Maintenance Coating of Weathering Steel:

Field Evaluation and Guidelines

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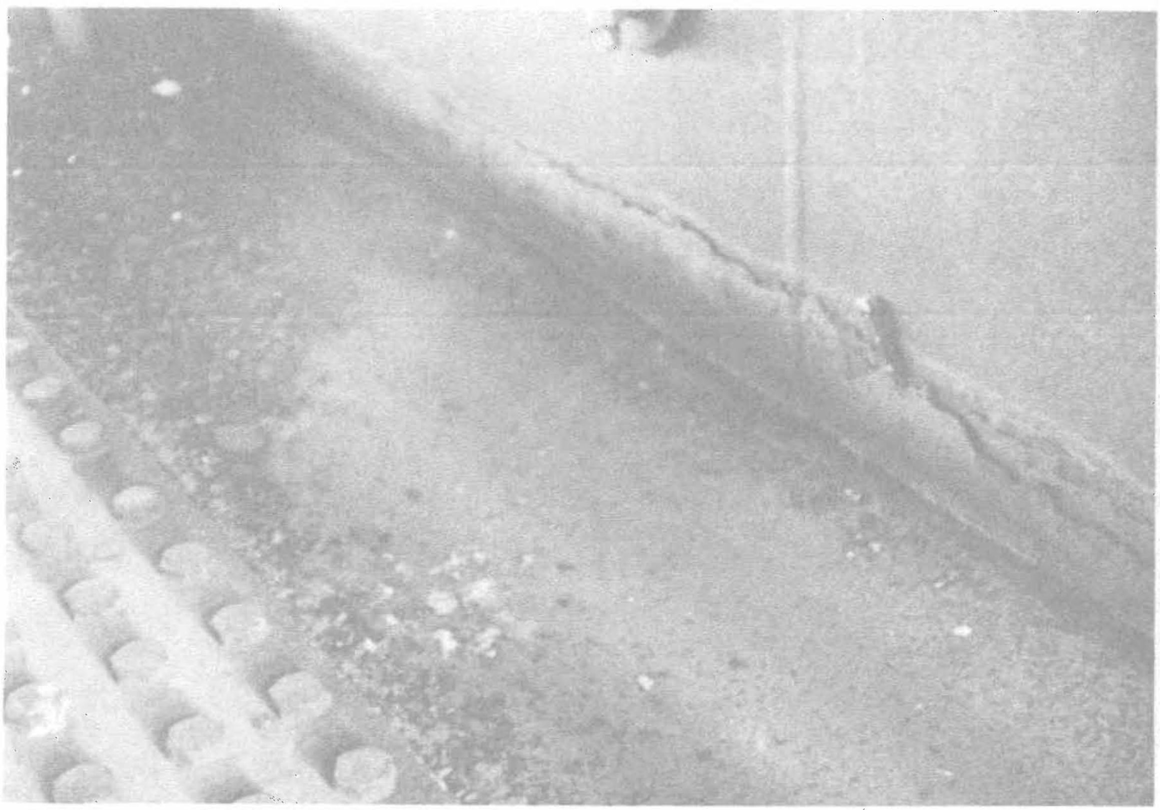

U.S. Department of Transportation

Federal Highway Administration

Research and Development
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FOREWORD

This report presents of research and evaluation of a range of protective coatings for use in maintaining weathering steel bridges. Different surface preparation methods and exposure regimes (both test fence and bridge sites) were used in the evaluations. Based on the results, a set of guidelines was developed for maintenance coating of weathering steel bridges; these guidelines were keyed to three field exposure possibilities, viz., new A-588 steel (high-chloride). This report will be of interest to bridge, material, and maintenance engineers concerned with maintaining weathering steel bridges.

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Director, Office of Engineering and Highway Operations Research and Development

NOTICE

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16. Abstract
This report describes a 4-year bridge and test fence evaluation of protective coatings for maintaining weathering steel bridges. The test specimens consisted of steel panels cut from existing aged weathering steel bridges, along with some new mill scale bearing weathering steel as a control. The condition of the specimens ranged from extensively pitted and corroded (from chloride exposure) to mildly corroded and non-pitted. Specimens were cut from angle irons, stiffeners, cover plates, and web areas of bridges.

Three methods of surface preparation were used: dry abrasive blasting, wet abrasive blasting and power tool cleaning using rotary peening and non-woven abrasive discs. The chloride levels of the test specimens were measured after surface preparation to determine the coatings' ability to tolerate different levels of chloride or other soluble salts on the surface. Chloride levels measured ranged from less than 5 to 150 $\mu g/cm^2$.

The test specimens were exposed at five sites, which included three bridges (Michigan, Pennsylvania and Louisiana) and two test fence locations: a severe marine site and a moderate industrial site. The following six coating systems were applied to each combination of surface preparations, steel conditions, and sites: epoxy zinc rich system, urethane zinc-rich system, epoxy mastic system, ethyl silicate zinc/vinyl system, water-borne alkali silicate/acrylic system, and oil-alkyd control. Additional systems tested included a thermal spray zinc system and a low-VOC ethyl silicate system.

The rusting and scribe undercutting of the test panels were evaluated over a 4-year period. The data were analyzed using comparison of means, analysis of variance, and linear correlation methods. The effect of each variable was evaluated and a comparison made between the ranking of the coatings in the field testing compared to the various types of laboratory testing. A total of 564 specimens was included in the test matrix. Each combination of surface preparation, coating system, substrate type, and test site was replicated.

Based on these data and evaluation of other bridge studies, a set of guidelines was developed for maintenance coating of weathering steel bridges. Recommendatons were given for three field conditions: new A-588, non-corroded weathered A-588 (low-chloride) and corroded (weathered) A-588 (high chloride). Recommendations were also based on the bridge exposure conditions which were classified as severe or mild/moderate.

Under this project, the following previous report was issued: "Maintenance Coating of Weathering Steel: Interim Report," FHWA RD-91-087, December 1991 (SSPC report 91-04).

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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		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

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		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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I. INTRODUCTION

A. NEED FOR STUDY

Weathering steel, introduced in the 1960's, is high strength steel containing low amounts of chromium and other alloys, which offers improved corrosion resistance compared to carbon steel. It was generally erected without painting. In recent years, however, it has been recognized that in areas of high humidity and condensation, and where chlorides can accumulate, severe corrosion, scaling, and pitting of weathering steel can occur. Bridges in these environments require corrosion protection by painting to avoid potential metal loss.

Painting of new uncontaminated weathering steel is generally not considered a problem. Test fence and laboratory data developed by the paint industry have indicated that conventional coating systems such as oil alkyds and epoxies will perform comparably on weathering steel and on carbon steel if the degree of surface preparation is equivalent.

