A DIVISION OF J.F. SHEA CO., INC.
17400 Clear Creek Road • P.O Box 494519 • Redding, California 96049-4519
Telephone (916) 246-2200 FAX (916) 246-0554

DATE 10/23/07

DESIGN OF CONCRETE MIX

REPORT TO: Golden State Bridge
901 Howe Road
Martinez, CA 94553

PROJECT: CA No.02-3C1414
LOCATION: Pit River Bridge
Redding, California

MATERIAL AND LABORATORY DATA

AGGREGATE SOURCE: F.A. Aggregate Products C.A. Aggregate Products

A.S.T.M.	C – 29	C – 127	C – 40	C – 117	C – 127
AGGREGATE	WEIGHT PER CU. FT.	SPECIFIC GRAVITY	ORGANIC	DECANTATION	ABSORPTION
25mm x 4.75mm		2.67			1.7
9.5mm x 2.36mm		2.65			2.3
Sand		2.62			2.5

MECHANICAL ANALYSES PERCENT PASSING U.S. STANDARD SIEVES

SIEVE			25 mm	19 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	F.M.
25mm x 4.75mm			100	78	8	2						7.12
9.5mm x 2.36mm				100	91	17	3					5.89
Sand						100	84	60	38	20	8	2.90
COMBINED			100	91	60	46	37	26	16	9	3	5.12

MIX DESIGN

CEMENT FACTOR, Kg/CUBIC METER 350 (Cement + 10% Flyash)

WATER CEMENT RATIO 0.51

MIN. 28 DAY STRENGTH 25.0 MPa

Penetration 50 MM MAX.

ADMIXTURE Darex II, Eclipse Plus,& WRDA 64

ENTRAINED AIR REQUIRED: 6 +or- 1 1/2%

TYPE CEMENT II - V

MIX NO. CT-350-6F10

CLASS II

MATERIAL	PERCENT OF PARTS	QUANTITIES KG	QUANTITIES LBS.
25mm x 1.75 mm	42.0	725	1594
9.5mm x 2.36mm	15.0	254	559
Sand	43.0	728	1602
Flyash		35	77
CEMENT		315	693
TOTAL WATER		180	396
ADMIXTURE Per Mfg. Specs.			
TOTALS	100.0	2237	4921 LBS.

BASED UPON AGGREGATES IN SATURATED SURFACE DRY CONDITION.

CORRECTION NECESSARY FOR FREE MOISTURE ON AGGREGATES.

