WASHING BRIDGES TO REDUCE CHLORIDE

Final Report

SPR 304-031

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by

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Washington, DC 20590

July 2005

Technical Report Documentation Page

1. Report No. FHWA-OR-DF-06-04	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle WASHING BRIDGES TO REDUCE CHLORIDE		5. Report Date July 2005 6. Performing Organization Code
7. Author(s) Steven Soltesz, Research Unit, Oregon Department of Transportation		8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon Department of Transportation Research Unit 200 Hawthorne Avenue SE, Suite B-240 Salem, Oregon 97301-5192		10. Work Unit No. (TRAIS) 11. Contract or Grant No. SPR 304-031
12. Sponsoring Agency Name and Address Oregon Department of Transportation Research Unit and 200 Hawthorne Avenue SE, Suite B-240 Salem, Oregon 97301-5192 Federal Highway Administration 400 Seventh Street S.W. Washington, DC 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Chloride ions are known to promote the corrosion of steel in reinforced concrete. This project was undertaken to investigate the efficacy of washing, to reduce existing chloride content and chloride ion uptake. The project consisted of a laboratory component over four years and a field component over two years.

In the field component test sections of a coastal bridge were pressure washed on a once per year and twice per year schedule. The laboratory effort consisted of washing trials conducted on concrete blocks exposed to salt water to determine whether chloride ions can be removed from the concrete and whether the ingress of chloride ions can be reduced. Field testing was discontinued after two years because the laboratory results indicated that the washing frequencies used on the bridge were much too low to produce any change in chloride levels. After four years, the laboratory trials showed that daily washing with fresh water can appreciably reduce the ingress of chloride ions, but occasional washing is ineffective. Washing does not appear to significantly reduce existing chloride concentrations in the bulk concrete.

17. Key Words Bridge, washing, chloride, concrete		18. Distribution Statement Copies available from NTIS, and online at http://www.oregon.gov//ODOT/TD/TP_RES/	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 30	22. Price

Technical Report Form DOT F 1700.7 (8-72) Reproduction of completed page authorized Printed on recycled paper

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

NOTE: Volumes greater than 1000 L shall be shown in m^3.

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

3ACKNOWLEDGMENTS

The author wishes to thank the following for their assistance and support of this project:

- ODOT District 4 personnel for providing needed equipment and materials
- Alan Kirk, ODOT Research Unit for editorial assistance

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WASHING BRIDGES TO REDUCE CHLORIDE

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1.0 INTRODUCTION

Oregon has invested heavily in impressed current cathodic protection on reinforced concrete coastal bridges to mitigate chloride induced corrosion. On smaller bridges, cathodic protection may not be practical due to the expense of installing and operating such systems. Washing, however, may offer a viable option. In principle, if the chloride concentration at the surface is reduced to near zero, there is a driving force for chloride ions in the concrete to diffuse to the surface where they may be washed away by subsequent washings. Even if washing does not remove chloride ions, washing may prevent or reduce any further uptake of chloride ions.

If washing is a viable alternative, the most effective washing frequency and amount of water applied for each wash need to be established. These conditions need to be considered in conjunction with the allowed washing period according to environmental regulations, which in Oregon is from November 15 to March 15 west of the Cascade Mountains. Other considerations include disruption of birds and bats, which commonly inhabit the undersides of bridges; this activity might violate environmental regulations.

Though bridge washing is practiced by some transportation agencies, the method seems to be a one-time pressure wash every spring to remove debris and deicing salts (*Carter 1989*). No research is known to the author that addresses washing as a means to reduce chloride content.

Thus this project was undertaken to investigate the efficacy of washing to reduce chloride content and chloride ion uptake. The project consisted of a laboratory and a field component over a period of four years. Wash frequency and water volume were the varying factors. This final report covers the methods used in the study and the results of the field and laboratory components after four years of study.

2.0 APPROACH

2.1 FIELD TEST SITE

The D River Bridge (ODOT Bridge No. 00922A) was selected for field evaluations. The Bridge, located within Lincoln City on the Oregon Coast Highway, U.S. Route 101, is a 30.5 m (110 ft), 3-span, reinforced concrete structure. It was selected because it showed signs of corrosion-induced damage, and it provided easy access to the underside of the deck without ladders or traffic control.

