Effect of Lithium Silicate and Silane Sealers on Chloride Permeability and Surface Densification of Concrete Barrier Walls

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ABSTRACT

Effect of Lithium Silicate and Silane Sealers on Chloride Permeability and Surface Densification of Concrete Barrier Walls

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The objective of this work was to evaluate applications of lithium silicate and a combination of lithium silicate and silane for sealing and densifying concrete barrier walls exposed to chloride-based deicing salts. The procedures followed in this research involved selection of three field sites along the Mountain View Corridor in northern Utah for topical applications of lithium silicate and silane and measurements of concrete surface hardness and chloride concentration before and after treatment. At each site, three adjacent sections of the concrete parapet or barrier wall were designated for particular treatments: 1) a silane base coat and lithium silicate top coat, 2) a single coat of lithium silicate, or 3) no sealant, which was defined as the control in this experimentation. Concrete surface hardness, measured in terms of Schmidt rebound number, and chloride concentration testing were performed at each site over a three-year period.

For the Schmidt rebound number analysis, the analyses indicated that the main effects of treatment and age on Schmidt rebound number were all statistically significant. Treatment with silane and lithium silicate and treatment with lithium silicate by itself generated an 8.6 and 2.8 percent decrease, on average, in Schmidt rebound number, respectively, compared to the control. Regarding the main effect of age on Schmidt rebound number, the data indicate that the Schmidt rebound number was, on average, 48.9 and 61.8 percent greater at 1 and 2 years, respectively, than the initial readings.

For the chloride concentration analysis, the analyses indicated that the main effects of treatment, age, and depth were all statistically significant. Treatment with silane and lithium silicate and treatment with lithium silicate by itself provide 100.0 and 62.8 percent reductions, on average, in chloride concentration, respectively, compared to the control. Regarding the main effect of depth on chloride concentration, the data indicate that the chloride concentration of the deeper lift was, on average, 64.2 percent less than the chloride concentration of the shallower lift. Concerning the main effect of age on chloride concentration, the data indicate that the chloride concentration increased by 257.9 and 330.2 percent, on average, after the first and second winter, respectively, compared to the baseline values measured before the wall sections were exposed to chlorides. For both the dual and single treatments studied in this research, the depths of penetration of the sealers, the densification of the treated concrete, and the permanency of the benefits need further investigation.

Key words: chloride concentration, concrete barrier wall, lithium silicate, Schmidt rebound number, silane

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CHAPTER 1 INTRODUCTION

1.1 PROBLEM STATEMENT

Chloride-induced corrosion of reinforcing steel in concrete structures is a leading cause of deterioration of highway infrastructure in cold regions, where the source of chlorides is usually deicing salts applied to roads and bridges during winter to melt ice. On concrete barrier walls, a specified thickness of concrete cover, usually between 1.5 and 2.0 in. (ACI 1995), is provided over the embedded reinforcing steel as a protective layer. When chloride ions penetrate the concrete cover and accumulate in critical concentrations, typically 2.0 lb of chloride per cubic yard of concrete for uncoated reinforcing steel (Hema and Guthrie 2005), corrosion of the reinforcement can occur. Since corrosion products are generally two to six times greater in volume than the parent steel (Young et al. 1998), the corrosion process can induce significant tensile stresses inside the concrete. Because concrete is relatively weak in tension, it can then sustain damage in the form of cracking, delamination, and spalling (Birdsall et al. 2007, Smith and Virmani 2000). These defects can lead to preferential ingress of chlorides into the wall, a corresponding acceleration of damage, and diminished long-term performance (Bentz et al. 2014).

To prevent such damage, concrete barrier walls can be treated with sealers that provide increased protection against chloride ingress (Cusson and Qian 2009, Poulsen and Mejlbro 2006). Among several types of sealers available in the industry, silicon-based products are perhaps the most commonly used, including silanes and silicates (Guthrie et al. 2005). Of particular interest in this research, lithium silicate is a comparatively new product with the potential to greatly reduce chloride ingress by causing chemical reactions that permanently densify concrete materials upon treatment. The product can be applied to new or old concrete using a handheld pressure sprayer, is environmentally friendly, and is relatively inexpensive (CCT 2007). Lithium silicate may also offer enhanced protection against chlorides when used in combination with silane (Argyle 2014), which, when used by itself, is not considered to be permanent (Barry 2003, Nolan et al. 1995). The degree to which chloride ingress can be reduced, however, either through the use of lithium silicate by itself or in combination with silane, has not yet been quantified.

1.2 SCOPE

The objective of this work was to evaluate applications of lithium silicate and a combination of lithium silicate and silane for sealing and densifying concrete barrier walls exposed to chloride-based deicing salts. Test sites were established along the Mountain View Corridor in northern Utah for monitoring through time. The scope of this research included three field sites, two surface treatment products, three variations of treatment application, concrete surface hardness testing, and chloride concentration testing. Two of the sites were parapets along bridges at 8200 South and Dannon Way within the Mountain View Corridor. The third site was an at-grade highway barrier wall located between West South Jordan Parkway and Bingham Creek Road, also within the Mountain View Corridor. The two surface treatment products used were Transil Plus, referred to as lithium silicate in this report, and Hydrozo 100, referred to as silane in this report, both of which were provided by Convergent Concrete Technologies.

1.3 OUTLINE

This report contains five chapters. Chapter 1 presents the problem statement, scope, and outline of the report. Chapter 2 provides background information on corrosion of reinforcing steel in concrete and silicon-based concrete sealers. Chapter 3 describes the procedures used in this research, including the experimental design, data collection, and statistical analyses. Chapter 4 gives the results of testing and analyses, and Chapter 5 presents conclusions and recommendations based on the research.

CHAPTER 2 BACKGROUND

2.1 OVERVIEW

This chapter presents information obtained through a literature review performed for this research. Discussions of corrosion of reinforcing steel in concrete and silicon-based concrete sealers are provided in the following sections.