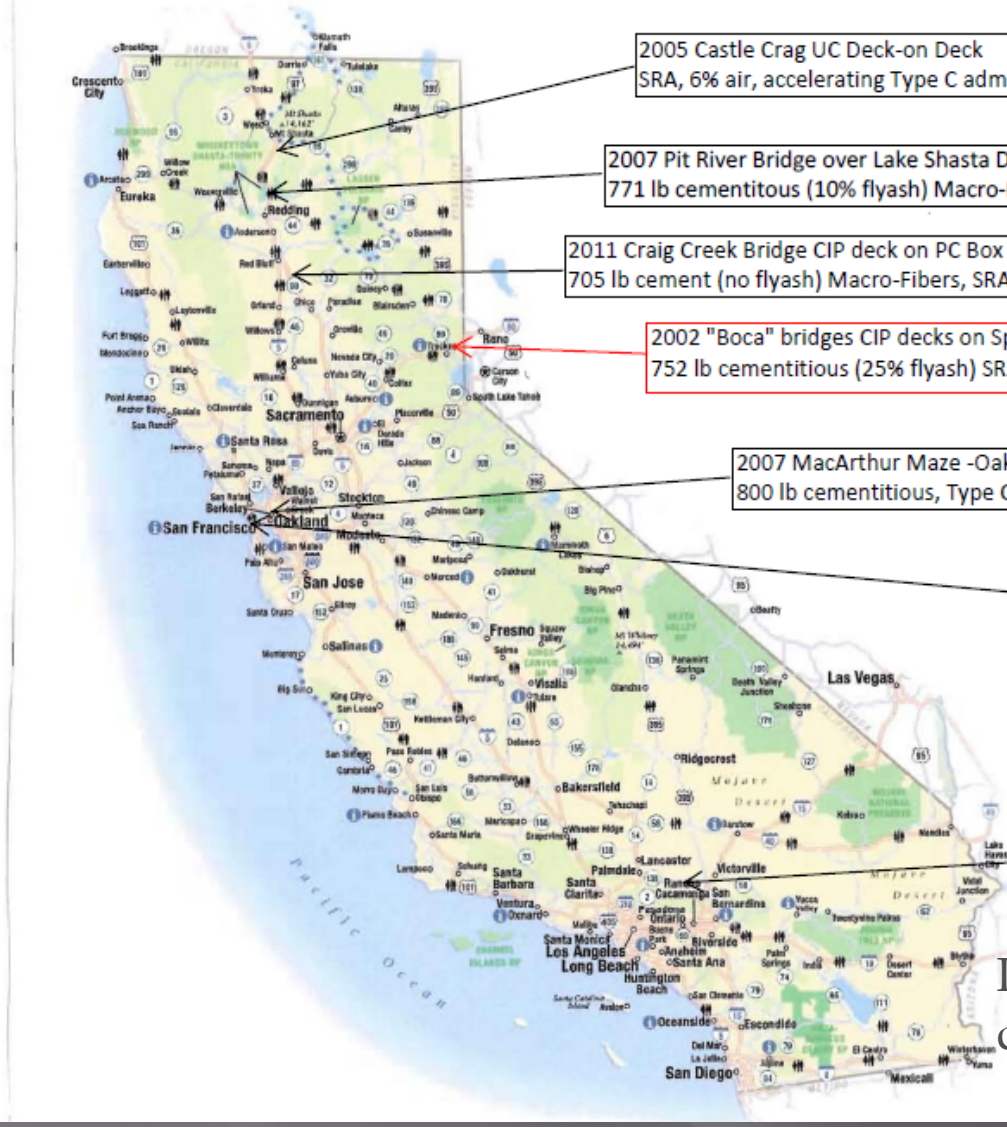
This mix will produce concrete meeting the design criteria when produced, sampled and tested in accordance with ASTM C-94.
Copies of test results shall be provided to Shasta Redi-Mix in accordance with ASTM C-94.4.6.

RESPECTFULLY SUBMITTED
SHASTA REDI MIX

BY Jim McKone
Jim McKone, Manager

After 5 years Polyolefin Fibers hold crack in Core

Successful CRACK-Less Decks



2005 Castle Crag UC Deck-on Deck
SRA, 6% air, accelerating Type C admixture

2007 Pit River Bridge over Lake Shasta Deck-on-Deck
771 lb cementitous (10% flyash) Macro-Fibers, SRA, 6% air, w/c=0.51

2011 Craig Creek Bridge CIP deck on PC Box beams
705 lb cement (no flyash) Macro-Fibers, SRA, 6% air, w/c=0.39, 3 day water cure

2002 "Boca" bridges CIP decks on Spliced PC bulb T girders
752 lb cementitious (25% flyash) SRA, 6% air w/c=0.36

2007 MacArthur Maze -Oakland Tanker Fire reconstruction
800 lb cementitious, Type C admixture, SRA 5 day water cure

2011 Doyle Drive roof/deck/tunnel invert
563 lb cementitious, Macro-Fibers, SRA

2008 Angeles Crest 208' SS Spliced PC bulb T girders
767 lb cementitious, SRA, 6% air

Indicates coverage of climate and diversity of local concrete mixes.

