## Bio – Kevin J. Folliard, Ph.D.

Dr. Kevin J. Folliard is the Warren S. Bellows Centennial Professor of Civil Engineering in the Department of Civil, Archictectural, and Environmental Engineer at the University of Texas at Austin, where he has been on the faculty since 1999. Prior to this, Dr. Folliard was an Assistant Professor at the University of Delaware from 1997-1999 and a Senior Research Engineer at W.R. Grace & Co. from 1995-1997. Dr. Folliard received his Ph.D. in Civil Engineering from the University of California at Berkeley in 1995. His main research interest is in the area of the durability of portland cement concrete and he teaches course related to civil engineering materials, concrete technology, and concrete durability.

Dr. Folliard is a Fellow of the American Concrete Institute (ACI), and he received the ACI Young Member Award for Professional Achievement in 2003 and the ACI Wason Medal for Materials Research in 2010 and 2015. In 2013, Dr. Folliard was honored with the highest teaching award given by the University of Texas System, the Regents' Outstanding Teaching Award. Dr. Folliard has been the Principal Investigator on over $20 million in research projects while on the faculty at the University of Texas at Austin, primarily in the area of concrete durability (especially alkali-silica reaction). Dr. Folliard has authored or co-authored over 150 technical publications in his career, including more than 80 refereed journal papers.

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## MANAGEMENT AND TREATMENT OF FIELD STRUCTURES AFFECTED BY ASR

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## Outline of Presentation

- Treatment Options for ASR-Affected Structures
- FHWA Field Trials
- Lessons Learned…

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## What is Alkali-Silica Reaction, ASR?

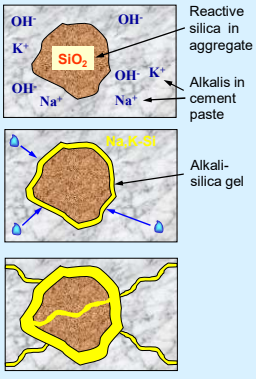
Reaction between the alkalis (Na, K & OH) from the cement react and unstable silica, $SiO_2$, in some types of aggregate

The reaction produces an alkali-silica gel

The gel absorbs water from the surrounding paste …

… and expands.

The internal expansion eventually leads to cracking of the surrounding concrete.




4

## Requirements for ASR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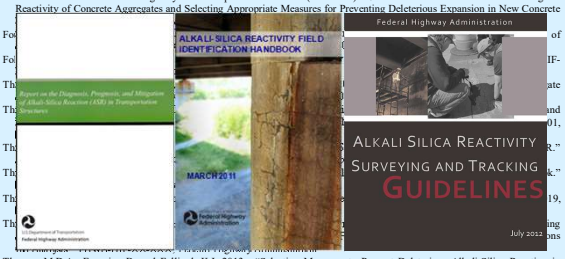
## FHWA ASR Development and Deployment Program (2008 – 2013)

American Association of State Highway and Transportation Officials (AASHTO). 2012. "Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete




Thomas, M.D.A., Fournier, B. and Folliard, K.J. 2013c. "Selecting Measures to Prevent Deleterious Alkali-Silica Reaction in Concrete: Rationale for the AASHTO PP65 Prescriptive Approach." FHWA-HIF-13-002, Federal Highway Administration.

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## Potential options for mitigating AAR – treating the cause vs. treating the symptom

| TREAT THE CAUSE | TREAT THE SYMPTOM |
|---|---|
| ***Chemical Treatment*** | ***Crack Filling*** |
| • $CO_2$ | • Aesthetics |
| • Lithium compounds | • Protection (e.g. from $Cl^-$ ingress) |
| ***Drying*** | ***Restraint*** |
| • Sealants | • Prevent Expansion |
| • Cladding | • Strengthen/Stabilize |
| • Improved drainage | ***Relieve Stress*** |
| | • Saw Cutting/Slot Cutting (accommodate movement) |

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## Mitigation Measures

- Improved drainage
- Application of coatings/sealers
- Application of cladding
- Crack filling

Aimed at lowering RH

- Application of lithium compounds
- Application of restraint (FRP, etc.)
- Saw cutting/slot cutting

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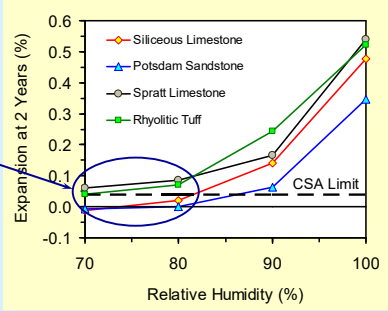
## Effect of Relative Humidity