2.2 CORROSION OF REINFORCING STEEL IN CONCRETE

In cold regions, chloride-based deicing salts are frequently applied to roads and bridges to maintain safe traveling conditions. As chlorides accumulate at the surface of concrete, the resulting gradient in chloride concentration within the concrete causes chloride ions to move deeper into the concrete (Bioubakhsh 2011), from areas of higher concentration to those of lower concentration. In the absence of cracking, this process of chloride diffusion is regarded as the primary method of chloride transport through concrete. Because chlorides diffuse mainly through the pore water in concrete, the degree of water saturation of the concrete can significantly affect the rate of chloride ingress. Specifically, wetting events such as the occurrence of precipitation can increase the rate of chloride diffusion by increasing the amount and interconnectivity of pore water within the concrete compared to concrete having a lower degree of water saturation (Bioubakhsh 2011).

As chlorides continue to penetrate the concrete, critical chloride concentrations can develop around the reinforcing steel. A chloride concentration of 2.0 lb of chloride per cubic yard of concrete is considered adequate to break down the passive oxide film that naturally develops on uncoated reinforcing steel embedded in concrete; in the presence of water and oxygen, corrosion of the reinforcement may then occur (Bioubakhsh 2011, Mindess and Darwin 2003, Poulsen and Mejlbro 2006). Because corrosion products are two to six times larger in volume than the parent steel (Young et al. 1998), cracking, delamination, and spalling of the concrete can result. At this level of damage, expensive repairs are generally required, as the concrete is no longer eligible for cost-efficient preventative maintenance applications. Early applications of products to seal and/or densify concrete are therefore desirable for delaying the rate of chloride diffusion in concrete and thereby extending the service life of treated structures.

2.3 SILICON-BASED CONCRETE SEALERS

Silicates, which contain silicon, oxygen, and one or more metals, are primarily used for densification purposes in the concrete industry. Sodium, potassium, and lithium silicates are available and can be applied topically to hardened concrete. When applied to concrete, silicates diffuse into the concrete, react with hydroxyl ions present in the pore solution, and produce calcium-silicate-hydrate (C-S-H). C-S-H, which is also the primary product of portland cement hydration, is a permanent cementitious product that provides both strength and durability to concrete. Formation of C-S-H in the pores of treated concrete reduces the pore volume, or densifies the concrete, and consequently reduces the permeability of the concrete within the treated depth, which can approach 1 in. (Folliard et al. 2007). While sodium and potassium can aggravate aggregate durability problems, such as alkali-silica reaction, lithium has been shown to mitigate this problem in concrete (Collins et al. 2004, Folliard et al. 2007); therefore, applications of lithium silicate may have additional benefits beyond just reducing the permeability of the concrete.

Silane consists of a monomeric silicon-centered molecule with four attached groups (Guthrie et al. 2005, Rust 2009, Selley 2009). Like silicates, silane can be applied topically to hardened concrete. When applied to concrete, silane forms a covalent bond with the concrete substrate and forms a polymer with adjacent silane molecules. Silane not only exhibits the deepest penetration of the silicon compounds (Rust 2009, Selley 2009), but it also provides excellent hydrophobicity while still allowing treated concrete to remain breathable; the silane polymer structure inhibits the movement of liquid water but permits water vapor to move through the concrete matrix.

Dual treatment systems involving the applications of silicates and silane together or in combination with other products can offer advantages, such as greater permanency and greater reductions in permeability, over the use of a single treatment. For example, although the actual scope of experimentation was not described, a silane base coat with an acrylic top coat was reported to be beneficial in one study (Basheer et al. 1997), while the benefits of a lithium silicate base coat with a silane top coat were documented in another study (Argyle 2014). In both cases, applications of the sealers were expected to significantly reduce the occurrence of chloride-induced corrosion of reinforcing steel in the treated concrete structures, but data specifically evaluating the resistance to chloride ingress were not presented.

2.4 SUMMARY

In the absence of cracking, the process of chloride diffusion is regarded as the primary method of chloride transport through concrete. When critical chloride concentrations develop around the reinforcing steel, corrosion of the reinforcement may then occur. Because corrosion products are two to six times larger in volume than the parent steel, cracking, delamination, and spalling of the concrete can result. Early applications of products to seal and/or densify concrete are therefore desirable for delaying the rate of chloride diffusion in concrete and thereby extending the service life of treated structures.

Silicates and silanes are commonly applied to seal and/or densify concrete surfaces. When applied to concrete, silicates produce C-S-H, which is a permanent cementitious product that provides both strength and durability to concrete, while silane forms a covalent bond with the concrete substrate and forms a polymer with adjacent silane molecules. Dual treatment systems involving the applications of silicates and silane together or in combination with other products can offer advantages, such as greater permanency and greater reductions in permeability, over the use of a single treatment.

CHAPTER 3 PROCEDURES

3.1 OVERVIEW

This chapter provides information about the procedures used in this research. The discussion includes experimental design, data collection, and statistical analyses.

3.2 EXPERIMENTAL DESIGN

The procedures followed in this research involved selection of three field sites for topical applications of lithium silicate and silane and measurements of concrete surface hardness and chloride concentration before and after treatment. The field sites were all located along the Mountain View Corridor in northern Utah. The treatments were applied to concrete parapet walls along bridge decks at two of the sites and to an at-grade concrete barrier wall along the highway at the third site. The two bridge decks were located at 8200 South and Dannon Way. At 8200 South, the east (inside) face of the parapet wall along the west edge of the deck carrying southbound traffic was tested, while at Dannon Way the west (inside) face of the parapet wall along the east edge of the deck carrying northbound traffic was tested. At the highway site, the east (inside) face of a concrete barrier wall on the west side of the highway carrying northbound traffic was tested. All three walls were within approximately 3 miles of each other, were newly constructed, and had not yet been exposed to deicing salts at the start of the study. The locations of the testing sites are shown in Figure 3.1.

Figure 3.1 Locations of field sites.

At each site, three adjacent sections of the concrete parapet or barrier wall were designated for particular treatments. Each section was at least 15 ft in length and 36 in. in height, with the section boundaries corresponding to joints in the walls installed during wall construction. Each section was then assigned one of three treatments: 1) a silane base coat and lithium silicate top coat, 2) a single coat of lithium silicate, or 3) no sealant, which was defined as the control in this experimentation. Figure 3.2 shows the layout of the experimental sections at each site.