Cost For CRACK-LESS Decks

CONSTRUCTION STATISTICS FROM 2012
130 Bridges at a cost of **$442,969,970**

2,256,721 SF deck area - say 50,000 CY deck concrete

COST ANALYSIS
Shrinkage Reducing Admixture @$25/gal
¾ gal/CY x 50,000CY = $937,500
Fibers @ $30/5 lb bag ($6/lb)
3lbs/CY x 50,000CY = $900,000

For preventive crack control added to 130 bridges, with tax, say **$2,000,000**

The increase cost for CRACK-Less bridge decks last year would have been:

$2,000,000/ $442,969,970 = **0.45%**

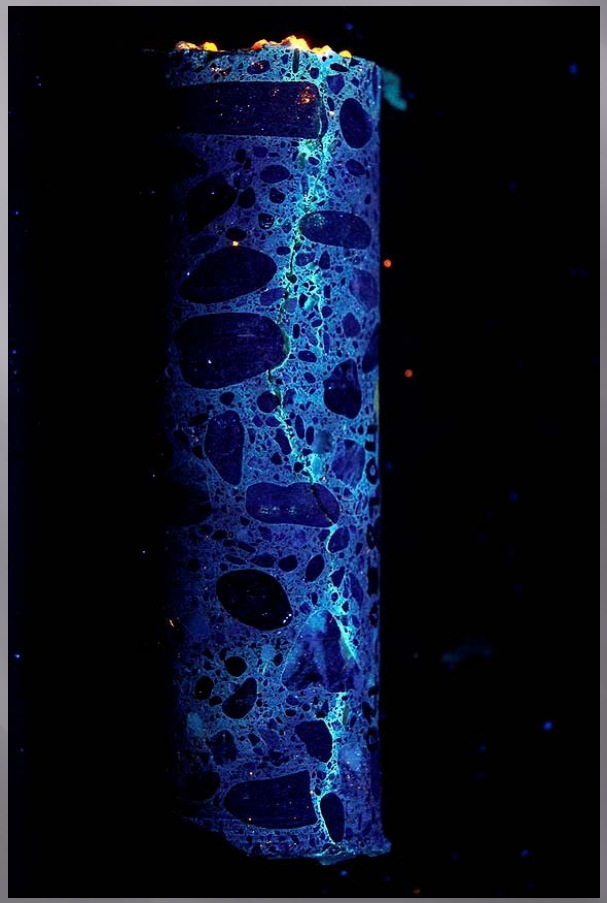
$2,000,000/ 2,256,721 SF = **$0.89/SF**

The Current Cost Of Doing Business v. CRACK-Less Deck

$50 MILLION TO SEAL CRACKS

$2 MILLION FOR CRACK-Less DECKS

Savings Can Be Substantial Over Time. Avoiding Inconvenience To The Public Is PRICE-Less! Perhaps you will be interested?



- CalTrans: $50 Million is spent annually to seal Deck Cracks with Methacrylate; 10 year cost = $500,000,000.

- Using Shrinkage Reducing Admixture and Fibers for *CRACK-Less Decks* would cost <$2 Million/yr; that could result in a 10 year **savings of**

$480,000,000!

Applications in Accelerated Bridge Construction

- High Performance Cure produces high quality early strength CIP deck in 3 days using CRACK-Less Deck formula with P-A-M membrane forming compound and water method
- On third day, curing blankets are removed, water cure is ceased, and additional curing compound is applied at 100 SF/gal
- Cure time is reduced by 57%, saving time, money and cure water; allows traffic to use the bridge sooner

Craig Creek ABC 2011

Craig Creek Mix Design

A&A Concrete Supply, Inc.