The major problem faced by highway departments and other owners of weathering steel structures is protecting weathering steel that has corroded in the presence of chlorides and other contaminants. Conventional cleaning techniques such as dry abrasive blasting do not remove the chlorides, which apparently penetrate the bases of pits in the steel. The performance of standard highway coatings such as oil alkyd, epoxies, and zinc-rich systems over chloride contaminated steel has not been satisfactory.

The problems posed by maintenance of weathering steel structures have been the subject of numerous studies. A comprehensive literature survey was conducted as part of the interim report of this work, additional pertinent material has subsequently been issued under the National Cooperative Highway Research Program (NCHRP), and guidelines on maintenance of uncoated weathering steel structures have been formulated by the Federal Highway Administration (FHWA).[1,2,3]

B. OBJECTIVE AND APPROACH

The principal objective of this program was to establish techniques, procedures, and guidelines for maintenance cleaning and coating of bridges constructed of weathering steel.

The first step was to review the existing literature to determine the extent and nature of the problem and to identify the chemical and physical processes and factors associated with this phenomenon.

Because of the critical importance of the surface condition to coating durability, a major effort was directed at the surface cleanliness of the steel. In particular, the role of chlorides in accelerating metallic corrosion and the paint degradation was studied.

Two aspects were considered: analysis of surface cleanliness and method of surface cleaning. A technique for detecting and measuring the amount of chloride or other soluble salt on the surface was developed. The goal was to provide a method which can be readily used in the field. It was first necessary to establish a standard laboratory reference technique to verify the accuracy and precision of any field technique.

The cleaning methods considered included standard surface preparation techniques such as dry abrasive blasting, various forms of wet and water blasting, along with other special techniques such as chemical or heat treatment of the surface. Each method was evaluated for its effectiveness in removing chloride as well as its practicality and suitability as a field cleaning technique.

Both of the above aspects of this research effort were reported in detail in the interim report describing the laboratory testing efforts.(1)

Although it would be desirable to remove all, or essentially all, of the chloride from the surface, this may not be economically feasible for most structures. Of principal interest was how the chloride remaining on the surface affects the adhesion and durability of the coating system.

The next step was, therefore, to evaluate the performance of candidate coating systems applied over surfaces containing varying levels of chloride. Coatings were selected on the basis of commercial availability, demonstrated performance under adverse circumstances, and practicality for field application.

Substrates used for this testing included actual specimens cut from corroded highway bridges to provide representative surface conditions.

The testing and evaluation of coatings was conducted in two phases. In the first (or screening phase) coatings were examined in laboratory accelerated aging tests. These tests are suitable for identifying in a relatively short time period, particularly poor coatings. Such coatings could be eliminated prior to the more costly and time consuming field exposures. The screening tests also provide information on the relative severity of the various substrates and on the type of failure which occurs in the candidate coating systems.

The ultimate test of the coating systems durability and suitability were the field exposure tests. These were conducted at aggressive highway bridge sites and offer the following major advantages:

- The substrates include pieces of angle and plate cut from previously exposed highway bridge steel. Thus, coatings were tested on angles and T's rather than on flat plates. The specimens also contained built up corrosion products and embedded chloride exactly as they occur on the bridges.

- The test specimens were exposed at some of the most corrosive areas of the bridges (i.e., under leaking deck joints, exposed to traffic splash). Thus the coating systems were exposed and evaluated at the precise environments where they are required to protect against corrosion.

- The test specimens consisted of small individual angles and plates. This feature allowed all the specimens to be coated under controlled and uniform circumstances, thus reducing the influence of application as a variable. In addition, because the specimens were small and numerous, a statistical design could be applied to the placement of the specimens and through the use of replicates.

The coating systems were monitored and evaluated for up to 4 years. This permitted the observation and recording of coating surface and underfilm degradation that takes some time to develop. It also allowed for relatively reliable estimates of the coating effectiveness and lifetime.

Based on all the above results, a set of guidelines has been prepared on how to maintain and protect weathering steel bridges. The guide provides the following type of recommendations:

- Techniques for evaluating the severity of the exposure and the extent of corrosion and surface contamination.

- Suitable techniques for preparing the surface and determining the degree of cleanliness.

- Suitable coating systems for various types of bridge exposures.

- General information about which structures or portions of structures require protective coatings.

II. FIELD EVALUATION OF COATINGS

A. DESIGN OF FIELD EVALUATION OF COATINGS

Based on the results from the laboratory phase of this project an experimental design was developed for field evaluation trials of coating systems for chloride-contaminated weathering steel. The design elements discussed are substrate, surface preparation, coatings, sample preparation, and sites.

1. Substrate

The main requirement was that the coating systems be tested over surfaces having contamination representative of bridges exposed to high salt environments. Thus, a major emphasis was on obtaining actual specimens of bridge steel which had been exposed to such conditions. The test design also included weathering steel having lower amounts of chloride. This was necessary because information was needed on coating performance on bridge areas which do not receive direct chloride leakage or splash. These areas may represent the majority of the surface area of the steel, including flange areas remote from joints and roadways, and web sections. The large beam from the New Jersey Turnpike was considered ideal for this requirement. The control substrate was as-received mill scale-bearing A 588. The control would also provide information on the relative merit of painting the steel when new.

2. Surface Preparation

The accelerated laboratory test data had shown that coatings applied over wet blasting had blister resistance slightly superior to coatings applied over dry blasting. Field testing performance of coatings applied over both methods of cleaning was needed to determine if these preliminary conclusions would be corroborated. The use of fine abrasives, ultrahigh pressure water jetting, and combinations of alternating blast and rinse cycles were not included, because the laboratory test data had shown them not to provide any advantage over conventional wet and dry blasting. It was felt preferable to use more panels and sites with fewer surface preparations to increase the precision and validity of the experiment.

Power tool cleaning to bare metal was included as a branch in the experimental design because performance of repair coatings had shown substantial improvements over hand tool cleaning and could provide a possible alternative means of preparing surfaces when blasting is restricted.

3. Coatings

The coatings were selected based on the results from the laboratory tests, experienced States and industry, and recommendations by the FHWA Contracting Officer's Technical Representative (COTR). The control coating system was a lead-containing oil alkyd system, Federal Specification TT-P-615, equivalent to AASHTO M-229. A summary of the systems is presented in table 1. In the laboratory testing, two-coat systems had been used in order to provide systems that would show failure in relatively short time intervals. For the field evaluations it was decided to use the full-protection systems recommended by the manufacturers, which generally

Table 1. Coatings used in field exposures.