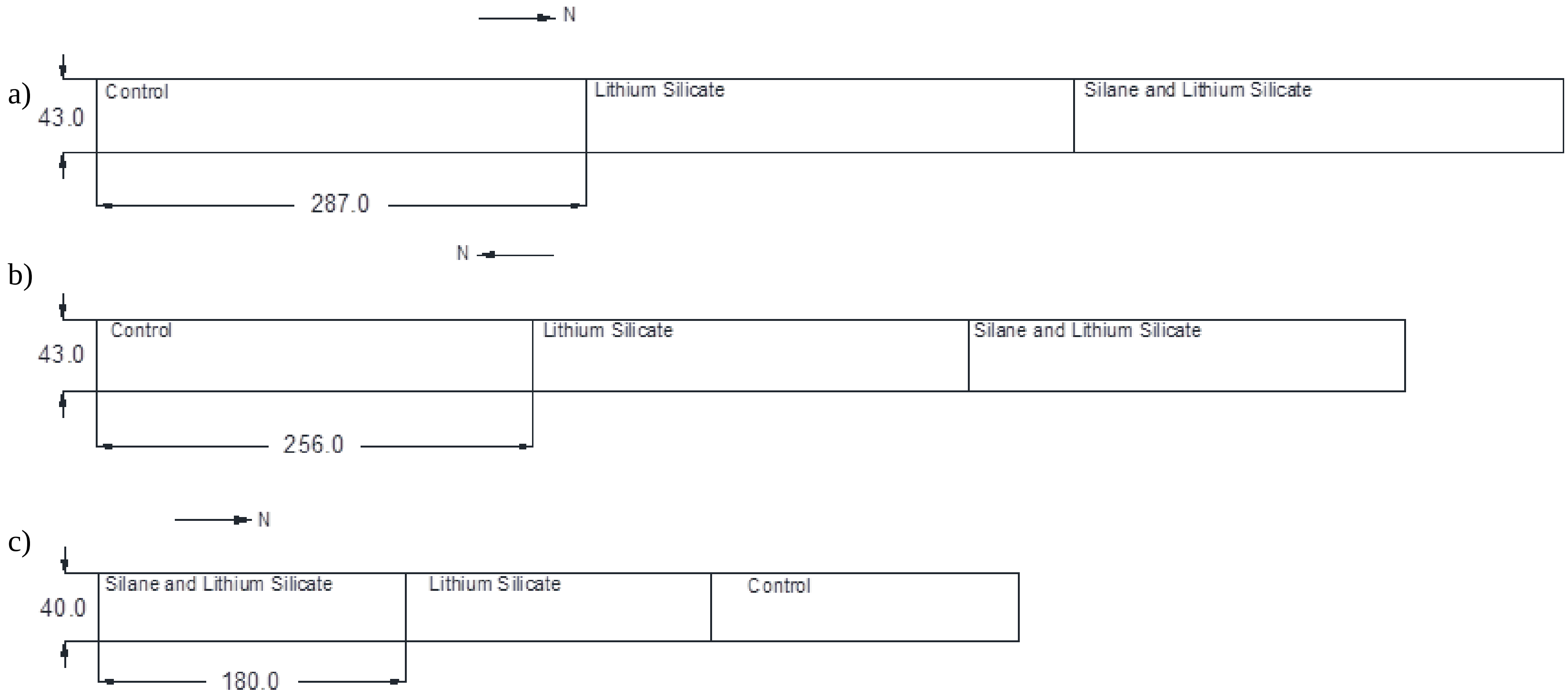

Figure 3.2 Test locations on experimental sections at a) 8200 South bridge parapet, b) Dannon Way bridge parapet, and c) at-grade highway barrier wall.

3.3 DATA COLLECTION

To establish baseline values for this experimentation, initial concrete surface hardness and chloride concentration tests were performed in the middle (horizontally) of each section at each site, with the test locations positioned at approximately 18 in. (vertically) from the deck or ground surface. For concrete hardness measurements, a Schmidt rebound hammer was used, and two rebound numbers were recorded at each site. As depicted in Figure 3.3, Schmidt hammer testing consisted of impacting the test location with the hammer oriented perpendicular to the concrete surface, which was first smoothed using a grinding stone. The orientation of the tested face of the wall was then measured using a level and a protractor, as shown in Figure 3.4, so that variations in the angle among sections could be accounted for in the statistical analyses.

Figure 3.3 Schmidt hammer testing.

Figure 3.4 Measurement of a wall angle.

Following Schmidt hammer testing, each wall section was subjected to chloride concentration sampling at the same test locations. Concrete powder samples were removed in two lifts with depths of 0.5 in. each. For the first lift, a hammer drill bit with a 1.5-in. diameter was used, while for the second lift a hammer drill bit with a 1.0-in. diameter was used; reducing the size of the bit for the second lift reduced the possibility of contamination that may have otherwise occurred due to inadvertent scraping of the shallower lift during drilling of the deeper lift. Use of the hammer drill is illustrated in Figure 3.5. Before a given lift was drilled, a plastic bag was taped to the concrete wall immediately beneath the sampling location to catch the concrete powder as it exited the hole during drilling. As illustrated in Figure 3.6, a small scoop and brush were also utilized to remove powder from the hole after the target drilling depth was reached and the drill bit was removed from the hole. The bag was then sealed and labeled; the drill bit, scoop, and brush were cleaned with compressed air; and the hole was vacuumed before

Figure 3.5 Drilling of a concrete wall.

Figure 3.6 Collection of concrete powder.

the next lift was drilled. The distance from the base of the wall at each initial sampling location to the edge of the nearest travel lane was also measured and recorded.

Following the initial chloride concentration sampling, each hole was lightly moistened and filled with non-shrink grout, and a permanent section label was written directly into the fresh grout in each case. The individual treatments were then applied to each section using a handheld pressure sprayer, as shown in Figure 3.7. An application rate of 250 to 300 ft^2 per gallon was used for the silane, and an application rate of 150 to 200 ft^2 per gallon was used for the lithium silicate. For the dual application, the lithium silicate was applied approximately 20 minutes after the silane was applied. The initial data collection and treatment applications were completed at all three sites in November 2012.

Following the first and second winters, additional Schmidt hammer testing and chloride concentration sampling were performed at each site to enable evaluations of the treatments. In May 2013 and May 2014, new test locations were established 12 in. to the right of each of the previous test locations, and the very same testing procedures applied in the initial testing were repeated, with the exception that three Schmidt rebound numbers instead of two were recorded at each site.

