STUDY OF THE EFFECTIVENESS OF LITHIUM AND SILANE TREATMENTS ON FIELD STRUCTURES AFFECTED BY ASR

Thano Drimalas[1], Kevin J. Folliard[1], Michael D.A. Thomas[2], Benoit Fournier[3], and Anthony Bentivegna[1]

[1]The University of Texas at Austin, Austin, TX, USA
[2]University of New Brunswick, Canada
[3]Laval University, Quebec City, Quebec, Canada

ABSTRACT
This paper presents information two of the different demonstration projects undertaken under FHWA's *Alkali-Silica Reactivity (ASR) Development and Deployment Program*, with an aim at implementing in the field a number of techniques for mitigating the deleterious effects of ASR in highway structures. This paper presents data of highway bridge columns in Houston, TX and jersey barriers in Leominster, MA that were treated different types of products in order to minimize expansion. Novel techniques including electrochemical lithium impregnation and other forms of applications are presented herein. These long-term demonstration projects provide accurate field evaluations of concrete deteriorating from ASR. A number of techniques are used to monitor these sites with the results to date are shown in this paper.

Keywords: Alkali-silica reaction, silane, mitigation and repair, sealant material, electrochemical treatments.

1. INTRODUCTION

Numerous concrete structures throughout the world are exhibiting deleterious damage occurring from alkali-silica reaction (ASR). The mitigation of these structures from an engineer's perspective is still unclear. Many techniques are used today without the proper knowledge of how these treatments will mitigate the reaction. A number of different techniques, such as the application of impermeable membranes or metallic cladding, topical applications of breathable sealing materials/products, electrochemical/pressure impregnation of ASR-affected elements (CO_2, lithium-based admixtures, etc.), strengthening/encapsulation of the affected element with steel, reinforced concrete or composite materials, slot-cutting, etc., have been implemented over the years [1,2]. However, the efficacy of such technologies in successfully mitigating/eliminating the problem often remains uncertain as in-situ monitoring and "post-mortem" reports on the above treatments are not commonly available.

Under FHWA's *Alkali-Silica Reactivity (ASR) Development and Deployment Program*, an opportunity was given to gather some of the above technologies and put them into practice through field applications and demonstration projects, the objective being to ultimately gain valuable knowledge about their long-term efficacy and practicality [3].

This paper provides data from two of the field implementation locations. Findings from bridge columns in Houston, Texas and median jersey barriers in Leominster, Massacchusetts are provided in this paper. Despite the fact that it is too early to conclude on the efficacy of the different technologies/treatments implemented on ASR-affected structures in this studies, this paper will serve as a reference/basis for further technical papers that will, in time, report on their efficacy.

2. Demonstration Projects

This paper provides information on two implementation projects conducted under the FHWA's *ASR Development and Deployment Program*. These sites were located and provided by state departments of transportations. Prior to any treatments occurring at these sites, a site visit which included the removal of cores occurred to properly assess the locations to verify ASR was the culprit to the damage. A process for the selection, implementation and monitoring of field demonstration projects related to mitigating the deleterious effects of ASR in concrete structures, was developed based on the protocol for selecting ASR-affected structures for lithium treatment [4] and the report on the diagnosis, prognosis and mitigation of ASR in transportation structures [2], both developed by the team. An earlier paper provides a background on these sites, with more of the most recent data presented in this paper [5].

2.1 Highway bridge columns in Houston, TX

A stretch of columns in Houston, TX which were constructed in the late 1990's and is used to carry a high occupancy vehicle lane into downtown Houston, began showing signs of distress within a few years of service. An initial site visit was conducted in 2005, to evaluate the distress mechanism. Under the ASR deployment project, it was determined that ASR was occurring in the columns which led to the selection of 10 columns to determine the efficacy of various post treatments to slowdown or mitigate the ASR expansion. The ten columns were divided into groups with moderate to severe damage and low to moderate damage. Columns 31-36 are considered to be moderately to severely damaged, while columns 41-46 are considered to be slightly to moderately damaged. The treatments selected for each of the above columns are listed below:

- Column 31 – Sodium silicate over blasted surface
- Column 32 – Topical silane over original painted surface
- Column 33 – Lithium vacuum impregnation
- Column 34 – Topical silane over blasted surface
- Column 35 – Electrochemical lithium impregnation
- Column 36 – Control
- Column 41 – Sodium silicate over blasted surface
- Column 42 – Topical silane over original painted surface
- Column 43 – Control
- Column 44 – Topical silane over blasted surface
- Column 45 – Lithium vacuum impregnation
- Column 46 – Electrochemical lithium impregnation

2.1.1 Treatments

For each group of deteriorated column sets, the same treatments were repeated for both. A column within each set was not treated and was used as a control.