Little significant expansion if the relative humidity is maintained below about 80%




*Pedneault, 1996*

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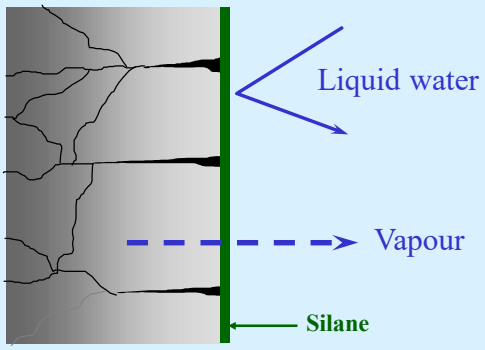
## Reducing R.H.

AAR "ceases" at RH < 80 to 85%

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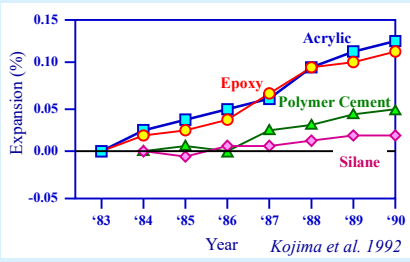
## Reducing R.H.




*Kojima et al. 1992*

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## Summary of laboratory tests – post-treatment with lithium compounds

- **Lithium compounds can reduce expansion of ASR-affected mortar/concrete in the lab (SHRP, Stokes et al (2000), Barborak et al (2004).**
- **Response appears to be aggregate-specific (similar to when used as admixture)**
- **BUT….**
  - **Data based on small specimens completely immersed in lithium**
  - **Accelerated tests not related to real-world lithium applications…**

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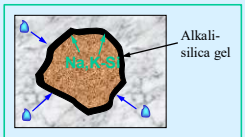
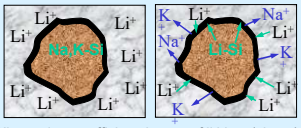
## Using Lithium Compounds to Control ASR

Without lithium




Without lithium present, a highly-reactive aggregate is attacked by the high pH solution, forming an ASR gel that absorbs water and causes the concrete to expand and crack.

With lithium




When using a sufficient dosage of lithium (nitrate) to control expansion, a highly-reactive aggregate is initially attacked by the high pH solution, forming an alkali silica gel. Lithium present in the pore solution then cation exchanges for the sodium and potassium in the gel, creating a non-expansive lithium-silica gel.

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## Topical application of lithium nitrate – most common application method in the field…

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## Topical Application

Examples of topical treatments of pavements since 1995:

- South Dakota - U.S. 14 (near Wolsey)
- Maryland - Bridge on I68 (near LaVale)
- Minnesota – New Ulm
- North Carolina – various
- New Mexico – Albuquerque
- Wyoming - Cheyenne
- Delaware – Dover
- Many others

- Very little monitoring
- Little, if any, data showing whether lithium helped…

**FHWA Field Trials**

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## FHWA Field Trials

| State | Structure | Mitigation/Prevention Technique |
|---|---|---|
| Alabama | Historic bridge arch | Silane sealer |
| Arkansas | Pavement | Silane sealer |
| Delaware | Pavement | Topical application of lithium nitrate |
| Delaware | Pavement | Monitoring an asphalt overlay of pavement with lithium nitrate |
| Hawaii | Aggregates | Testing aggregates and development of field exposure site |
| Massachusetts | Median barrier | Silane sealers; topical application of lithium nitrate |
| Massachusetts | Aggregates | Testing aggregates and development of field exposure site |
| Maine | Bridge abutments and piers | FRP wrap; silane sealer; electrochemical application of lithium nitrate |
| Texas | Bridge Columns | Electrochemical application of lithium nitrate; vacuum impregnation of lithium; silane sealers |
| Texas | Precast Bridge Girders | Aggregate testing and investigation of specific mixture designs |
| Vermont | Bridge barrier walls | Silane sealers |