Figure 3.7 Application of sealant to a concrete wall.

After the concrete powder samples were collected in the field, they were transported to the Brigham Young University (BYU) Highway Materials Laboratory, where they were analyzed using laboratory titration in general accordance with American Association of State Highway and Transportation Officials (AASHTO) T 260 (Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials). In this process, a 0.1-oz sample from each bag was oven-dried for 24 hours and then digested using nitric acid and hydrogen peroxide, as shown in Figure 3.8, to release the acid-soluble chlorides. Each solution was then filtered, and the filtrate was titrated with silver nitrate. The chloride concentration percentage resulting from the titration was then multiplied by an assumed concrete density of 150 lb per cubic foot, which is a common value for normal-weight concrete (Montgomery 2014), and converted to units of lb of chloride per cubic yard of concrete for statistical analyses.

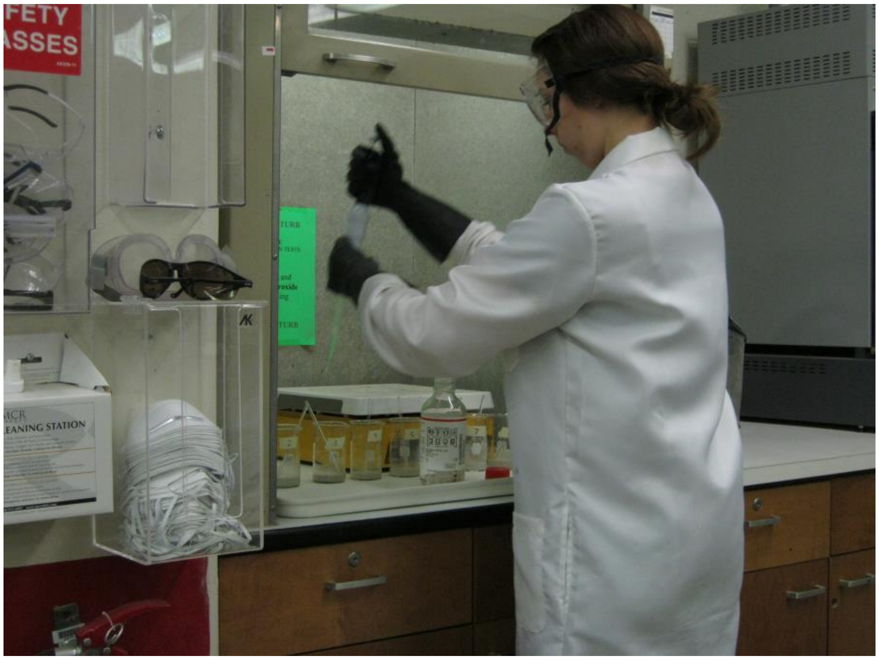

Figure 3.8 Digestion of concrete powder samples.

3.4 STATISTICAL ANALYSES

To evaluate the treatments, a fixed-effects analysis of variance (ANOVA) with interaction was performed together with a Tukey-Kramer post-hoc pairwise comparison. In the ANOVA for Schmidt hammer testing, the dependent variable was Schmidt rebound number, and the independent variables were treatment and age. In the ANOVA for chloride concentration testing, the dependent variable was chloride concentration, and the independent variables were treatment, age, and depth. Distance from the base of the wall to the edge of the nearest travel lane was included as a covariate, as the analysis needed to account for the variable exposure to chlorides through splash and spray that resulted from the varying distances, which ranged from 148 in. to 246 in., of each section from the travel lane.

A full model was initially developed for each dependent variable using all independent variables and all possible two- and three-way interactions between the independent variables. A reduced model was then developed for each dependent variable by removing from the full model each main effect or interaction having a *p*-value exceeding 0.15, which is a default threshold commonly specified for variable selection. For the statistically significant main effects and interactions, which were identified in this research as those having *p*-values less than or equal to 0.05, least squares means were computed, and Tukey-Kramer post-hoc pairwise comparisons were applied. A *p*-value less than or equal to 0.05 indicated a statistically significant difference in the Tukey-Kramer comparisons.

3.5 SUMMARY

The procedures followed in this research involved selection of three field sites for topical applications of lithium silicate and silane and measurements of concrete surface hardness and chloride concentration before and after treatment. At each site, three adjacent sections of the concrete parapet or barrier wall were designated for particular treatments: 1) a silane base coat and lithium silicate top coat, 2) a single coat of lithium silicate, or 3) no sealant, which was defined as the control in this experimentation.

To establish baseline values for this experimentation, initial concrete surface hardness and chloride concentration tests were performed in the middle (horizontally) of each section at each site, with the test locations positioned at approximately 18 in. (vertically) from the deck or ground surface. Following Schmidt hammer testing, each wall section was subjected to chloride concentration sampling at the same test locations. After the concrete powder samples were collected in the field, they were transported to the BYU Highway Materials Laboratory, where they were analyzed using laboratory titration in general accordance with AASHTO T 260 (Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials).

The initial data collection and treatment applications were completed at all three sites in November 2012. Following the first and second winters, additional Schmidt hammer testing and chloride concentration sampling were performed at each site in May 2013 and May 2014 to enable evaluations of the treatments. To evaluate the treatments, a fixed-effects analysis of variance (ANOVA) with interaction was performed together with a Tukey-Kramer post-hoc pairwise comparison.

CHAPTER 4 RESULTS

4.1 OVERVIEW

This chapter provides the results of concrete surface hardness and chloride concentration testing and also presents the results of statistical analyses performed on the collected data. While some potentially useful observations can be made from visual inspection of the data, the focus of this work is on the results obtained through formal statistical analyses. Applicable to the analyses of both Schmidt rebound number and chloride concentration, the angles of each wall relative to a vertical line and the distances from the base of the wall at each test location to the edge of the nearest travel lane are shown in Table 4.1.