System		Primer, Intermediate, and Topcoats		Target DFT per coat (mils)	Target DFT per coat (microns)
1	oil-alkyd/alkyd (control)	1	oil/alkyd, basic lead silico-chromate (TT-P-615, II)	1.5-2.5	38-64
		2	oil-alkyd	1.5-2.5	38-64
		3	alkyd (SSPC Paint 104)	1.5-2.5	38-64
			System Target Range —>	4.5 - 7.0	125-175
2	inorganic zinc/vinyl HB	1	ethyl silicate inorganic zinc (2-package)	2.0-4.0	50-100
		2	vinyl high build	2.0-4.0	50-100
		3	vinyl	1.0-2.0	13-25
			System Target Range —>	5.0-10.0	125-250
3	epoxy zinc/epoxy/ urethane	1	zinc-rich epoxy-polyamide (2-package)	2.0-4.0	50-100
		2	epoxy polyamide high build	4.0-6.0	100-150
		3	aliphatic urethane	1.5-2.5	38-64
			System Target Range —>	8.0-12.0	200-300
4	epoxy mastic/ urethane	1	penetrating epoxy primer (100% solids)	0.5-1.0	13-25
		2	epoxy polyamide high solids mastic	4.0-8.0	100-200
		3	epoxy polyamide high solids mastic	4.0-8.0	100-200
		4	aliphatic urethane	1.5-2.5	38-64
			System Target Range —>	10.0-18.0	250-450
5	zinc urethane/epoxy/	1	moisture-cured zinc-filled urethane (1-package)	2.0-4.0	50-100
	urethane	2	epoxy polyamide high-build	2.5-4.0	64-100
		3	aliphatic urethane	1.5-2.5	38-64
			System Target Range —>	6.0-10.0	150-200
6	water-borne zinc/acrylic	1	water-borne alkali silicate inorganic zinc (self-cure)	3.0-5.0	75-125
		2	water-borne acrylic	2.5-3.5	64-89
		3	water-borne acrylic	2.5-3.5	64-89
			System Target Range —>	8.0-11.0	200-275
7	zinc flame spray	1	**System Target Range —>**	4.0-6.0	100-150
8	low-VOC inorganic zinc urethane	1	low-VOC (3.5 lb/gal [420 g/l) ethyl silicate inorganic	2.0-3.0	50-75
		2	low-VOC high-build aliphatic urethane	3.0-5.0	75-125
			System Target Range —>	5.0-8.0	125-200

included three coats: primer, intermediate, and topcoat. Because of the level of contamination of the surfaces, the severity of the exposure environment, the 5-year exposure time, and limited resources, only the systems having the greatest chance of providing long-term durability and protection as identified previously were evaluated.

The following systems were selected:

1. Three-coat oil alkyd system (two coats of TT-P-615 [oil alkyd with basic lead silico-chromate] and alkyd topcoat)

Although it did not perform well in salt spray, this system is a standard which is extensively used by highway departments. It was included primarily as a control as the continuous use of lead or chromate containing coatings has been discouraged. In addition, despite the salt spray shortcomings, it has given very good field performance on carbon steel and also in some limited evaluations on field weathering steel.

2. Inorganic zinc (ethyl silicate)/vinyl high-build/vinyl topcoat

This system is also widely used among highway agencies. It was selected despite its relatively poor performance of the topcoated system in the salt spray test.

3. Zinc-rich epoxy-polyamide/high-build epoxy/urethane

This system was among the best in the laboratory testing. It was also the system recommended for use on chloride-contaminated weathering steel by both Michigan and Texas DOT's.

4. Penetrating epoxy primer/high-solids epoxy mastic/urethane topcoat

This system had the highest overall ratings of the coatings tested over hand cleaned weathering steel. It had also shown good performance in other evaluations over hand cleaned weathering steel and carbon steel.

5. Zinc-filled moisture-cured urethane/high-build epoxy/urethane

This system had given best overall performance of the coatings tested in branch A (blast cleaned steel) in immersion, salt spray, and UV-Con/Freeze-Thaw.

6. Water-based inorganic zinc primer (two-package)/water-based acrylic topcoat (two-coat)

This system, though not tested in the laboratory phase, was added to the matrix for field evaluations at the request of the COTR. The rationale was that there was an urgent need for systems that would be Volatile Organic Content (VOC) compliant in addition to meeting the performance requirements. The system had met with success in some limited application and laboratory evaluations by a fabricator and a highway department.

7. Thermal spray zinc/sealer/topcoat

This system had given outstanding performance in salt spray testing. The metallic zinc coating is also a solvent free system and therefore does not contribute to the VOC emissions.

8. Low-VOC ethyl silicate zinc-rich primer/low-VOC urethane

This system was designated as a low-VOC alternative (less than 3.5 lb/gal [420 g/l]) to the inorganic zinc vinyl system. This system was applied to a limited number of test specimens in field exposures at the request of the COTR.

9. Coatings not included in field trials

The polar wax coating, which had done very poorly in salt spray and had poor application and handling properties, was deleted. In addition the second urethane system (system 6 in chapter 5 of the interim report) was excluded because it had the poorest performance of the coatings tested over blast cleaned steel. In the field evaluation trials, only one epoxy-zinc system was chosen, as opposed to the two tested in the laboratory phase.

Because of limitations in the number of specimens available for testing, the distribution of coating systems was not equal at each site for every substrate, a summary of the site distribution of coated specimens is given in table 2.

4. Sample Preparation

Sample Selection

With the exception of the A 588 steel control panels (uncontaminated), all samples would be obtained from steel sections retrieved from actual weathering steel bridges. The samples used afforded a wide range of substrate contamination and degree of corrosion. The typical ranges of contamination levels for each surface preparation and substrate configuration are estimated (table 3). The estimates are based on the results of salt retrieval experiments performed on statistical pulls from the total population of panels performed in the laboratory phase of this work.

Sample Cutting

The various steel sections obtained earlier in the study were cut up into samples according to the general layout shown in figures 1 and 2. Three distinct types of samples were made available for the field evaluation phase. Most samples consisted of inverted T sections derived by slicing of an I-beam along the center point of the web section. Examples of resultant T sections include Maryland bottom T's, Maryland top T's and Louisiana top and bottom T's. Other sample configurations included L's cut from angles and flat plates cut from various plate sections, which were obtained from A 588 steel provided by the Ontario Ministry of Transportation. Cutting plans are shown in figures 3 and 4 for these sections.

All steel sections were initially cut into manageable pieces by torch. These torch-cut sections were then further divided into standard sample sizes by dry cutting with a mechanical

Table 2. Experimental design of field exposures.