- Silane over original painted surface: Topical silane application was applied to columns 32 and 42. Degussa hydrozo Silane 40 VOC was used for the treatment. The treatment was applied over the paint to help determine if this would benefit the owner by not having to remove paint. The removal of paint from a structure in some states is considered to be hazardous and increases significantly the treatment costs.
- Silane over blasted surface: The surface of columns 34 and 44 were blasted prior to silane application. The silane was applied topically similar to columns 32 and 42. Degussa Hydrozo Silane 40 VOC was chosen for this treatment. .

- Vacuum Impregnation: Lithium vacuum impregnation was applied to columns 33 and 45. The surface was first blasted to remove any paint from the surface of the column. Lithium nitrate (Euro Arc Treatment) was then applied at a rate of 1.63 L/m^2 on each face of the column to a height of 7.5 m (25 ft).
- Lithium Electrochemical Migration: Lithium impregnation by electrochemical migration occurred on columns 35 and 46. The electrochemical technique took 8 weeks perform.

2.1.2 Instrumentation and monitoring

Instrumentation and monitoring began in 2006. Instrumentation included expansion measurements, relative humidity monitoring, and crack mapping. These measurements have continued since 2006 with measurements occurring once or twice a year. The majority of the columns have horizontal and vertical expansions measurements on two faces, and three humidity locations at different depths (25 mm (1 inch), 50 mm (2 inch), and 75 mm (3 inch)) on most of the columns. In addition, crack indices are recorded from each of the expansion measurement locations [6].

2.2 Median Jersey Barriers in Leominster, Massachusetts

The Leominster field site is located on Route 2 west of Boston, Massachusetts. Jersey Barriers dividing the west and eastbound lanes began showing signs of distress soon after placement, and in 2004 an initial site visit occurred to determine the cause of the cracking. Petrography from cores taken from the barriers and from the visual inspection showed that ASR was the cause of damage in the structure. Multiple test sections were evaluated for various treatments that are listed below.

- C1 – Control section 1
- C2 – Control section 2
- C3 – Control section 3
- T1 – Single topical application of lithium
- T2 – Double topical application of lithium
- T3 – Four topical applications of lithium
- T4 – Double topical application of lithium and double topical application of silane
- T5 – Topical silane application
- T6 – Topical silane application
- T7 – Topical silane application
- T8 –Lithium silicate sealer
- VA - A –Long-tern vacuum impregnation of lithium on one side and short term on the other side
- VA – B –Short-term vacuum impregnation of lithium on both sides + topical silane application
- VA - C – Short-term vacuum impregnation of lithium on both sides
- VA – D - 2 short-term vacuum impregnations on both sides of the barrier

2.2.1 Treatments

For each treatment, the north and south faces of the jersey barriers were treated. The following provides more information on the treatments used on the barriers:

- Topical lithium: Lithium nitrate (Euro Arc Treatment) was applied topically with a hand held pump sprayer at a rate of 0.10 L/m^2 (2.5 gal/1000 ft^2) to 3 test sections (T1, T2, and T3). Test section T1 received a single topical application of lithium, test section T2 received two applications of lithium nitrate, and test section T3 received four applications of lithium nitrate applied topically. The application was applied onto the existing concrete.

- Topical Lithium plus topical silane: Test section T4 had two applications of lithium nitrate with each application at a rate of 0.10 L/m^2 (2.5 gal/1000 ft^2) plus two applications of Masterseal SL 40 silane with each application at 0.04 L/m^2 (1 gal/125 ft^2).
- Topical silane: Three different products of silane were chosen for topical application. Test section T5 received two topical applications of Masterseal SL 40 (rate of 0.10 L/m^2 (2.5 gal/1000 ft^2) per application). Test section T6 received two topical applications of Masterseal 20 (rate of 0.10 L/m^2 (2.5 gal/1000 ft^2) per application). Test section T7 received two topical applications of Degussa Enviroseal 20 (rate of 0.10 L/m^2 (2.5 gal/1000 ft^2) per application).
- Penetrating internal Membrane: Test section T8 had two lithium silicate based sealer applications (Dynacrete PIM+) at a rate of 0.10 L/m^2 (2.5 gal/1000 ft^2) per application.
- Lithium vacuum impregnation: VA-A had 2 long-term (i.e about 7.25 hours) vacuum treatments on one side and 1 short term (about 15 minutes) on the other side. VA-B had two short-term vacuums on both sides followed by a double application of silane (Enviroseal 20) (rate of 0.10 L/m^2 (2.5 gal/1000 ft^2) per application). VA-C had two short-term vacuums. VA-D had short term vacuums repeated twice on each side of the barrier.