Table 4.1 Concrete Barrier Wall Measurements

Test Site	Test Section	Angle of Wall from Vertical (degrees)	Distance from Wall to Nearest Travel Lane (in.)
8200 South Bridge Parapet	Silane and Lithium Silicate	24	148.0
	Lithium Silicate	24	148.0
	Control	24	149.0
Dannon Way Bridge Parapet	Silane and Lithium Silicate	24	149.0
	Lithium Silicate	24	148.0
	Control	22	148.0
At-Grade Highway Barrier Wall	Silane and Lithium Silicate	12	246.0
	Lithium Silicate	12	235.0
	Control	12	224.5

4.2 SCHMIDT REBOUND NUMBER

The results of the Schmidt hammer testing are presented in Table 4.2, in which higher Schmidt rebound numbers indicate higher concrete surface hardness. For this analysis, the full and reduced models developed in the ANOVA were the same, and the results are shown in

Table 4.2 Schmidt Rebound Hammer Data

Test Site	Test Section	Repetition	Schmidt Rebound Number		
			2012	2013	2014
8200 South Bridge Parapet	Silane and Lithium Silicate	1	32	46	52
		2	36	44	47
		3	-	46	46
	Lithium Silicate	1	32	55	49
		2	32	46	50
		3	-	55	52
	Control	1	34	49	50
		2	34	54	51
		3	-	51	55
Dannon Way Bridge Parapet	Silane and Lithium Silicate	1	30	45	47
		2	32	44	50
		3	-	44	46
	Lithium Silicate	1	30	47	56
		2	30	47	56
		3	-	48	59
	Control	1	30	44	54
		2	34	46	54
		3	-	47	54
At-Grade Highway Barrier Wall	Silane and Lithium Silicate	1	32	49	55
		2	36	51	52
		3	-	50	52
	Lithium Silicate	1	32	48	50
		2	33	50	59
		3	-	46	57
	Control	1	31	46	54
		2	32	50	54
		3	-	52	51

Table 4.3. The model indicates that the main effects of treatment and age on Schmidt rebound number were all statistically significant, as well as the covariates of angle and distance. However, the interaction between treatment and age was not statistically significant, as the *p*-value was not less than or equal to 0.05. The coefficient of determination, or R^2 value, was 91.5 percent for the reduced model, indicating that 91.5 percent of the variation observed in Schmidt rebound number in this study can be explained by variation in the factors included in the model.

The least squares means computed for each main effect on Schmidt rebound number are presented in Table 4.4 and Figures 4.1 and 4.2. These data indicate that treatment with silane and lithium silicate and treatment with lithium silicate by itself generate an 8.6 percent and 2.8 percent decrease, on average, in Schmidt rebound number, respectively, compared to the control, which is the opposite of the expected effect. As shown in Table 4.5, statistically significant differences were identified between the silane and lithium silicate treatment and both the lithium silicate treatment and the control. Further research is needed to develop possible explanations for this unexpected outcome.

Regarding the main effect of age on Schmidt rebound number, the data indicate that the Schmidt rebound number was, on average, 48.9 and 61.8 percent greater at 1 and 2 years, respectively, than the initial readings. These observed differences, which are shown in Table 4.5 to be statistically significant, were expected due to the nature of concrete strength gain over time.

Table 4.3 Full and Reduced Model from ANOVA on Schmidt Rebound Number

Factor	*p*-Value
Treatment	0.002
Age	0.000
Treatment*Age	0.066
Angle	0.012
Distance	0.006

Table 4.4 Least Squares Means from ANOVA on Schmidt Rebound Number

Treatment	Schmidt Rebound Number
Silane and Lithium Silicate	42
Lithium Silicate	45
Control	46
Age (yr)	
0	32
1	48
2	52

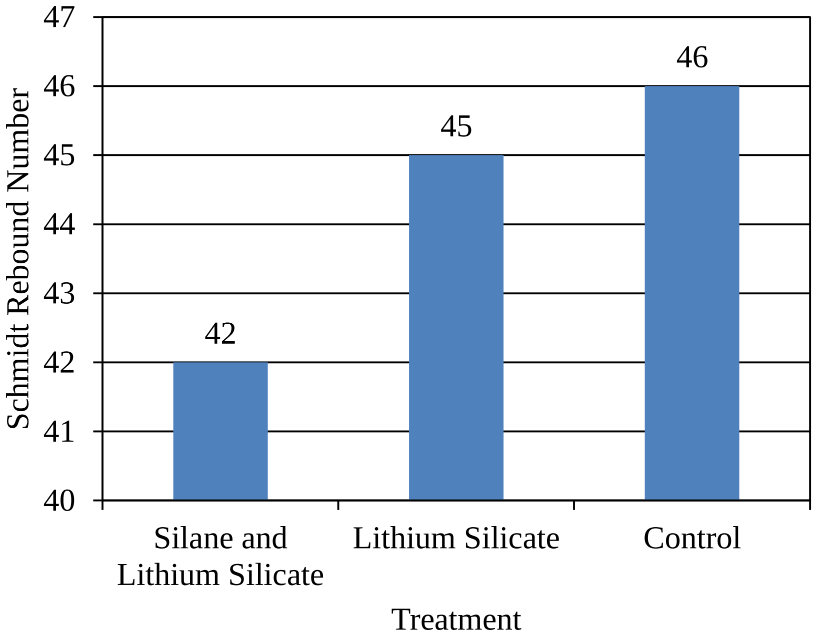

Figure 4.1 Least squares means showing main effect of treatment on Schmidt rebound number.

Although not selected as independent variables in this research, the barrier wall angle and the distance from the base of the wall to the edge of the nearest travel lane were statistically significant covariates. The data show that decreasing angle and increasing distance generally correspond to increasing Schmidt rebound number. While the apparent effect of the barrier wall