Five test sections, A – E, on the south span of the Bridge were used for washing trials. Each section was located between girders, starting at the most westerly girder as shown schematically in Figure 2.1. An initial set of chloride profiles to a depth of 95 mm (3.75 in) was made from samples extracted from the locations numbered 1 – 10 in Figure 2.1. Subsequent chloride profiles were planned after 4 years for positions between the initial two locations for each section. Prior to extracting samples, the concrete was sounded to avoid sampling through a delaminated area.

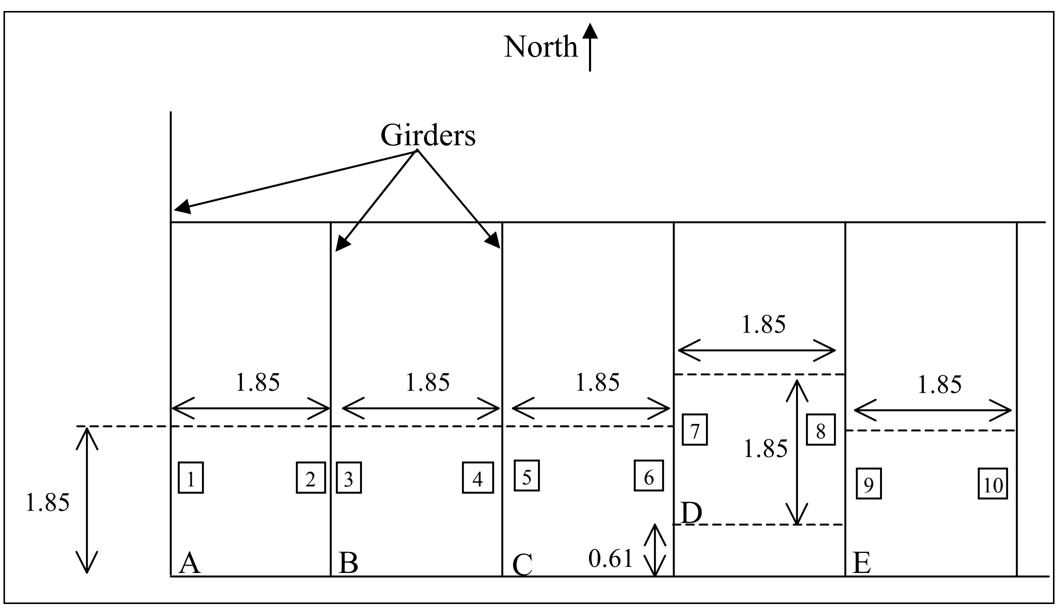

Figure 2.1: Test section locations and initial chloride profile locations. Dimensions are in meters.

The sections were pressure washed according to the schedule in Table 2.1. Two wash durations (1.8 minutes and 3.6 minutes) and two wash frequencies (1 time per year and 2 times per year) were used.

Table 2.1: Washing schedule for each section

Section	Wash Duration (minutes)	Wash Frequency (per year)	Wash Dates
A	3.6	2	11/29/00 3/12/01 11/20/01 3/12/02 11/20/02 3/11/03
B	1.8	1	11/29/00 11/20/01 11/20/02
C	Control – not washed	-	-
D	3.6	1	11/29/00 11/20/01 11/20/02
E	1.8	2	11/29/00 3/12/01 11/20/01 3/12/02 11/20/02 3/11/03

2.2 FIELD EVALUATIONS

Eight samples were extracted from the bridge to generate each of the ten initial chloride profiles. A rotary hammer with a hollow bit pulverized the concrete in 13 mm increments (0.5 in). A vacuum cleaner and filter assembly connected to the bit captured the powder while the rotary hammer operated. Each sample consisted of concrete from the same depth from three holes, all within 300 mm (12 in) of each other. If reinforcing steel was encountered in a hole, the remaining holes still produced enough material for analysis. The samples were analyzed for total chloride in accordance with AASHTO T260-97 (*2003b*) and for cement content in accordance with AASHTO T178-97 (*2003a*) in order to calculate the weight percent of chloride in the cement paste.