Sample Origin	Surface Preparation	Chloride Level [1] µg/cm2	Exposure Site and Paint Systems Employed [2]				
			Neville	Michigan	Louisiana	Pennsylvania	Kure
A588 Steel	Dry Blast	4	1,2,3,4,5,6,7,8	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6,7	1,2,3,4,5,6,7
A588 Steel	Wet Blast	8	1,2,3,4,5,6,7,8	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6,7	1,2,3,4,5,6,7
A588 Steel	Power Tool	8				1,2,3,4,5,6	
Louisiana T-Piece	Dry Blast	25			1,2,3,4,5,6		
Louisiana T-Piece	Wet Blast	35			1,2,3,4,5,6		
MD T-Salted	Dry Blast	30	1,2,3,4,5,6,7,8	1,2,3,4,5,6		1,2,3,4,5,6,7	1,2,3,4,5,6,7
MD T-Salted	Wet Blast	50	1,2,3,4,5,6,7,8	1,2,3,4,5,6		1,2,3,4,5,6,7	1,2,3,4,5,6,7
MD T-Salted	Power Tool	150				1,2,3,4,5,6	1,2,3,4,5,6
MD T-unsalted	Dry Blast	20	1,2,3,4,5,6,7,8	1,2,3,4,5,6		1,2,3,4,5,6,7	1,2,3,4,5,6,7
MD T-unsalted	Wet Blast	30	1,2,3,4,5,6,7,8	1,2,3,4,5,6		1,2,3,4,5,6,7	1,2,3,4,5,6,7
NJ Bridge	Dry Blast	12	1,2,3,4,5,6,7				
NJ Bridge	Wet Blast	10	1,2,3,4,5,6,7				
Ontario Angle	Dry Blast	2	1,2,3,4,5,6		1,2,3,4,5,6		
Ontario Angle	Wet Blast	2	1,2,3,4,5,6		1,2,3,4,5,6		
Ontario Coverplate	Dry Blast	2	1,2,3,4,5,6,7			1,2,3,4,5,6,7	
Ontario Coverplate	Wet Blast	2	1,2,3,4,5,6,7			1,2,3,4,5,6,7	
Ontario Coverplate	Power Tool	3				1,2,3,4,5,6	

[1] Surface contamination levels derive from statistical sampling of panels prepared, as reported in interim report, reference 1.

[2] See table 1 for descriptions of individual coating systems.

Table 3. Average rusting data from final year of field exposure.

Site	Specimen Type	Salt Level	Surface Preparation	Coating Systems[1] 1	2	3	4	5	6	7	8	Average Per Substrate Systems 1-7	Average per Substrate Systems 1-6
KURE	A588	5	DB	10	10	10	9.5	10	8	10		9.64	9.58
KURE	A588	8	WB	10	10	10	10	10	6.5	10		9.50	9.42
KURE	MTS	30	DB	9.5	8.6	8.8	7.6	8.7	5.5	10.0		8.38	8.11
KURE	MTS	150	PT	8.3	7.6	7.5	5.4	6.6	6.4			6.96	6.96
KURE	MTS	50	WB	9.5	8.6	8.8	8.6	8.9	6.3	10.0		8.67	8.45
KURE	MTU	20	DB	9.8	10.0	10.0	9.3	9.7	6.8	10.0		9.35	9.24
KURE	MTU	30	WB	9.7	9.6	8.8	9.1	9.3	6.9	10.0		9.06	8.90
LA	A588	5	DB	9.0	9.5	8.5	8.0	9.0	6.5				8.42
LA	A588	8	WB	9.0	10.0	9.0	8.0	8.5	6.0				8.42
LA	LATS	25	DB	8.8	9.9	8.3	10.0	8.9	6.2				8.68
LA	LATS	35	WB	8.9	9.8	8.4	8.3	8.8	6.2				8.38
LA	ONTANG	3	DB	7.8	9.7	8.8	8.6	8.7	7.7				8.53
LA	ONTANG	2	WB	7.6	9.8	8.7	8.2	8.7	6.5				8.23
MI	A588	5	DB	10.0	9.7	10.0	9.5	10.0	8.3				9.58
MI	A588	8	WB	10.0	10.0	10.0	10.0	10.0	8.2				9.69
MI	MTS	30	DB	9.3	9.8	9.4	9.3	9.8	8.9				9.43
MI	MTS	50	WB	9.5	10.0	8.9	9.5	9.6	8.2				9.30
MI	MTU	20	DB	10.0	10.0	10.0	9.8	9.5	8.8				9.67
MI	MTU	30	WB	9.9	10.0	9.7	9.9	9.9	8.7				9.69
NEV	A588	5	DB	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.00	10.00
NEV	A588	8	WB	10.0	10.0	10.0	10.0	10.0	10.0	10.0		10.00	10.00
NEV	MTS	30	DB	10.0	10.0	10.0	10.0	10.0	9.7	10.0	10.0	9.95	9.94
NEV	MTS	50	WB	10.0	10.0	9.7	10.0	10.0	9.2	10.0	10.0	9.85	9.81
NEV	MTU	20	DB	10.0	10.0	10.0	10.0	9.9	9.5	10.0		9.92	9.91
NEV	MTU	30	WB	10.0	10.0	10.0	10.0	10.0	9.5	10.0	10.0	9.94	9.92
NEV	NJBR	12	DB	10.0	10.0	10.0	10.0	10.0	10.0	10.0		10.00	10.00
NEV	NJBR	10	WB	10.0	10.0	10.0	10.0	10.0	10.0	10.0		10.00	10.00
NEV	ONTANG	3	DB	10.0	10.0	10.0	10.0	10.0	9.2				9.86
NEV	ONTANG	2	WB	10.0	9.8	9.9	10.0	10.0	8.5				9.69
NEV	ONTCOV	3	DB	10.0	10.0	10.0	10.0	10.0	10.0	10.0		10.00	10.00
NEV	ONTCOV	4	WB	10.0	10.0	10.0	10.0	10.0	10.0	10.0		10.00	10.00
PABR	A588	5	DB	9.7	10.0	10.0	9.9	10.0	9.9	10.0		9.91	9.90
PABR	A588	8	PT	9.7	10.0	9.9	0.0	9.9	8.5				7.98
PABR	A588	8	WB	9.9	9.7	10.0	10.0	10.0	8.5	10.0		9.71	9.67
PABR	MTS	30	DB	9.1	9.1	9.3	9.1	9.8	7.3	9.9		9.07	8.94
PABR	MTS	150	PT	9.1	5.1	9.3	8.5	9.4	7.9				8.21
PABR	MTS	50	WB	8.8	8.9	9.2	9.2	9.6	7.4	9.9		9.01	8.85
PABR	MTU	20	DB	9.4	9.8	9.9	9.6	9.8	8.3	9.9		9.52	9.46
PABR	MTU	30	WB	9.5	9.8	9.3	9.6	9.8	7.9	9.9		9.38	9.30
PABR	ONTCOV	3	DB	10.0	10.0	10.0	10.0	10.0	7.5	10.0		9.64	9.58
PABR	ONTCOV	4	PT	9.7	10.0	10.0	8.5	10.0	7.0				9.19
PABR	ONTCOV	4	WB	9.9	10.0	10.0	10.0	10.0	8.9	10.0		9.81	9.78
AVERAGE for Dry Blasting				9.67	9.80	9.62	9.00	9.71	8.21	9.99	10.00	9.66	9.33
AVERAGE Wet Blasting				9.56	9.84	9.54	9.44	9.62	8.16	9.99	10.00	9.59	9.36
AVERAGE Power Tool Cleaning				8.90	7.86	8.97	8.17	8.84	7.49			8.49	8.37
AVERAGE Overall For Systems 1-6				9.55	9.63	9.52	9.12	9.59	8.12			9.49	9.25