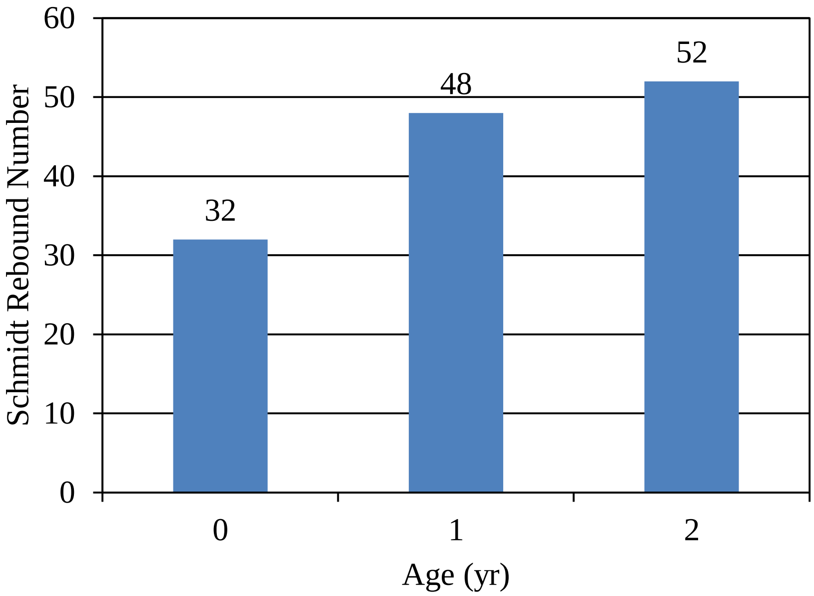

Figure 4.2 Least squares means showing main effect of age on Schmidt rebound number.

Table 4.5 Results from Tukey-Kramer Analysis of Schmidt Rebound Number

p -Value by Pairwise Comparison		
Treatment	Lithium Silicate	Control
Silane and Lithium Silicate	0.0071	0.0030
Lithium Silicate	-	0.3773
Age (yr)	1	2
0	0.0000	0.0000
1	-	0.0000

angle may actually result from differences in concrete mixture designs rather than differences in wall geometry, a possible explanation for higher Schmidt rebound numbers at test sections situated farther from the travel lane is that less splash and spray resulted in greater drying of the concrete surfaces compared to test sections situated closer to the travel lane; drier concrete would then yield higher Schmidt rebound numbers.

4.3 CHLORIDE CONCENTRATION

The results of the chloride concentration testing are presented in Table 4.6. The full model developed in the ANOVA is shown in Table 4.7, and the reduced model is shown in Table 4.8. The reduced model indicates that the main effects of treatment, age, and depth were all statistically significant, as well as the covariates of angle and distance. However, none of the interactions between these variables were determined to be statistically significant. The R^2 value was 65.1 percent for the reduced model, indicating that 65.1 percent of the variation observed in chloride concentrations in this study can be explained by variation in the factors included in the model.

Table 4.6 Chloride Concentration Data

Test Site	Test Section	Lift	Chloride Concentration (%) by Year			Chloride Concentration ($lb\ Cl^-/yd^3$ Concrete) by Year		
			2012	2013	2014	2012	2013	2014
8200 South Bridge Parapet	Silane and Lithium Silicate	1	0.0107	0.0133	0.0072	0.4	0.5	0.3
		2	0.0087	0.0082	0.0054	0.4	0.3	0.2
	Lithium Silicate	1	0.0124	0.0571	0.1711	0.5	2.3	6.9
		2	0.0091	0.0083	0.0484	0.4	0.3	2.0
	Control	1	0.0094	0.1514	0.1946	0.4	6.1	7.9
		2	0.0079	0.0656	0.0759	0.3	2.7	3.1
Dannon Way Bridge Parapet	Silane and Lithium Silicate	1	0.0092	0.0114	0.0081	0.4	0.5	0.3
		2	0.0074	0.0098	0.0057	0.3	0.4	0.2
	Lithium Silicate	1	0.0104	0.0858	0.0334	0.4	3.5	1.4
		2	0.0084	0.0136	0.0081	0.3	0.6	0.3
	Control	1	0.0116	0.1383	0.1502	0.5	5.6	6.1
		2	0.0089	0.0233	0.0171	0.4	0.9	0.7
At-Grade Highway Barrier Wall	Silane and Lithium Silicate	1	0.0104	0.0129	0.0073	0.4	0.5	0.3
		2	0.0097	0.0094	0.0068	0.4	0.4	0.3
	Lithium Silicate	1	0.0094	0.0115	0.0094	0.4	0.5	0.4
		2	0.0114	0.0094	0.0057	0.5	0.4	0.2
	Control	1	0.0129	0.0091	0.0160	0.5	0.4	0.6
		2	0.0132	0.0098	0.0086	0.5	0.4	0.3

Table 4.7 Full Model from ANOVA on Chloride Concentration

Factor	*p* -Value
Treatment	0.000
Age	0.011
Depth	0.003
Treatment*Age	0.131
Treatment*Depth	0.091
Age*Depth	0.110
Treatment*Age*Depth	0.604
Angle	0.009
Distance	0.020

Table 4.8 Reduced Model from ANOVA on Chloride Concentration

Factor	*p* -Value
Treatment	0.000
Age	0.009
Depth	0.003
Treatment*Age	0.118
Treatment*Depth	0.083
Age*Depth	0.101
Angle	0.008
Distance	0.018

The least squares means computed for each main effect on chloride concentration are presented in Table 4.9 and Figures 4.3 to 4.5. These data indicate that treatment with silane and lithium silicate and treatment with lithium silicate by itself provide 100.0 and 62.8 percent reductions, on average, in chloride concentration, respectively, compared to the control. (In the analysis, the actual least squares mean for treatment with silane and lithium silicate was -0.2 lb of chloride per cubic yard of concrete; however, as chloride concentration cannot be negative in reality, the value is shown as 0.0 in Table 4.9 and Figure 4.3.) As shown in Table 4.10, statistically significant differences were identified between the silane and lithium silicate

Table 4.9 Least Squares Means from ANOVA on Chloride Concentration

Factor	Chloride Concentration (lb Cl^-/yd^3 Concrete)
Treatment	
Silane and Lithium Silicate	0.0
Lithium Silicate	1.0
Control	2.8
Depth (in.)	
0.5	1.8
1.0	0.6
Age (yr)	
0	0.4
1	1.5
2	1.8