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## The ASR Avengers

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## FHWA Field Trials

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## Effects of silanes


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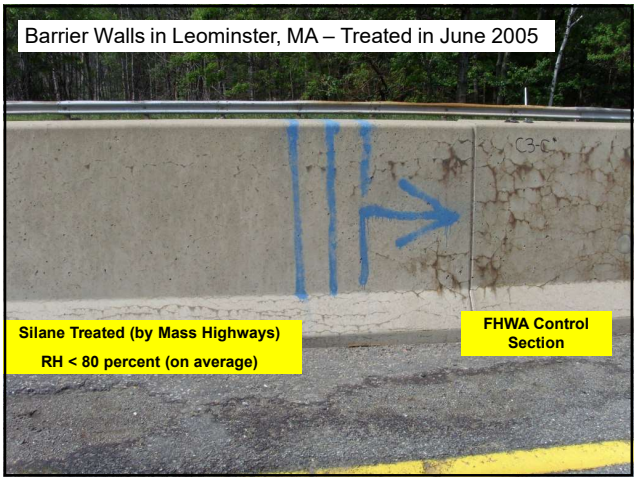


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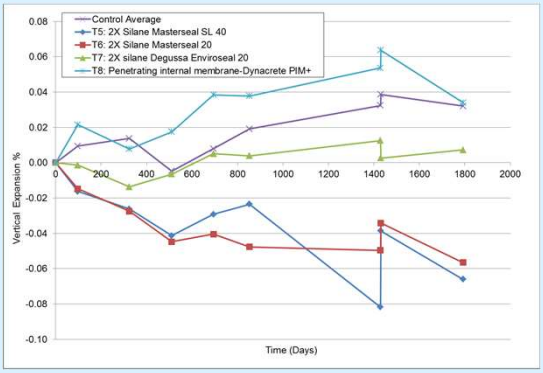
## Effects of silanes on expansion

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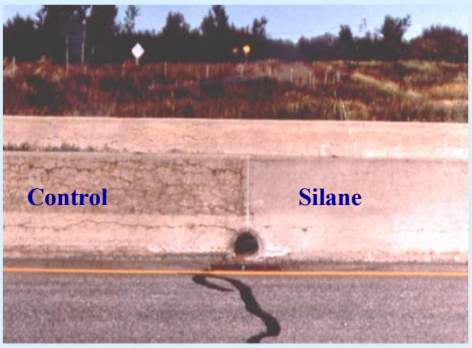
## Canadian experience…

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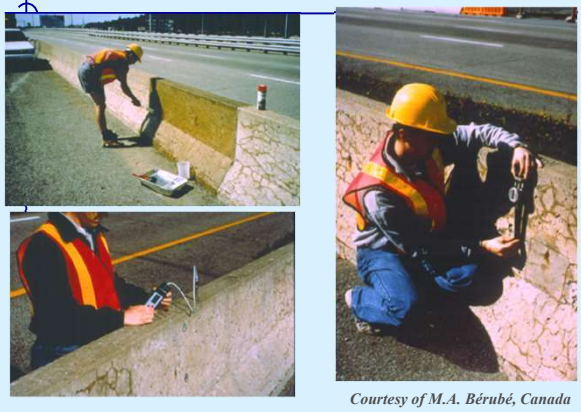
## *Use of Sealers (Quebec City)*



*Courtesy of M.A. Bérubé, Canada*

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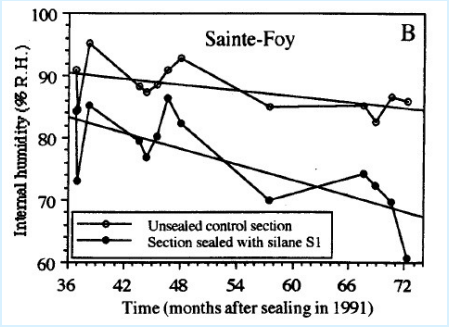
## *Use of Sealers (Quebec City)*




*Bérubé et al. (1998)*

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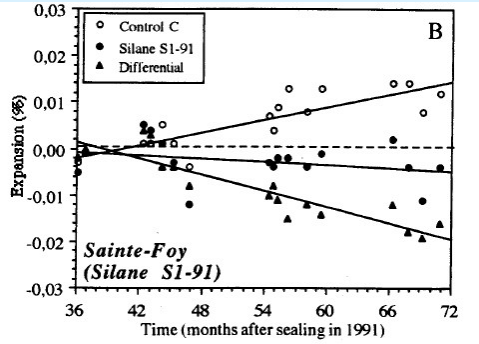
## Use of Sealers (Quebec City)




*Bérubé et al. (1998)*

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| Vermont | Bridge barrier walls | Silane sealers |