Key Samples: A 588 = Control Panels; MTU = Maryland T Unsalted; MTS = Maryland T Salted; NJBR = New Jersey Bridge Steel; OntAng = Ontario Angle; OntCov = Ontario Cover Plate.
Key Sites: PABR = Pennsylvania Bridge; LA = Louisiana Bridge Site; MI = Michigan Bridge Site; Kure = La Que Corrosion Center, Kure Beach (25 m lot); NEV = SSPC Neville Island Site, (Pitt Des Moines Steel).
Key Surface Preparation: DB = Dry abrasive blasting; WB = Wet abrasive blasting; PT = SSPC SP 11 Power Tool Cleaning.

[1] Coating systems are described in table 1.

- System 1 oil-alkyd/alkyd (control)
- System 2 inorganic zinc/vinyl HB
- System 3 epoxy zinc/epoxy/urethane
- System 4 epoxy mastic/urethane
- System 5 zinc urethane/epoxy/urethane
- System 6 water-borne zinc/acrylic
- System 7 zinc flame spray
- System 8 low-VOC inorganic zinc/urethane

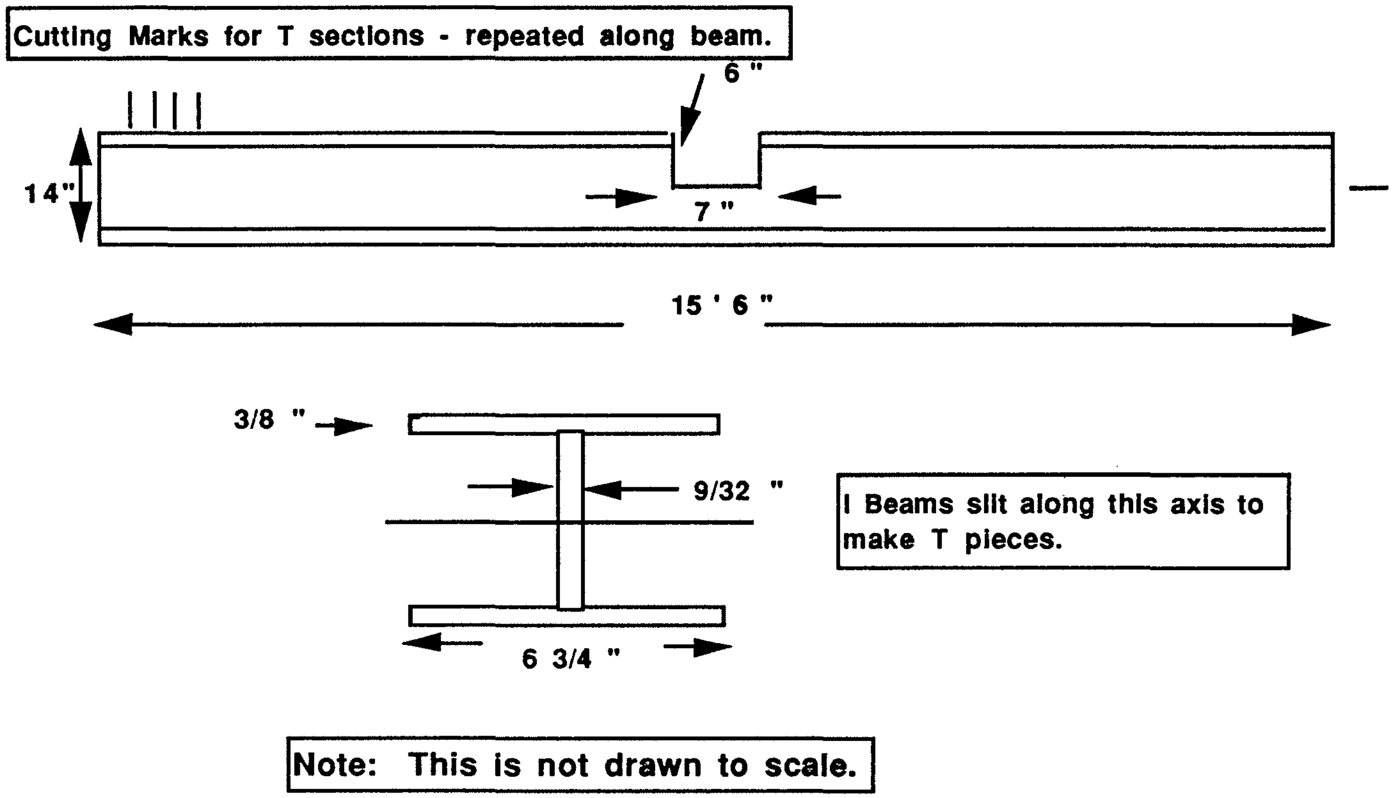


Figure 1. Cutting plans for typical Maryland beam to create T sections.