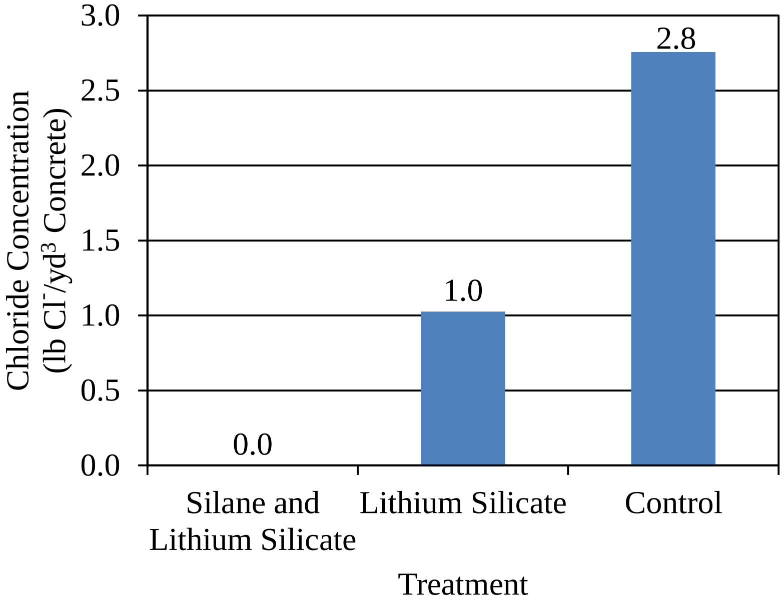

Figure 4.3 Least squares means showing main effect of treatment on chloride concentration.

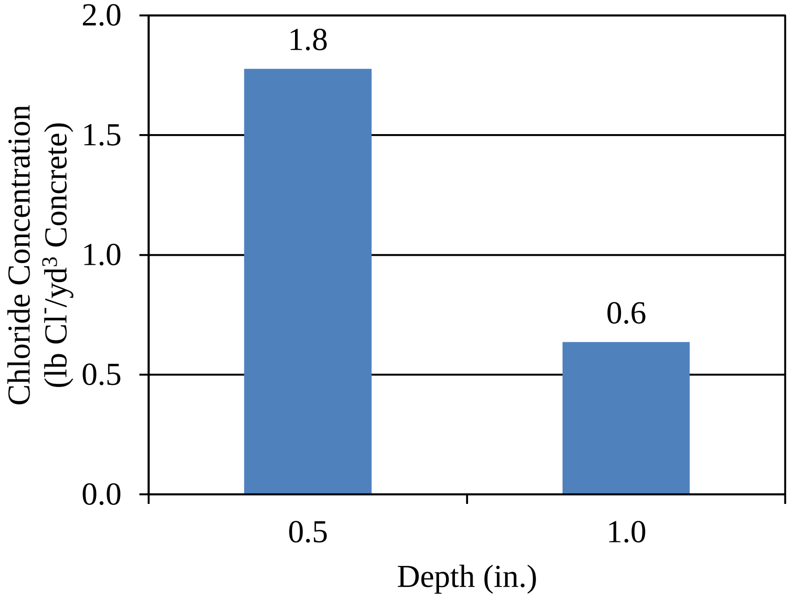

Figure 4.4 Least squares means showing main effect of depth on chloride concentration.

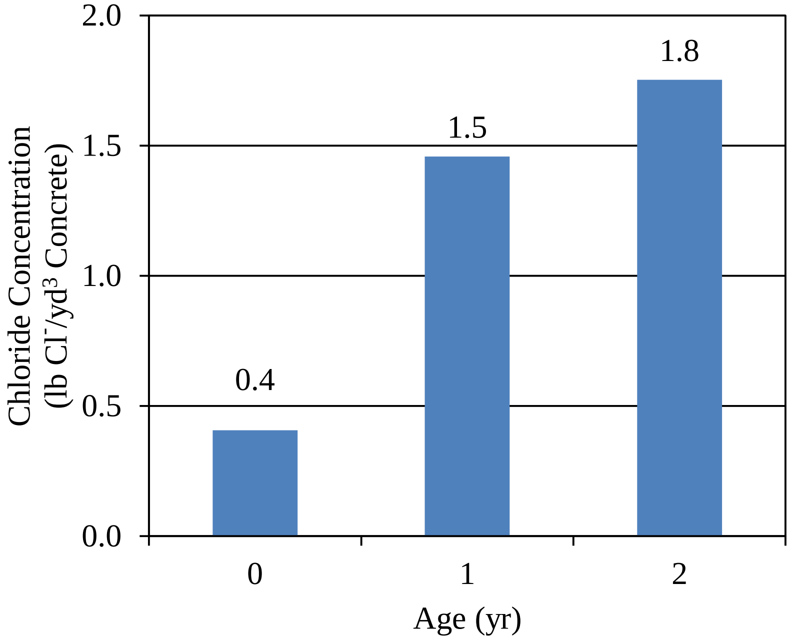

Figure 4.5 Least squares means showing main effect of age on chloride concentration.

Table 4.10 Results from Tukey-Kramer Analysis of Chloride Concentration

p -Value by Pairwise Comparison		
Treatment	Lithium Silicate	Control
Silane and Lithium Silicate	0.0361	0.0001
Lithium Silicate	-	0.0067
Depth (in.)	1.0	
0.5	0.0027	
Age (yr)	1	2
0	0.0525	0.0101
1	-	0.7782

treatment and both the lithium silicate treatment and the control, as well as between the lithium silicate treatment and the control. The results indicate that both treatments provide a chloride reduction relative to no treatment and that the dual treatment provides a greater reduction than lithium silicate by itself.

Regarding the main effect of depth on chloride concentration, the data indicate that the chloride concentration of the deeper lift was, on average, 64.2 percent less than the chloride concentration of the shallower lift. This observed difference, which is shown in Table 4.10 to be statistically significant, was expected due to the nature of chloride diffusion from areas of higher concentration to areas of lower concentration.

Concerning the main effect of age on chloride concentration, the data indicate that the chloride concentration increased by 257.9 and 330.2 percent, on average, after the first and second winter, respectively, compared to the baseline values measured before the wall sections were exposed to chlorides. The difference between the chloride concentration measured before the first winter and the chloride concentration measured after the second winter was determined to be statistically significant, as shown in Table 4.10. Overall differences across age can probably be attributed to the varying severity of winter weather and the subsequent variations in deicing salt applications across the years of the study.