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## Pavement in Idaho


- 5-km section of I94 treated in Sept 2004 – 0.24 L/m$^2$ (6 gal/1000 ft$^2$)
- Approx. 2/3 pavement area treated a second time in May 2005
- Approx. 1/3 pavement area treated a third time in Oct 2005
- Low, moderate & high severity of ASR

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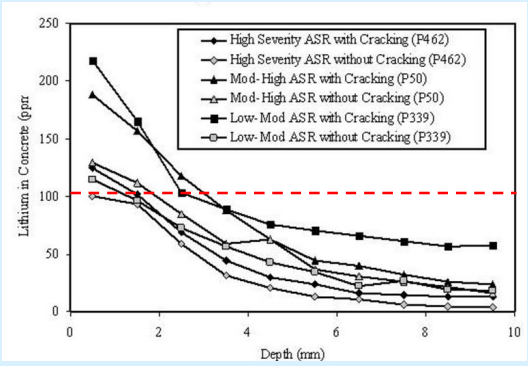
## Field Studies – I94, Idaho

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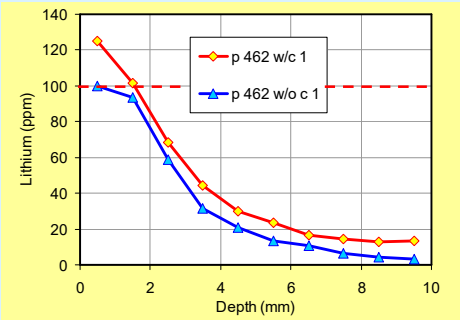
## Field Studies – I94, Idaho

Lithium profiles in panel 462 after 3 treatments

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## Field Studies – Barrier Wall, Leominster, MA

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## Field Studies – Barrier Wall, Leominster, MA

- Controls – 3 sets of 3 wall sections
- Vacuum treatment – 4 sets of 2 wall sections
- Topical treatment – 8 sets of 3 wall sections

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## Field Studies – Barrier Wall, Leominster, MA

**Vacuum Treatment**

- 8 sections treated
- Short Term: 0.25 hours*
- Long Term: 7.25 hours*
- 4 different types of treatments were applied:
  - VA-1 and VA-2: Long term vacuum treatment using lithium on one side and short term vacuum treatment using lithium on opposite side
  - VB-1 and VB-2: Short term vacuum treatment to both sides using lithium nitrate followed by a topical application of silane
  - VC-1 and VC-2: Short term vacuum treatment to both sides using lithium nitrate
  - VD-1 and VD-2: Short term treatment using lithium to both sides applied twice throughout the field application

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## Field Studies – Barrier Wall, Leominster, MA

**Vacuum Treatment**

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## Field Studies – Barrier Wall, Leominster, MA

**Vacuum Treatment**

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## Field Studies – Barrier Wall, Leominster, MA

- T1-A, B and C: Single Application Lithium
- T2-A, B and C: Double Application Lithium
- T3-A, B and C: Quadruple Application Lithium
- T4-A, B and C: Double Application Lithium followed by 40% Silane Sealer (isopropyalcohol based)
- T5-A, B and C: Masterseal 40 Silane sealer (isopropyalcohol based)
- T6-A, B and C: Masterseal 20 Silane sealer (isopropyalcohol based)
- T7-A, B and C: Enviroseal Silane sealer (water based)
- T8-A, B and C: Dynacrete PIM+ (lithium silicate based)

**Application rate information in report*

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## Field Studies – Barrier Wall, Leominster, MA

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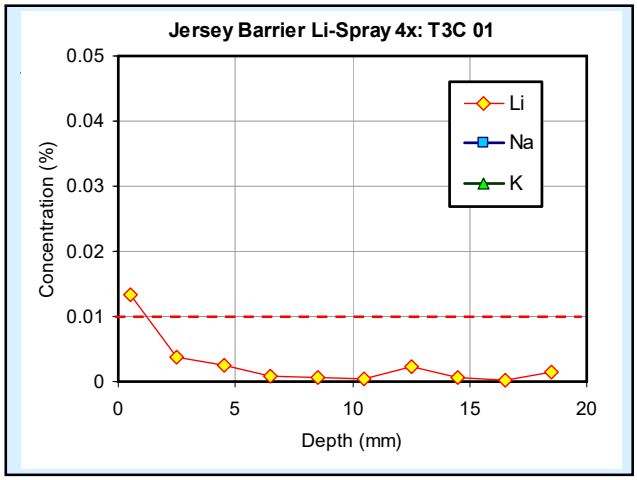
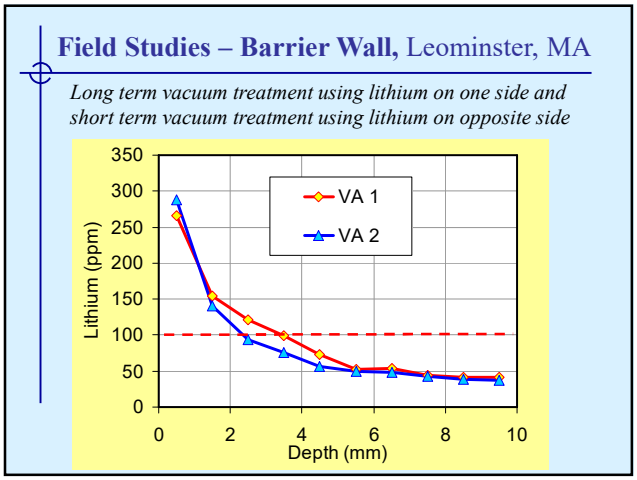