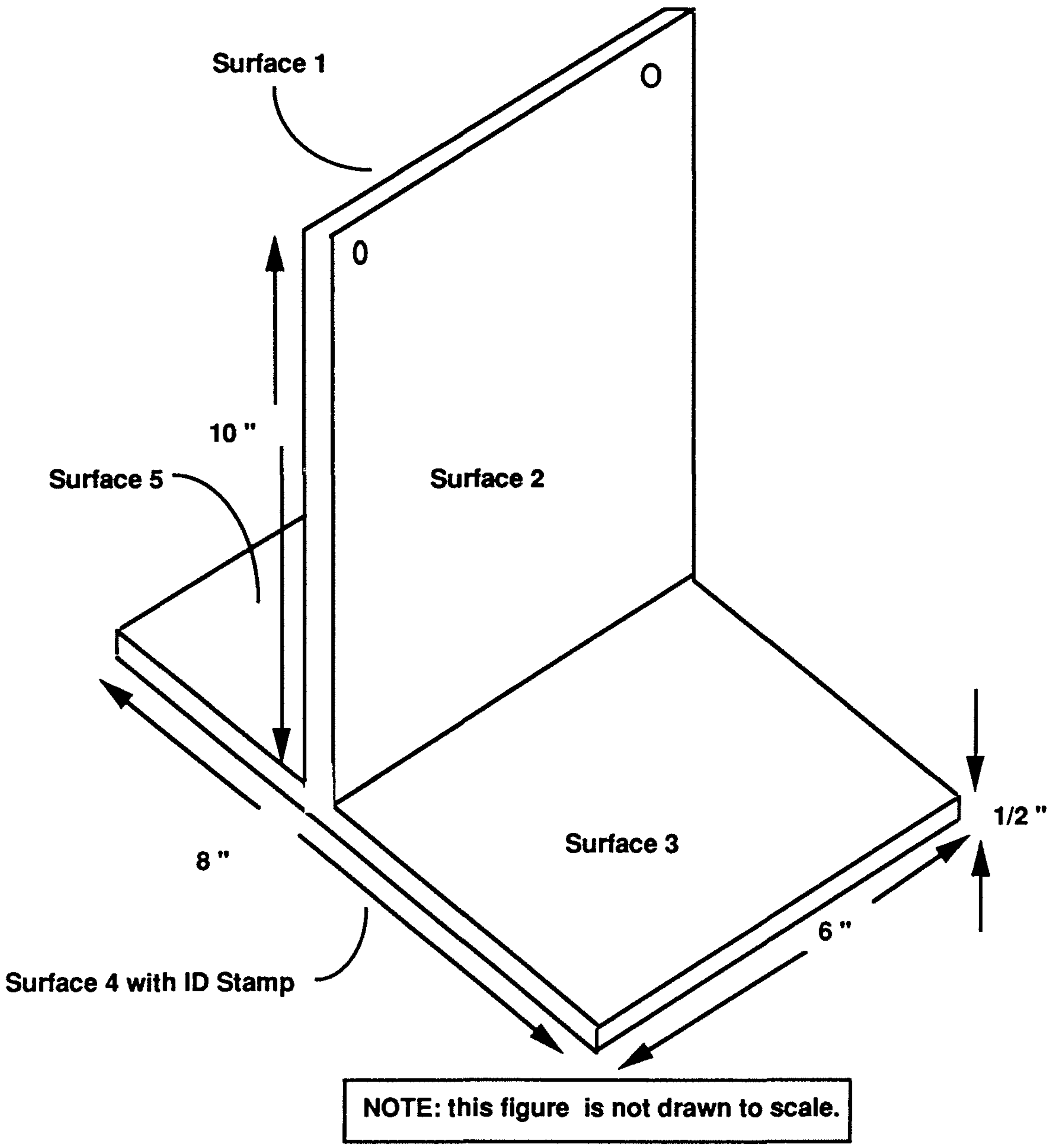


Figure 2. Finished disposition of T pieces after cutting.