8272 Berry Avenue
Sacramento, CA 95828 Phone (916) 383-3756 Fax (916) 383-8427 www.AAReadyMix.com

CONTRACTOR: Blaisdell Construction

PROJECT: Craigs Creek Bridge

MIX USE: 3500 PSI @ 2-Days 3-5" Slump***

PLACEMENT METHOD: Check with your pumping Contractor

BATCH PLANT: **Chico #33**

MIX DESIGN #: **z1755020**
DATE: October 18, 2011
MAX SIZE AGG: 1.0
DESIGN STRENGTH**: 5000 Psi @ 28-Days
PROJECT STRENGTH*: 3500 Psi @ 2-Days***
W/(C+P): 0.39
SLUMP: 3-5" 8" Max.
MATERIAL SOURCES:
CEMENT: ASTM C-150 Type II-V
FLY ASH: ASTM C-618 ~ Class "F"
COARSE AGG: Knife River - Orland
FINE AGGREGATE: Knife River - Orland
ADMIXTURES: Master Builders - BASF Admixtures

CONCRETE MIX DESIGN FOR 1.0 CUBIC YARD (SSD)

AGGREGATE GRADATION *
(%Passing U.S. Standard Sieve)

SIZE:	No.2	No.3	No.4	WCS	COMB.
Agg%	0%	60%	0%	40%	100%
2.0"	100	100	100	100	100
1.5"	98	100	100	100	100
1.0"	22	100	100	100	100
3/4"	8	86	100	100	91
3/8"	2	46	96	100	67
#4		16	14	100	50
#8		1	4	89	36
#16			1	63	25
#30				40	16
#50				18	7
#100				5	2
#200				1.2	0.5
F.M.	7.86	7.23	6.85	2.85	5.44

			SP.GR.	ABS.VOL. CU.FT.	BATCH WT. LBS./CY
Cement:	7.5	Sks. (C+F)	3.15	3.59	**705**
Fly Ash:	0%	% Rep.	2.30	0.00	**0**
1.5" Agg.:	0	% Agg	2.65	0.00	**0**
1.0" Agg.:	60	% Agg	2.65	11.07	**1830**
3/8" Agg.:	0	% Agg	2.65	0.00	**0**
W/C. Sand:	40	% Agg	2.65	7.53	**1246**
Water:	33.0	Gal.	1.00	4.41	**275**
Total Air %	1.5%			0.41	----
			Totals:	27.00	**4056**
ADMIXTURE:					
Polyheed 1025	7	oz / cwt.		oz / cu.yd.	**49.4**

PERTINENT PROPERTIES:
Unit Weight, pcf: (ASTM C-138) **150.2**

Cementitious Factor: (Sacks / Cubic Yard) 7.5

W/(C+P): 0.39 By Wt.

Notes:
* Aggregate gradations provided by aggregate producer
** The compresive strength will meet or exceed the strength listed above if tested in accordance with current ASTM Standards and or water cement ratio is not exceeded.
*** 3-5" max slump to meet the 3500 PSI @ 2-Days.
***** Eclipse 4500 at 0.75 gallons per cubic yard and Strux Fiber 90/40 at 3 lbs per cubic yard to be requested by the Contractor when placing the order.**

PREPARED BY:

Pete Conlin
Technical Service Manager

Concrete Fibers and Shrinkage Reducing Admixtures

Deck Pour Craig Creek

Spray Cure

“High Performance Cure”

3 Day Cure : Water + Curing Compound

Tremper & Spellman reported curing more than 3 days had no additional benefit to reducing drying shrinkage and even after 2 the benefit was slight.

(circa 1963)

3 Day Cure : Water, Burlene + Curing Compound

Second Application of Curing Compound on 3rd Day

Open For Traffic 3rd Day

Diamond Drum Grinding
7 weeks later

No Cracks!