Jersey Barrier Li-Spray 4x: T3C 01
Concentration (%)
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
20
Depth (mm)
Li
Na
K

37


Field Studies – Barrier Wall, Leominster, MA
Long term vacuum treatment using lithium on one side and short term vacuum treatment using lithium on opposite side
Lithium (ppm)
350
300
250
200
150
100
50
0
0
2
4
6
8
10
Depth (mm)
VA 1
VA 2

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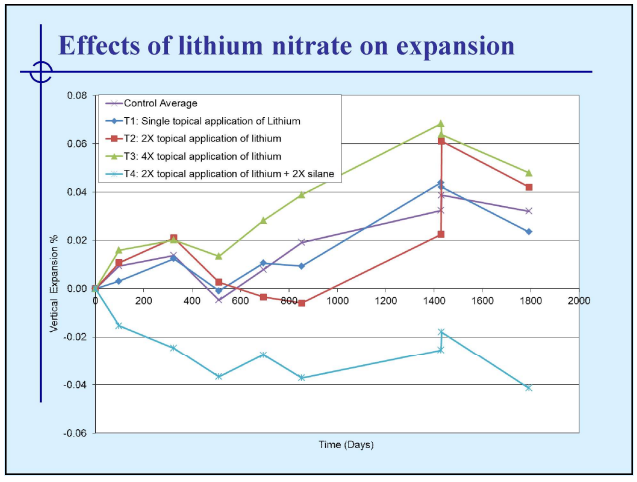
Effects of lithium nitrate on expansion
Vertical Expansion %
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (Days)
Control Average
T1: Single topical application of Lithium
T2: 2X topical application of lithium
T3: 4X topical application of lithium
T4: 2X topical application of lithium + 2X silane

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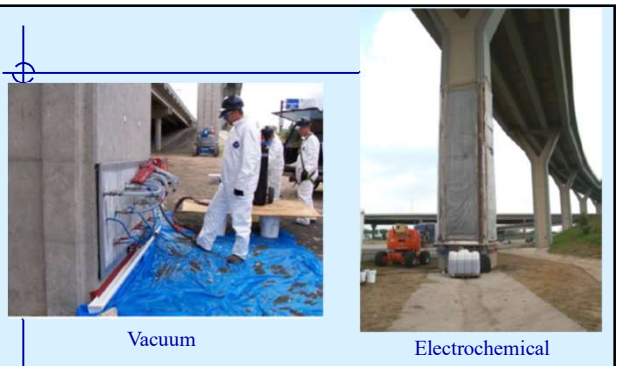
Houston columns – field trial
Column 46 – Electrochemical Treatment
Column 45 – Vacuum Treatment
Column 44 – Topical Silane on Blasted Surface
Column 43 – Control
Column 42 – Topical Silane on Painted Surface

40



Vacuum

Electrochemical

*No topical applications of lithium were performed for this field trial (based on minimal depths of penetration in ID, MA, and lab)*

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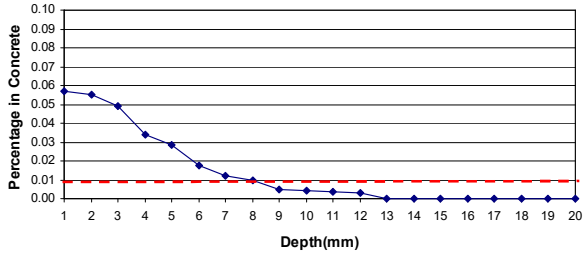
## Houston column (#45) – Depth of lithium penetration for vacuum treatment