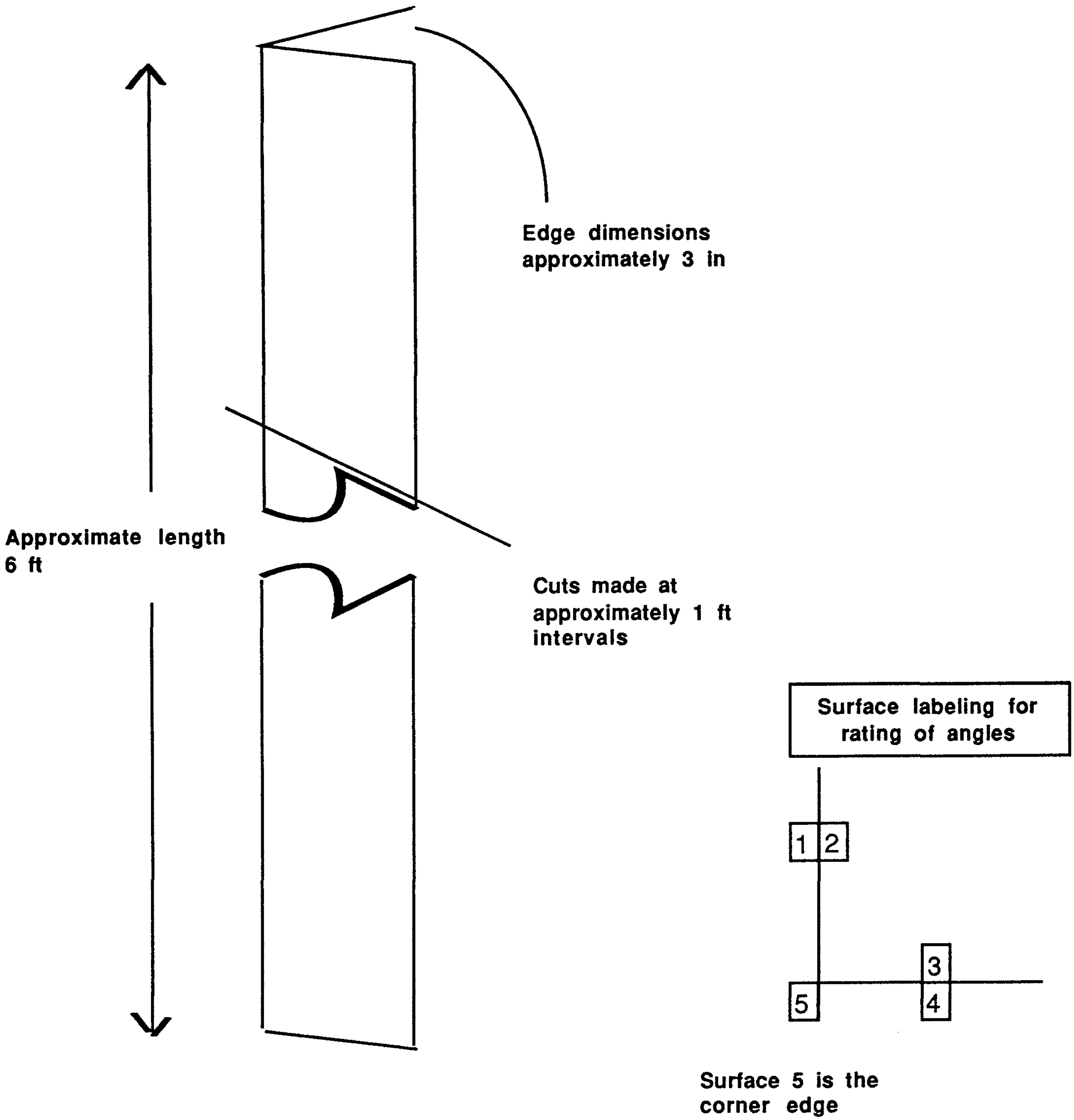
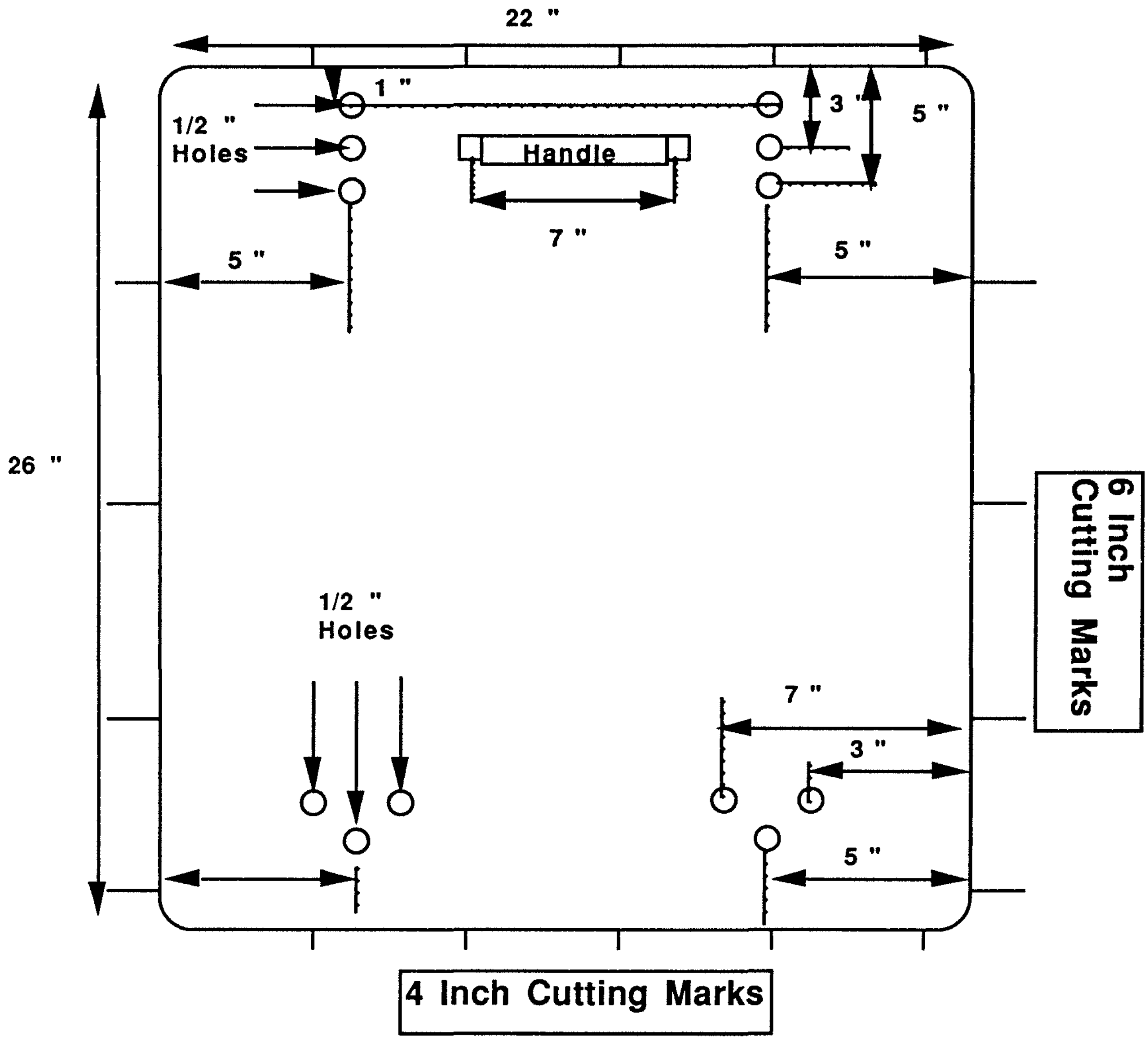


Figure 3. Representation of cutting plan for Ontario angle specimens.



Note: Not all of the cover plate could be used, certain sections had to be discarded. This figure is not drawn to scale.

Figure 4. Ontario Ministry of Transportation hatch cover plate configuration and cutting plan.

saw. Burnt areas were cleaned using power tools to remove slag and spatter, yet a few samples used still had rougher panel edges due to previous torch cutting. This did not present a problem because edge effects were discounted in subsequent evaluations of coating systems applied to these panels.

To prepare the samples for placement in the field on bridges, holes were cut in the web section of the panels by drilling.

Surface Preparation

Three separate surface preparation methods were used. Dry abrasive sandblasting was the first, second was wet abrasive blasting, third was power tool cleaning to bare metal. Both abrasive blasting methods sought to achieve a Steel Structures Painting Council (SSPC)-SP 10 "Near White Metal" finish. The power tool cleaning was to meet the requirements of SSPC-SP 11 "Power Tool Cleaning to Bare Metal," this was achieved using a double pass of cleaning with "Kleen and Strip" discs followed by profiling the surface with a Roto-Peen impact shot power tool.

Coating Application

All coating applications, save that of the thermal spray zinc, system 7, were conducted at the shop facilities of Pittsburgh Des Moines Steel on Neville Island, Pennsylvania. At the time coatings were applied the ambient temperature was in the 90 to 95 °F (32 to 35 °C) range. This did not affect the application of any of the organic coatings, nor that of the ethyl silicate inorganic zinc coatings. For the application of the high ratio silicate, water-borne inorganic zinc applications were conducted in the presence of a manufacturer's representative. The representative's presence was requested because it was the first time that this material had been employed in this test program. It was noted that the high temperature conditions induced very rapid drying of the water borne inorganic zinc (this will be referred to later in discussing the results from the field evaluations).

Following application of each component of the coating systems, readings of dry film thickness were taken in accordance with SSPC-PA 2, "Measurement of Dry Film Thickness Using Magnetic Gages." The dry film thickness readings and statistics for the same are summarized in appendix 1.

The application of the thermally sprayed zinc coatings took place at the shop facilities of ASBM Inc. in Barberton, Ohio.