2.2.3 Instrumentation and monitoring

Instrumentation and monitoring began in 2006 for these jersey barriers which included expansion measurements, relative humidity monitoring, and crack mapping. These measurements have continued since 2006 with measurements occurring once or twice a year. The majority of the testing segments have 2 monitoring sites per side. In addition, crack indices are recorded from each of the expansion measurement locations [6] (Figure 2).

3 RESULTS AND DISCUSSION

A drawback of field instrumentation and monitoring of structures is that it may take many years to determine the efficacy of a treatment on a structure. With over 5 years of monitoring of these two site projects, conclusive evidence is becoming apparent.

3.1 Houston Bridge Column Results

Expansion and relative humidity (RH) data is presented for the Houston bridge columns. Figure 3 and 4 provide the average horizontal expansions for columns 31-36 and 41-46, respectively. The vertical expansions are not provided since the measurement is taken parallel to the predominant direction of reinforcement. The horizontal expansions are averaged from the southeast and southwest faces of each column.

Columns 31-36 show an increase in expansion for every column. However, a few columns do provide higher expansions. Column 35 (Electrochemical lithium impregnation) has shown the highest level of expansion to date. This column has suffered severe etching to the surface from acid attack caused from the electrochemical process. Figure 5 provides an image of the etched surface. In addition, column 34 (topical silane over blasted surface) and column 36 (control), show the next highest levels of expansion. Columns 31, 32, and 33 are expanding at a lower rate.

Prior to treatment, columns 41-46 were visually rated to have less cracking than columns 31-36. Columns 44, 45, and 46 show the highest level of expansion. These are the only columns from this set that are expanding. The control column 43 is not showing any signs of expansion which makes things a little difficult to compare treatments. The columns that are expanding include blasted surface treated with silane, electrochemical impregnation of lithium, and lithium impregnation by vacuum. The electrochemical treated column shows similar etching to the surface of that found on column 35. The electrochemical treated column by lithium provided the least prevention from both sets of columns. The blasted surface with topical lithium also expanded in both sets; however, the application of this silane over paint has provided successful results.

Table 1 provides relative humidity data for both sets of columns. In all cases, the columns that contained silane had the lowest relative humidity.

3.2 Boston Jersey Barrier Results

Expansion and humidity data are presented below for Leominster, MA jersey barriers. This test section covers 180 linear meters (600 linear feet) of barrier wall with both sides being instrumented. The expansion values presented are averaged for measurements taken on both sides of the barrier; one should look at overall trends as expansion values given in those figures have not been corrected for differences in ambient temperature at the time of measurements. Three separate areas along the treatment section were used as control sections. The control sections have averaged 0.04% expansion over the 1800 days of monitoring. Figure 6 provides the expansions of the vacuum treated sections. VA-B provides the lowest amount of expansion. VA-B is similar to VA-C, however it has a double coat of silane applied after the lithium vacuum impregnation. There are not considerable differences between short (VA-C) or long-term durations (VA-A) of vacuum impregnation of lithium into the concrete. VA-D does show a dramatic decrease of expansion at the last measurement, but the trend prior to this measurement was similar with the other expanding test sections. VA-B with the silane application after treatment provided the overall best lithium vacuum impregnation section.

Figures 7 and 8 provide expansion information for treatments T1-T4 and T5-T8, respectively. T1-T3 are lithium topical applications with different amounts of times of applications. T4 is similar to T2 but has a silane applied topically after the lithium application. Expansions from treated sections 1-3 are similar to the control with the double and 4X lithium sections having slightly higher expansions. T4 has the lowest expansion of these 4 test sections. This section is similar to T2 (double lithium application) but has the silane application. T4 with silane has expanded 0.08% less than the same section without silane.

In Figure 8, all of the silane sections are providing expansions less than the control. T5 and T6 products provide the best results followed by T6. Treatment T8 (lithium silicate sealer) did not work to provide a decrease in expansion. A dramatic aesthetic difference occurs with the use of silane. Staining is not noticeable on the silane sections whereas the control and other non-silane treated treatments show staining and cracks more noticeably.