Fibers sticking up from surface

Groove Deck

In 29 days- Old bridge removed and New bridge built; no cracks using SRA, Fibers, and High Performance Cure

Craig Creek Schedule

Craig Creek Accelerated Bridge Construction As-Built Schedule

MAJOR ACTIVITIES TO MAINLINE
24 HOUR FLAGGER CONTROLLED DETOUR

Task	Start date	End date	Duration (days)	
Drive CISS piles & paved over	10/11/2010	10/15/2010	5	(previous season)
Temporary Mabey Bridge Launched	9/25/2011	9/26/2011	2	
TRAFFIC DETOURED OFF BRIDGE ALIGNMENT	9/26/2011	10/24/2011	29	
Bridge Demolition	9/26/2011	9/28/2011	3	
Abutment Excavation	9/29/2011	10/3/2011	3	
Set Abutments	10/4/2011	10/5/2011	2	
CISS/Abutment Closure concrete	10/5/2011	10/5/2011	1	
Abutment Closure pour & cure	10/4/2011	10/7/2011	4	
Set PC Girders	10/8/2011	10/9/2011	2	
Abutment Backfill	10/10/2011	10/18/2011	7	
Deck Rebar	10/14/2011	10/17/2011	2	
20% Transverse Stressing	10/14/2011	10/14/2011	1	
Grout Keyways	10/15/2011	10/15/2011	1	
Complete Transverse Stressing (80%)	10/17/2011	10/17/2011	1	
Edge of Deck Forms	10/18/2011	10/19/2011	2	
Bidwell setup	10/19/2011	10/19/2011	1	
Deck Pour HPC	10/20/2011	10/20/2011	1	
Grout Transverse tendons	10/21/2011	10/21/2011	1	
Water Cure HPC deck / HMA paving	10/21/2011	10/23/2011	3	
Add'l spray curing compound & k-rail	10/24/2011	10/24/2011	1	
TRAFFIC RETURNED TO MAINLINE ALIGNMENT	10/24/2011	10/24/2011	1	
Temporary Mabey Bridge shipped back	10/27/2011	10/27/2011	1	

* Barrier rail installed behind temporary k-rail, one-way flagging used during daytime construction activities

"CRACK-LESS DECK CONCRETE™" specified by CalTrans:
Deck High Performance Concrete 7.5 sks with:
- polyheed 1025 @ 7oz/cwt
- Eclipse 4500 @ 0.75 oz/CY
- Strux 90/40 Fiber @ 3 lbs/CY