2.3 LABORATORY EVALUATIONS

Eight 305 x 305 x 178 mm (12 x 12 x 7 in) mortar slabs were cast with a water-to-cement ratio of 0.4 and a water-to-sand ratio of 0.47. The slabs were cured for 18 days at 23^{o}C and 95% relative humidity.

After curing, a 13 mm (0.5 in) dam was placed around the edge of four of the slabs using latex caulk. These four slabs were ponded at ambient laboratory temperature with 13% saltwater solution made from reagent-grade NaCl and deionized water. Plastic sheeting was placed over the blocks to prevent evaporation. Figure 2.2 shows a slab undergoing ponding. The ponding was conducted for 12 weeks with the solution replaced after 6 weeks.

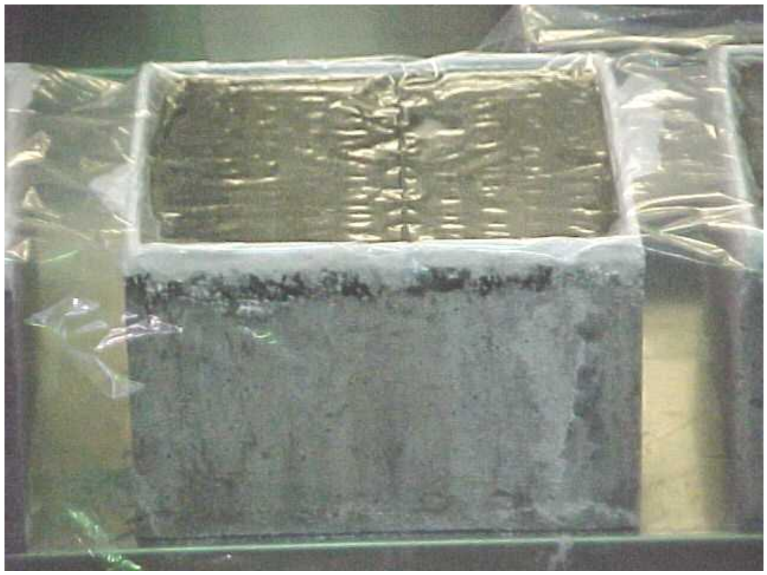

Figure 2.2: Concrete slab undergoing ponding

After the ponding period two chloride profiles to a depth of 95 mm (3.75 in) were generated for each of the four ponded slabs. The surface of each slab was cleaned with a wire brush and vacuumed. Powder samples were extracted in 13 mm (0.5 in) increments from the ponded slabs with the rotary hammer and vacuum system used on the Bridge. After sample removal, the holes were filled with silicone caulk.

The four slabs that were not ponded were stored under ambient laboratory conditions after the 18-day cure.

All eight slabs were then placed on a wash rack, as shown in Figure 2.3, and washed according to the schematic shown in Figure 2.4. Four types of wash treatment were applied to the slabs, one treatment type for each of four slab pairs consisting of one ponded and one unponded slab: once per day, once per week, once per month, and no washing. The ponded slabs were positioned with the ponded face down.

Figure 2.3: Rack for washing slabs

Water was applied to the washed slabs with a mister positioned 380 mm (15 in) under each slab. Electronic valves controlled by a timer were used for the slabs washed 1/day and 1/week. A manual valve was used for the slabs washed 1/month. A wash cycle lasted 2 minutes, which delivered approximately 1 liter of water, which is equivalent to approximately 11 liters/square meter. An activated charcoal water filter was installed at the tap to remove chlorine from the city water.

The slabs that were not ponded were sprayed once per week with a 3.4% saltwater solution to simulate a marine exposure. The purpose of the salt water-sprayed slabs was to determine whether washing would prevent the ingress of chloride ions. The saltwater was applied at a random time during work hours with a hand-held plant mister.