4 CONCLUSIONS

Overall from both test locations, it has shown that it takes many years to provide a definite answer on how a treatment will mitigate a structure deteriorating from ASR. The use of lithium as a post-treatment for ASR has often shown limited efficiency at limiting the progress of expansion in ASR-affected elements treated. The Houston bridge columns see the highest levels of expansion with columns treated by electrochemical impregnation of lithium. Similar results show that vacuum impregnated columns of lithium are not beneficial as well. Similar results in Leominster site, MA showed any use of lithium compounds applied by vacuum or topically do not contribute at slowing down the expansion of the ASR-affected concrete. On the other hand, silane applications were generally shown to be beneficial in reducing expansion rates (compared to control sections) at both test locations except for cases that had the surface blasted prior to silane application. Houston columns and Leominster barriers with the silane applied topically have shown to be the best, amongst the products/treatements used in this study, at slowing down and, in some cases, controlling the expansion; however, it is noted that blasting the surface to remove any paint prior to silane application may not be as beneficial as applying directly on the surface.

5 ACKNOWLEDGEMENTS

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6. REFERENCES

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TABLE 1: Relative Humidity taken during the most recent monitoring in Houston, TX. The columns that were silane treated are highlighted.

Column	RH	Column	RH
31	88.7%	41	77.7%
32	81.6%	42	70.4%
33	93.8%	43	84.4%
34	81.5%	44	72.2%
35	85.0%	45	84.7%
36	91.0%	46	88.8%

FIGURE 1: Photo of a typical bridge column treated in Houston, Texas

FIGURE 2: Photo of a typical Jersey barrier treated in Leominster, Massachusetts. A grid is being drawn on the surface of the barrier for the determination of the Crack Index [6].

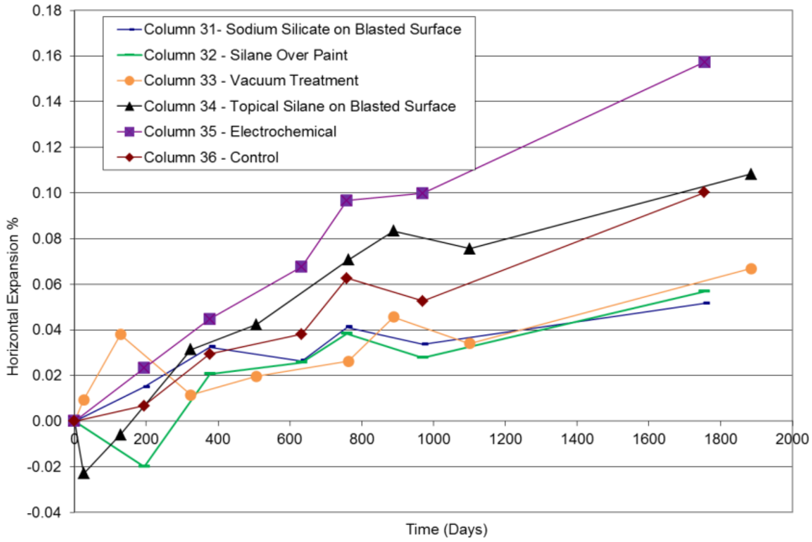

FIGURE 3: Expansion of moderately to severely damaged bridge columns after treatments