Finally, although not selected as independent variables in this research, the barrier wall angle and the distance from the base of the wall to the edge of the nearest travel lane were statistically significant covariates. The data show that decreasing angle and increasing distance generally correspond to decreasing chloride concentration. While the apparent effect of the barrier wall angle may actually result from differences in concrete mixture designs rather than differences in wall geometry, as previously stated, a possible explanation for higher chloride concentrations at test sections situated farther from the travel lane is that less splash and spray resulted in less chloride exposure. Specifically, the at-grade barrier wall was sufficiently removed from the zone of splash and spray that exposure to chlorides was greatly reduced at that test site. As another possible explanation for lower chloride exposure at the barrier wall site compared to the bridge parapets, snow plow operators frequently dispense more salt on bridges than along at-grade pavements.

4.4 SUMMARY

The results of the testing include concrete surface hardness, measured in terms of Schmidt rebound number, and chloride concentration. For the Schmidt rebound number analysis, the full and reduced models developed in the ANOVA were the same, and the model indicates that the main effects of treatment and age on Schmidt rebound number were all statistically significant, as well as the covariates of barrier wall angle and distance from the base of the wall to the edge of the nearest travel lane. However, the interaction between treatment and age was not statistically significant. Treatment with silane and lithium silicate and treatment with lithium silicate by itself generate an 8.6 and 2.8 percent decrease, on average, in Schmidt rebound number, respectively, compared to the control. Regarding the main effect of age on Schmidt rebound number, the data indicate that the Schmidt rebound number was, on average, 48.9 and 61.8 percent greater at 1 and 2 years, respectively, than the initial readings.

For the chloride concentration analysis, the reduced model from the ANOVA indicates that the main effects of treatment, age, and depth were all statistically significant, as well as the covariates of barrier wall angle and distance from the base of the wall to the edge of the nearest travel lane. However, none of the interactions between these variables were determined to be statistically significant. Treatment with silane and lithium silicate and treatment with lithium silicate by itself provide 100.0 and 62.8 percent reductions, on average, in chloride concentration, respectively, compared to the control. Regarding the main effect of depth on chloride concentration, the data indicate that the chloride concentration of the deeper lift was, on average, 64.2 percent less than the chloride concentration of the shallower lift. Concerning the main effect of age on chloride concentration, the data indicate that the chloride concentration increased by 257.9 and 330.2 percent, on average, after the first and second winter, respectively, compared to the baseline values measured before the wall sections were exposed to chlorides.

CHAPTER 5 CONCLUSION

5.1 SUMMARY

The objective of this work was to evaluate applications of lithium silicate and a combination of lithium silicate and silane for sealing and densifying concrete barrier walls exposed to chloride-based deicing salts. Three field sites were established along the Mountain View Corridor in northern Utah for monitoring through time. Two of the sites were parapets along bridges at 8200 South and Dannon Way within the Mountain View Corridor. The third site was an at-grade highway barrier wall located between West South Jordan Parkway and Bingham Creek Road, also within the Mountain View Corridor.

The procedures followed in this research involved selection of three field sites for topical applications of lithium silicate and silane and measurements of concrete surface hardness and chloride concentration before and after treatment. At each site, three adjacent sections of the concrete parapet or barrier wall were designated for particular treatments: 1) a silane base coat and lithium silicate top coat, 2) a single coat of lithium silicate, or 3) no sealant, which was defined as the control in this experimentation.

To establish baseline values for this experimentation, initial concrete surface hardness, measured in terms of Schmidt rebound number, and chloride concentration tests were performed at each site. Following Schmidt hammer testing, each wall section was subjected to chloride concentration sampling at the same test locations. The initial data collection and treatment applications were completed at all three sites in November 2012. Following the first and second winters, additional Schmidt hammer testing and chloride concentration sampling were performed at each site in May 2013 and May 2014 to enable evaluations of the treatments. To evaluate the treatments, a fixed-effects ANOVA with interaction was performed together with a Tukey-Kramer post-hoc pairwise comparison.

5.2 FINDINGS

The results of the testing include Schmidt rebound number and chloride concentration. For the Schmidt rebound number analysis, the full and reduced models developed in the ANOVA were the same, and the model indicates that the main effects of treatment and age on Schmidt rebound number were all statistically significant, as well as the covariates of barrier wall angle and distance from the base of the wall to the edge of the nearest travel lane. Treatment with silane and lithium silicate and treatment with lithium silicate by itself generate an 8.6 percent and a 2.8 percent decrease, on average, in Schmidt rebound number, respectively, compared to the control. Regarding the main effect of age on Schmidt rebound number, the data indicate that the Schmidt rebound number was, on average, 48.9 and 61.8 percent greater at 1 and 2 years, respectively, than the initial readings.

For the chloride concentration analysis, the reduced model from the ANOVA indicates that the main effects of treatment, age, and depth were all statistically significant, as well as the covariates of barrier wall angle and distance from the base of the wall to the edge of the nearest travel lane. Treatment with silane and lithium silicate and treatment with lithium silicate by itself provide 100.0 and 62.8 percent reductions, on average, in chloride concentration, respectively, compared to the control. Regarding the main effect of depth on chloride concentration, the data indicate that the chloride concentration of the deeper lift was, on average, 64.2 percent less than the chloride concentration of the shallower lift. Concerning the main effect of age on chloride concentration, the data indicate that the chloride concentration increased by 257.9 and 330.2 percent, on average, after the first and second winter, respectively, compared to the baseline values measured before the wall sections were exposed to chlorides.

5.3 RECOMMENDATIONS

The results of this research indicate that treatment with silane and lithium silicate and treatment with lithium silicate by itself reduce chloride ingress in concrete barrier walls exposed to chloride-based deicing salts. Because these sealers products can be easily applied using a handheld pressure sprayer, are environmentally friendly, and are relatively inexpensive, their use is recommended to provide increased protection against chloride ingress in concrete barrier walls and other similar structures to delay the rate of chloride diffusion and thereby extend the service life of treated structures.

In this research, the dual treatment involving the application of lithium silicate and silane together provided a greater reduction in chloride ingress than the application of lithium silicate by itself and may therefore warrant consideration on projects where greater levels of protection are needed. To maximize benefit from the dual treatment, further research is recommended to investigate and optimize the sequence and timing of application for the two sealers. For both the dual and single treatments studied in this research, the depths of penetration of the sealers, the densification of the treated concrete, and the permanency of the benefits also need further investigation.

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