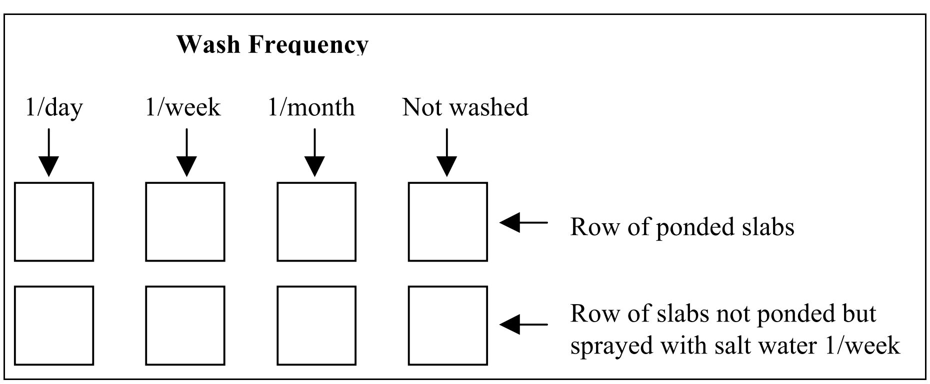

Figure 2.4: Schematic of slab position on the wash rack and treatment

After 25 and 49 months, chloride profiles were generated for each slab. Each profile was based on powder samples from two locations on the block. The surface of each slab was cleaned with a wire brush and vacuumed. Powder samples were extracted in 13 mm (0.5 in) increments with the rotary hammer and vacuum system used on the bridge.

3.0 RESULTS AND DISCUSSION

3.1 FIELD RESULTS

Both the field and laboratory components of the project were conducted during the same time period. Baseline chloride profiles for the D River Bridge are included in Appendix A. Interim findings from the laboratory component (discussed in the next section) provided strong evidence that the bridge washing cycles of 1/year and 2/year were unlikely to affect chloride ion content. Consequently, no further washing was conducted on the D River Bridge after March of 2003 (2 ½ years into the project), and no post-washing chloride profiles were generated for the bridge. Thus no data analysis was conducted.

3.2 LABORATORY RESULTS

The chloride data for the laboratory slabs are included in Appendix B. The duplicate tests for the pre-washing condition showed relatively little variance for this type of measurement. The results for the ponded laboratory slabs after 25 months and 49 months of washing are graphed in Figure 3.1.

The ponded laboratory slabs showed a decrease in chloride content at the washing frequency of 1/day. The no-washing condition, however, also showed a decrease in chloride levels. The 1/week and 1/month washing frequencies showed no clear advantage in reducing chloride content. Thus the data did not consistently show that washing results in removing chloride ions from concrete.