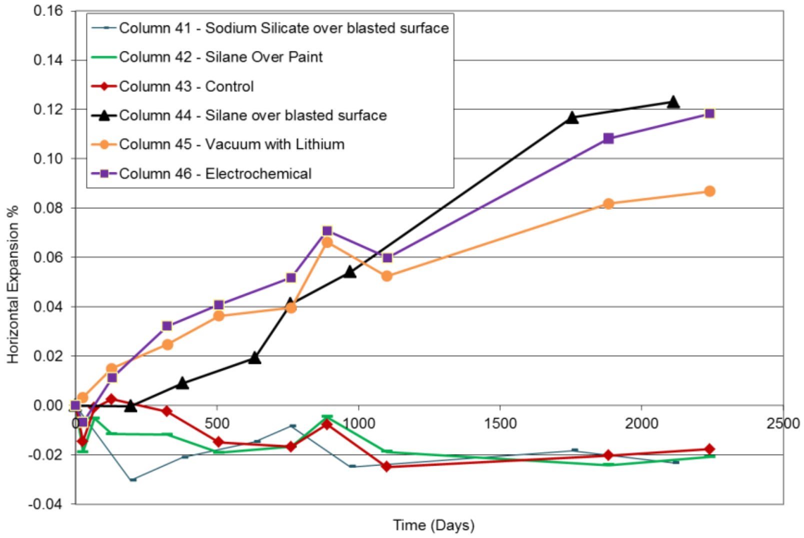

FIGURE 4: Expansion of moderately damaged bridge columns after treatments

FIGURE 5: Etched surface from the electrochemical lithium migration column 46

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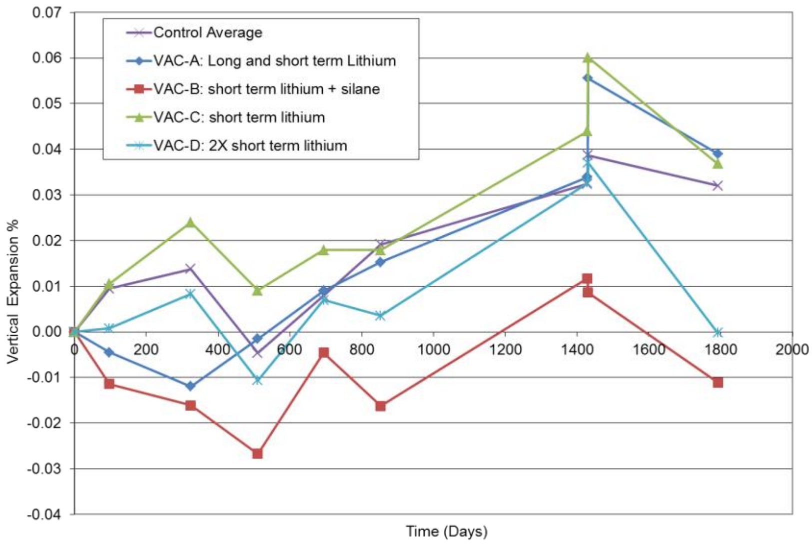

FIGURE 6: Expansions of vacuum treated jersey barriers

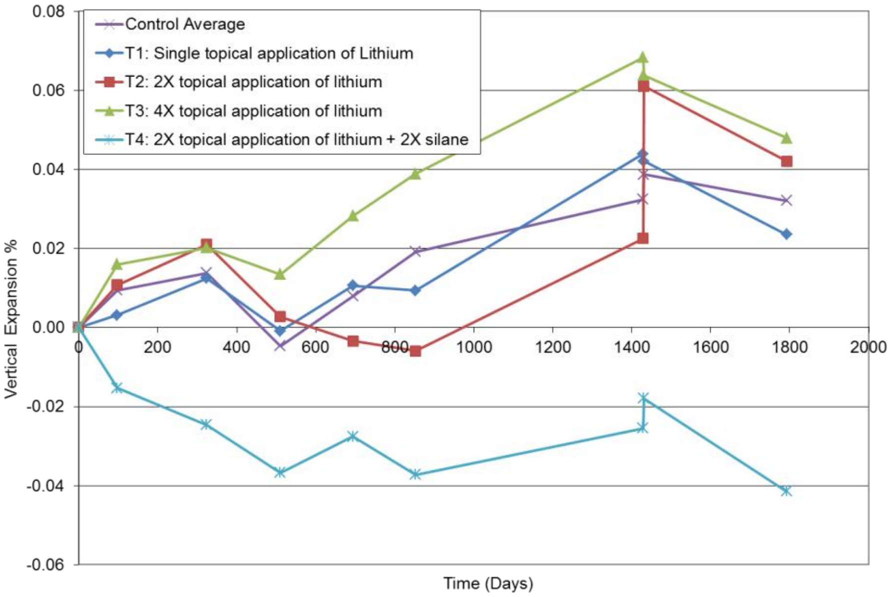

FIGURE 7: Expansions of topically-treated Jersey barriers

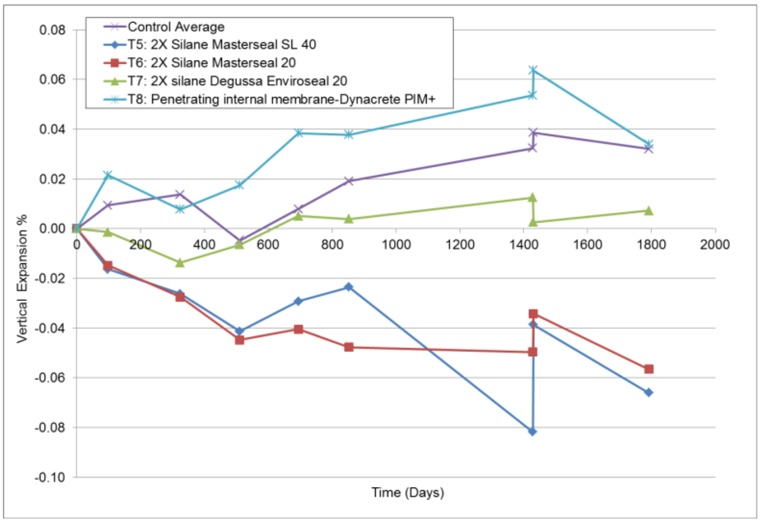

FIGURE 8: Expansions of topically-treated Jersey barriers (continued)