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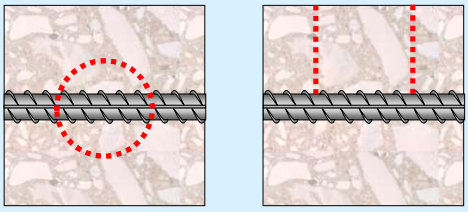
## Houston Columns: Core 46-1 @ Rebar

Column was treated electrochemically with lithium for 8 weeks prior to extraction of core located over rebar



Plan

Side View

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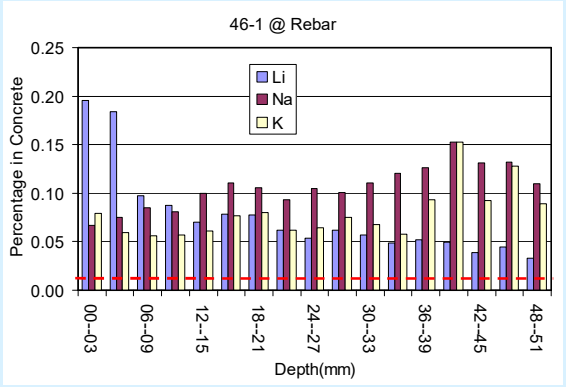
## Profile of Alkali Ions (Li, Na & K) in Columns Subjected to Electrochemical Treatment

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## Houston columns

Cracking of Column 35 – after electrochemical lithium treatment

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## Summary of lithium penetration data*…

| State | Element | Treatment method | Depth to which "threshold" level of lithium was measured (mm) |
|---|---|---|---|
| ID (field-treated) | Pavement | Topical (3x) | 1 – 4 |
| ID (lab-treated) | Pavement | Topical (3x) | 1 – 5 |
| MA | Barrier wall | Topical (4x) | 0.5 – 1.5 |
| MA | Barrier wall | Vacuum ("long-term") | 2.5 – 3.5 |
| TX | Column | Vacuum | 8 |
| TX | Column | Electrochemical | 50 (to depth of rebar) |

*Similar experience with topical applications in lab….

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Jobe control

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Jobe (ponded with lithium for 8 months)

48

**Jobe (sprayed every week for 32 weeks – 4 gallons per 1000 sq. ft each treatment)**

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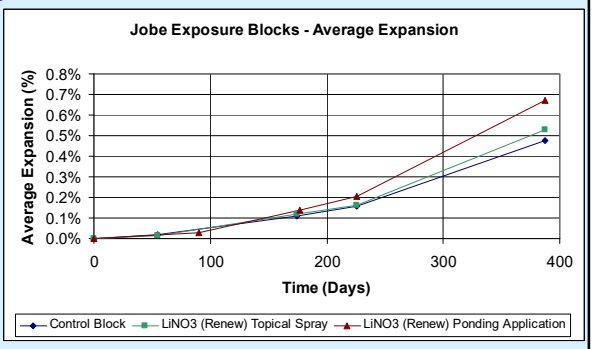
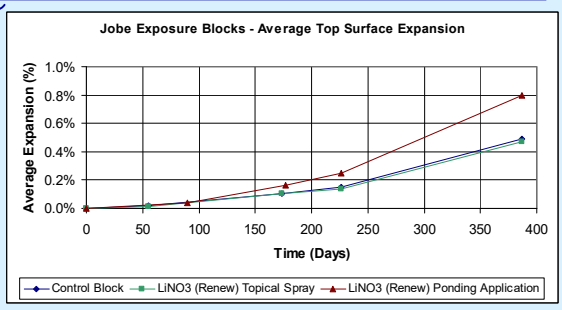
## Effects of lithium spraying or ponding on expansion of ASR exposure blocks




50

## Effects of lithium spraying or ponding on expansion of ASR exposure blocks

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## Conclusions

- Silanes were found to be highly effective when applied to highway barriers – jury is still out on effects on large columns
- Topical treatment of lithium nitrate does not appear to be effective due to lack of penetration
- Vacuum impregnation has also yielded minimal penetration of lithium nitrate.
- Driving lithium nitrate into reinforced columns was effective using electrochemical method, but will increased $OH^-$, $Na^+$, and $K^+$ exacerbate ASR at rebar surface?
- Long-term ponding and multiple topical applications of lithium in exposure blocks has been ineffective in reducing expansion/cracking
- It is always best to prevent ASR in the first place!!!

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