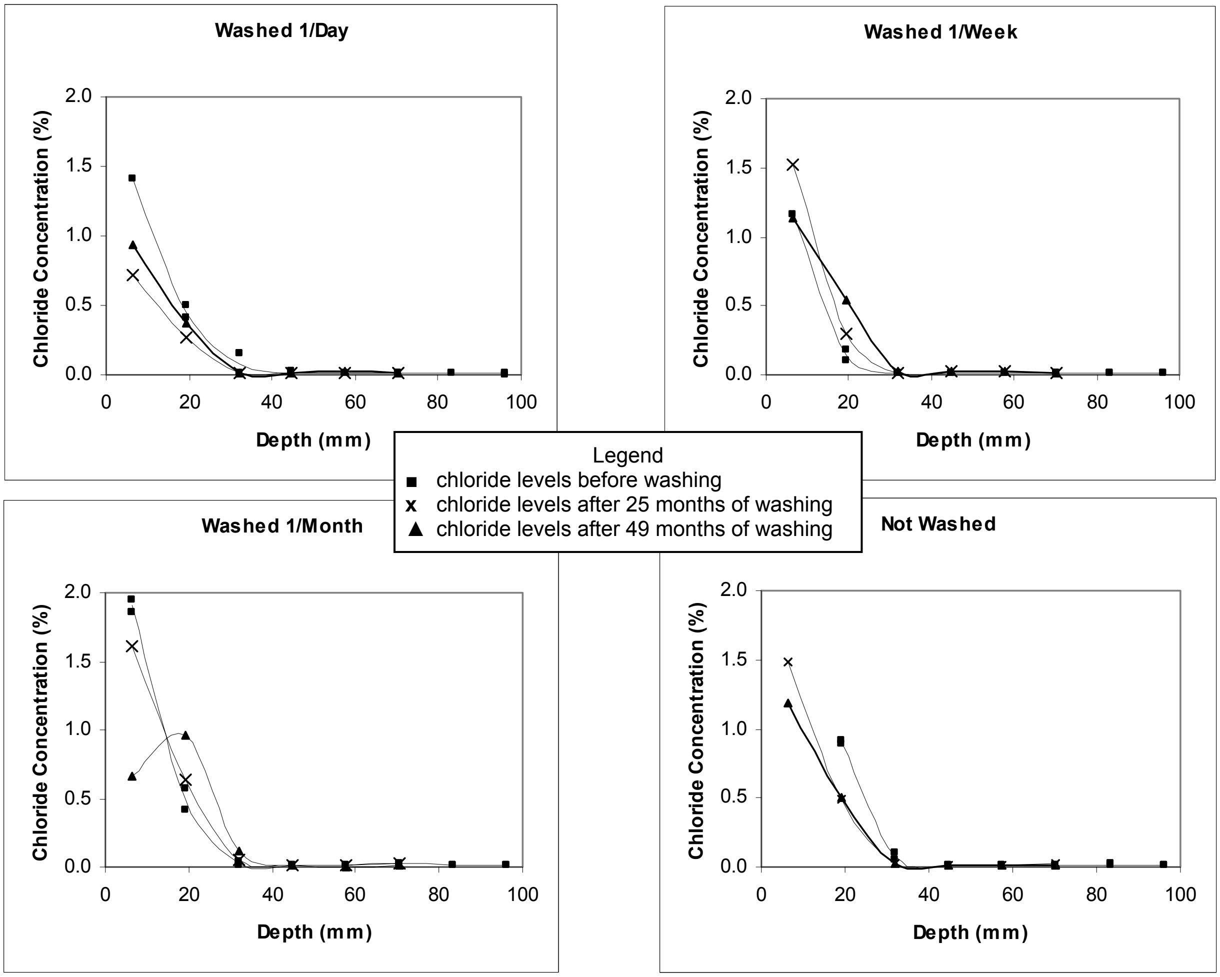

Figure 3.1: Chloride profiles for ponded specimens

For the unponded slabs sprayed with salt water, washing 1/day resulted in substantially less chloride content than no washing after 25 months and 49 months, as shown in Figures 3.2 and 3.3. To a lesser extent, washing 1/week and 1/month also resulted in lower levels of chloride. Comparing the data in the two figures suggests that even though the uptake of chloride was reduced with washing, chloride content still increased over time.

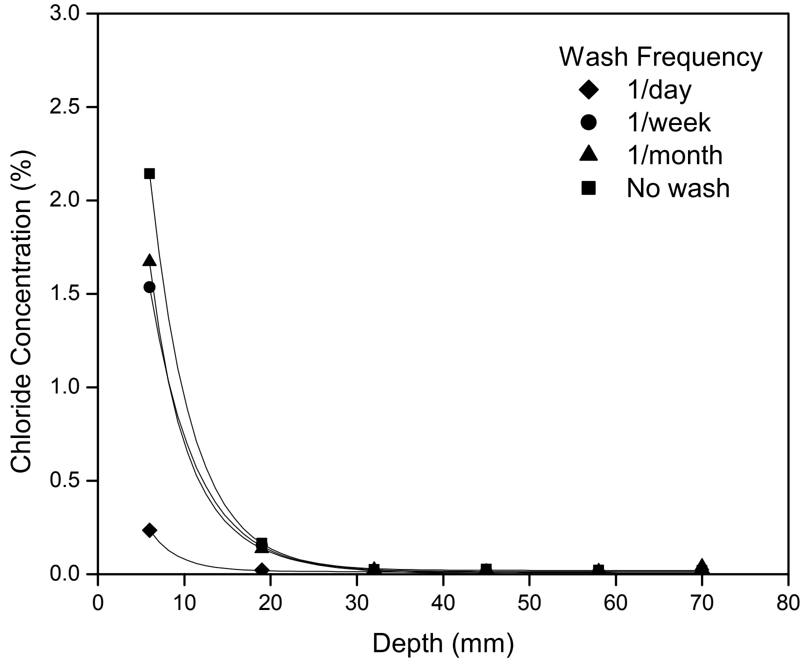

Figure 3.2: Chloride profiles for salt water-sprayed specimens after 25 months of washing