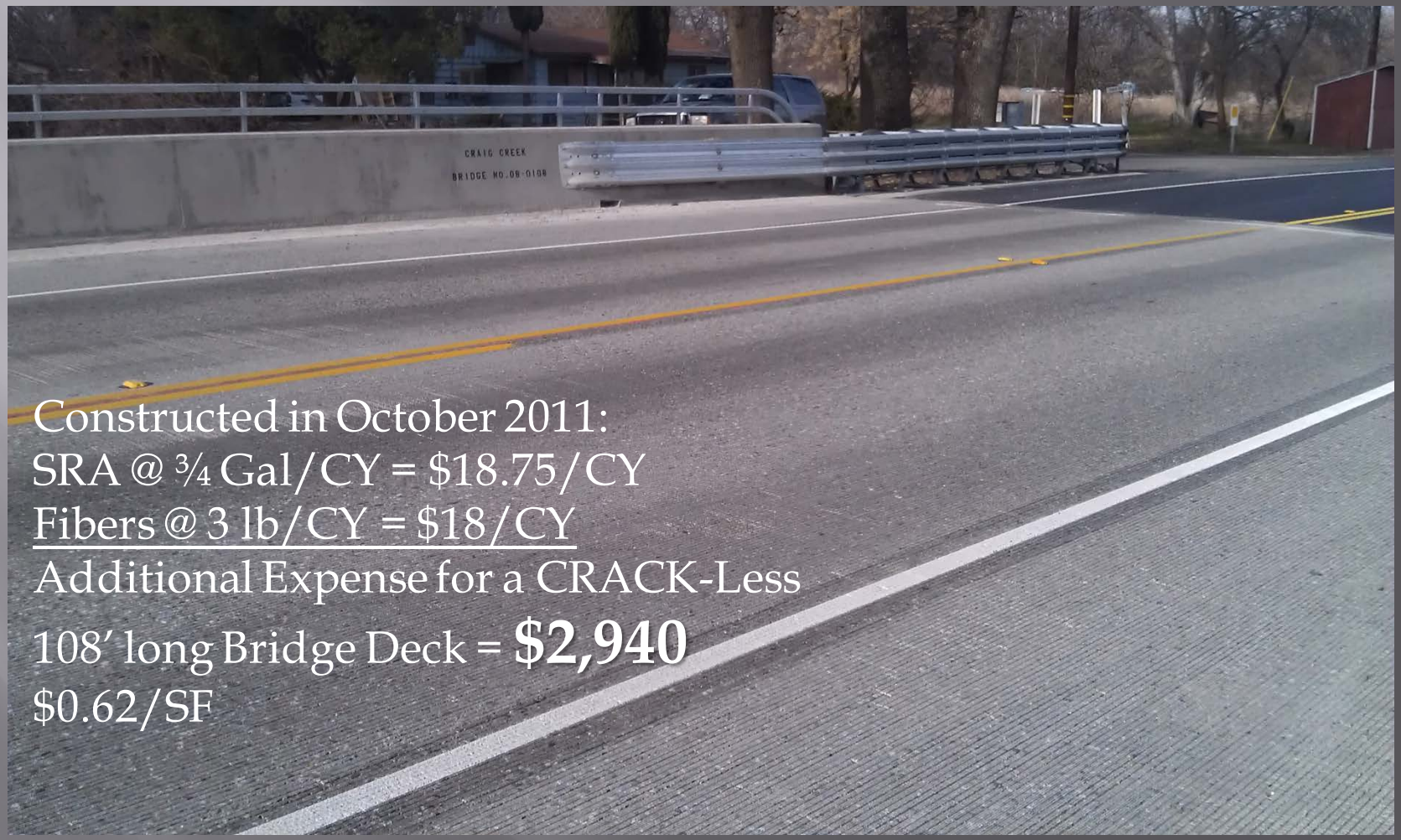
Concrete Strengths:
- 2 day: 3150 psi
- 4 day: 4010 psi
- 7 day : 4540 psi
- 28 day: 5900 psi

High Performance Cure:
- Shrinkage Reducing Admixture, Macro Fibers added to concrete.

"CRACK-Less DECK CONCRETE™" specified for Craig Creek:

- **Deck High Performance Concrete 7.5 sks with:**
- Polyheed 1025 @ 7oz/cwt — Water reducer
- Eclipse 4500 @ ¾ gal/CY — Shrinkage reducer
- Strux 90/40 Fiber @ 3 lbs/CY — Macro Polyolefin Fibers
- Concrete Strengths:
- 2 day: 3150 psi
- 4 day: 4010 psi
- 7 day : 4540 psi
- 28 day: 5900 psi
- **High Performance Cure:**
- Shrinkage Reducing Admixture, Macro Fibers added to concrete.
- Curing compound and Water Cure 3 days followed by heavy application of curing compound after water cure prior to traffic

Craig Creek 2 years later, still no cracks!



Constructed in October 2011:
SRA @ ¾ Gal/CY = $18.75/CY
Fibers @ 3 lb/CY = $18/CY
Additional Expense for a CRACK-Less
108' long Bridge Deck = **$2,940**
$0.62/SF

ABC's of CRACK-Less Bridge Decks

THANKS!

What will be the next breakthrough, what's cost effective for the best Return on Investment?

- Internal Cure
- Self-Healing Concrete
- Hydrophobic Concrete
- Evaporation Control
- ?

For additional information, see our article in ACI's publication *Concrete International,* July 2013, *pp. 36-41* "Controlling Shrinkage Cracking - Available technologies can provide nearly crack-free concrete bridge decks" *by Ric Maggenti, Craig Knapp, and Sonny Fereira*

An ounce of Prevention is worth a pound of Cure! - BF
Build it SAFE, RIGHT, and FAST; and in that order – SF