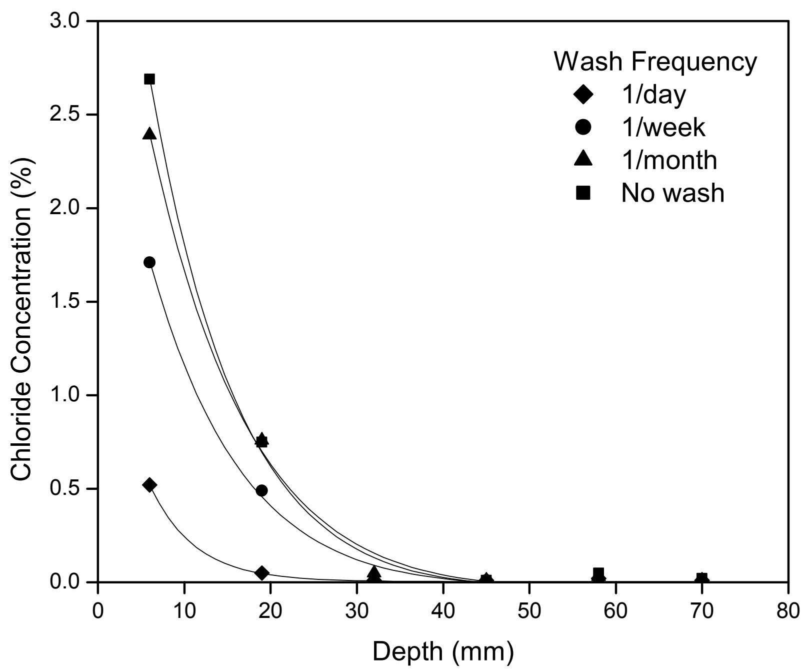

Figure 3.3: Chloride profiles for salt water-sprayed specimens after 49 months of washing

The difference in chloride content can be quantified by comparing the areas under the curves as shown in Table 3.1. Included in Table 3.1 is the percent reduction in chloride content achieved with each washing frequency compared to no washing (wash frequency of 0). Based on the water used and a comparison of the areas under the curve, the data showed that the uptake of chloride ion was reduced by 86% by applying 11 liters/square meter/day of fresh water for 49 months. Applying 11 liters/square meter/week of fresh water reduced the chloride ion uptake by 36%, and applying 11 liters/square meter/month reduced the chloride ion uptake by 5%.

Table 3.1: Percent reduction in chloride ion concentration due to washing

Wash Frequency	25 Months	49 Months
0	15.9	27.4
1/day	1.69 (89%)	3.90 (86%)
1/week	11.7 (26%)	17.4 (36%)
1/month	12.5 (21%)	25.9 (5%)

(Note: Values are the areas under the curves from Figures 3.2 and 3.3, with percent reduction shown in parentheses.)

3.3 DISCUSSION

Clearly, washing with fresh water did not stop the ingress of chloride, but the data showed that frequent washing could appreciably reduce the amount of chloride that would otherwise be taken up by concrete. Unfortunately, daily washing would require installing a sprinkler system, which may not be practical. The results indicated that occasional washing with the expectation of reducing chloride uptake probably has little value.

4.0 CONCLUSIONS

Based on the results of the laboratory tests, the following conclusions can be made:

- Washing with fresh water is ineffective in removing chloride ions from concrete.
- Daily washing with fresh water can appreciably reduce the amount of chloride ion uptake in concrete exposed to salt in the environment.
- Occasional washing to reduce chloride ion uptake is ineffective.

5.0 REFERENCES

AASHTO T178-97. "Cement Content of Hardened Portland Cement Concrete." *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 23rd edition*. Washington, DC: American Association of State Highway and Transportation Officials. 2003a.

AASHTO T260-97. "Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials." *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 23rd edition.* Washington, DC: American Association of State Highway and Transportation Officials. 2003b.

Carter, Paul D. "Preventive Maintenance of Concrete Bridge Decks." *Concrete International.* Vol. 11, Issue 11. pp. 33-36. November 1989.

APPENDICES

APPENDIX A

Chloride results for Field Samples

Table A-1: Percent total chloride per cement from D River Bridge before washing

Location (See Fig. 2.1)	Depth (mm)							
	6	**19**	**32**	**44**	**57**	**70**	**83**	**95**
1	0.38	0.34	0.44	0.38	0.37	0.40	0.38	0.41
2	0.53	1.03	1.47	0.81	0.68	0.57	0.53	0.52
3	0.23	0.16	0.20	0.23	0.19	0.27	0.30	0.35
4	0.30	0.36	0.32	0.38	0.37	0.42	0.44	0.48
5	0.15	0.16	0.15	0.17	0.21	0.22	0.24	0.28
6	0.41	0.47	0.43	0.37	0.31	0.31	0.30	0.34
7	0.13	0.10	0.13	0.14	0.19	0.22	0.26	0.27
8	0.48	0.43	0.35	0.28	0.30	0.32	0.34	0.37
9	0.11	0.15	0.17	0.17	0.19	0.25	0.27	0.32
10	0.24	0.25	0.34	0.29	0.31	0.36	0.40	0.42

APPENDIX B

Chloride Results for Laboratory Samples

Table B-1: Percent total chloride per cement for ponded blocks (no salt spray) before washing
(Note: Two profiles were made for each block.)

Wash Frequency	Profile	Depth (mm)							
		6	19	32	44	57	70	83	95
1/day	1	1.416	0.503	0.148	0.023		0.011	0.008	0.005
	2		0.406	0.016	0.008	0.007	0.007		0.008
	average	1.416	0.455	0.082	0.016	0.007	0.009	0.008	0.006
1/week	1	1.160	0.104	0.011	0.009	0.008	0.009	0.010	0.009
	2		0.182	0.009	0.009	0.012	0.008	0.009	0.007
	average	1.160	0.143	0.010	0.009	0.010	0.009	0.009	0.008
1/month	1	1.946	0.577	0.032	0.012	0.015	0.030	0.013	0.011
	2	1.862	0.418	0.013	0.010	0.009	0.010	0.011	0.009
	average	1.904	0.498	0.023	0.011	0.012	0.020	0.012	0.010
No wash	1		0.893	0.099	0.012	0.012	0.012	0.022	0.011
	2		0.913	0.054	0.009	0.010	0.010	0.009	0.011
	average		0.903	0.076	0.010	0.011	0.011	0.016	0.011

Table B-2: Percent total chloride per cement for ponded blocks (no salt spray) after washing for 25 months
(Note: Two profiles were made for each block, but the powder samples at each depth were combined.)

Wash Frequency	Depth (mm)					
	6	19	32	44	57	70
1/day	0.720	0.271	0.012	0.008	0.013	0.015
1/week	1.521	0.293	0.018	0.021	0.023	0.016
1/month	1.615	0.632	0.056	0.017	0.015	0.029
No wash	1.479	0.486	0.020	0.015	0.015	0.019

Table B-3: Percent total chloride per cement for ponded blocks (no salt spray) after washing for 49 months
(Note: Two profiles were made for each block, but the powder samples at each depth were combined.)

Wash Frequency	Depth (mm)					
	6	19	32	44	57	70
1/day	0.940	0.370	0.010	0.010	0.020	0.010
1/week	1.140	0.540	0.020	0.020	0.020	0.010
1/month	0.660	0.960	0.120	0.010	0.005	0.010
No wash	1.190	0.500	0.020	0.010	0.010	0.010

Table B-4: Percent total chloride per cement for unponded blocks (salt spray) after washing for 25 months
(Note: Two profiles were made for each block, but the powder samples at each depth were combined.)

Wash Frequency	Depth (mm)					
	6	19	32	44	57	70
1/day	0.235	0.023	0.009	0.008	0.009	0.009
1/week	1.536	0.156	0.015	0.015	0.016	0.017
1/month	1.672	0.136	0.025	0.015	0.017	0.043
No wash	2.143	0.165	0.025	0.027	0.022	0.020

Table B-5: Percent total chloride per cement for unponded blocks (salt spray) after washing for 49 months
(Note: Two profiles were made for each block, but the powder samples at each depth were combined.)

Wash Frequency	Depth (mm)					
	6	19	32	44	57	70
1/day	0.520	0.050	0.010	0.010	0.020	0.010
1/week	1.710	0.490	0.010	0.010	0.020	0.010
1/month	2.390	0.760	0.050	0.010	0.030	0.010
No wash	2.690	0.750	0.020	0.010	0.050	0.020