Post Application Treatments

After samples were coated all edges of the samples were protected from undercutting and early failure by the application of two or more coats of SSPC Paint 9, Vinyl Paint. This same edge protection was also used to protect against undercutting at holes cut for hanging panels on bridge sections.

A deliberate defect in the form of a vertical scribe was placed onto all flat panel sections and L sections. No deliberate defect was placed on the T sections cut from the supplied I-beams.

5. Exterior Exposure Sites

The test sites selected included three bridge locations in Michigan, Louisiana, and Pennsylvania, and two standard SSPC exposure locations, marine (Kure Beach, North Carolina) and industrial (Neville Island, Pittsburgh, Pennsylvania). The coating systems used at each field site testing are summarized in table 2.

Exterior exposures are considered the most representative means of evaluating coating performance. Despite the assurance that real effects of road salt, marine and industrial pollutants, sunlight, and rainfall will cause coating deterioration, these factors are not uniform from site to site. Corrosion rate monitors comprised of blasted carbon steel plates were placed at each site to determine its severity. The rate of metal weight loss from these coupons is used as a measure of the aggressiveness of the exposure site. This technique was used for the Kure Beach, Neville Island, and Pennsylvania bridge sites. No corrosion monitoring was performed on the bridge sites in Michigan and Louisiana. For these sites an estimate of environmental severity can be made based on the corrosion rate of the A 588 steel bridges where the panels were exposed.

The expected order of site severity, based on corrosion of bare A-588 steel is as follows: Kure Beach > Pennsylvania Bridge > Louisiana Bridge > Michigan Bridge >> Neville Island.

Each site also can be considered in terms of a microclimate (a description of each site in these terms follows). The microclimate is composed of the general location of the exposure site and the disposition of the panels within that site. Differences in microclimate can have a significant impact on the rate of deterioration of coated specimens. The actual severity of each site will be decided by a combination of local climactic conditions and corrosivity. The only true measure of site severity within this experiment will be the relative performance of identical coatings placed on identical surfaces.

Neville Island Site

In addition to being the site with the lowest overall severity in the series for outdoor exposures, Neville Island exposures were made more temperate because of the means by which the panels were exposed. Panel racks consisted of trestles with an exposed center section where the panels rested with their outer edges supported by the inner sections of each horizontal trestle. Packed close together, they formed an inverted T section with the bottom flange down. This arrangement still allowed drainage between panels and free air circulation under the panels. The areas under a bridge with high times of wetness would not be adequately mimicked with such a sample disposition. This creates a milder microclimate for panel exposure. The innate corrosivity of the site is also lower than several others.

Pennsylvania Bridge Site

At the Pennsylvania bridge site panels were exposed by attachment to wooden beams using galvanized bolts and insulating washers. The beams were set along the axis of the supporting steel beams above which rested open grating that formed the travelled road surface. The distance between the panels and the stream below was about 7 ft (2.1 m), but at times of high rainfall, the panels could be temporarily immersed along with the steel supporting beams. Being in close proximity to the water line, and being partially sheltered from sunlight, the microclimate was one with a high time of wetness. Finally the open grating permitted passing traffic to deposit road salts, grit, dirt and other contaminants onto the panels, these deposits would accumulate increasing the time of wetness on the upper surfaces of the flanges. For these reasons the Pennsylvania site is considered more aggressive than Neville Island in the field evaluation.

Michigan Bridge Site

Panels were affixed to supporting structural sections of an inside girder overpass structure in a manner similar to that employed at the Pennsylvania site. The positioning of the panels was such that they would experience deposition of road salts and a high time of wetness. The extensive use of road salts in the Detroit area and the panel disposition helps make this a very aggressive site.

Louisiana Bridge Site

The Louisiana site also involved panels placed under the bridge deck where low sunlight created a high time of wetness. Unlike the Michigan exposures, this bridge site is a marsh crossing near the coast. Saline conditions, elevated temperature, and the uniformly higher humidity of this site also increase the severity of exposure.

Kure Beach Site

Exposures at Kure Beach were conducted at the 25 m (80 ft) lot. This site is recognized as one of the most corrosive and aggressive sites in North America. It was the one used for initial testing of the utility of low alloy high strength steels during their development. Characterized by high salt mist deposition rates, intense solar irradiation, and long times of wetness, the Kure Beach site is always a severe test for coated steel products.

A summary of the experimental design is as follows:

- Coating System: Eight systems in total, the first six of which are exposed at all sites.
- Surface Preparation: Three methods in total, wet or dry abrasive blasting and power tool cleaning; only the blast cleaning methods are represented at all sites.
- Specimen Type: Of the seven principal specimen categories exposed, only the control A 588 panels are common to all sites. Specimen type is also related to contamination level.
- Site: Five sites are used in the experiment. Three are real bridge sites. Two, Kure Beach and Neville Island, are control exposures.

- Contamination Level: This is a direct result of both the type of specimen and the surface preparation used.

B. DISCUSSION OF FIELD EVALUATION RESULTS

1. Format and Treatment of Data

The complete data derived from the field evaluations of coated panels is shown in appendix 1. Rust data was taken for every panel exposed. Scribe data was taken only for the flat specimens such as the A 588 panels and the Ontario cover plates. For the T pieces and angles, rust data was taken on each of the five surfaces depicted in figure 1, an overall rating was then given to the specimen as a whole (note that this is not a numerical average rating). Rust ratings were made in accordance with SSPC Vis-2/ASTM D 610 criteria. Scribe ratings were performed in accordance with the requirements of ASTM D 1654 and recorded in increments of $^1/_{32}$ of an inch.

The first step in data handling was conversion of the SSPC-Vis 2/ASTM D 610 records for extent of rusting to a pure numerical scale ranging from 10 to 1. This was required because the scale was modified during the rating of field exposed panels. A plus sign (+) was used for ratings above the nearest simple digit, a minus sign (-) was used for ratings below the nearest simple digit. In the conversion ratings a 9- became 8.7, a 9+ became 9.3 and other nonintegral ratings were treated in a similar fashion.

Whenever possible statistical tools such as correlation matrices and analysis of variance (ANOVA) were employed. These measure the influence of different variables on system performance and the significance of system performance differences for representative subsets of data.

Reduced data sets were on occasion created to facilitate examination of specific effects. When ANOVA was performed it was always on a full factorial subset of the total data set. This approach was taken to allow comparison of "apples to apples." Instances arise in the total experimental design of only one coating or a unique substrate being exposed at a limited number of sites. The full factorial sets of rust and scribe undercutting data eliminate these instances.

To examine as many factors from the design as possible, several ANOVA's were performed. The only factors not examined in an ANOVA were the performance of paint system 8 and that of coatings applied to the Louisiana T beams. General conclusions regarding these samples are of course discussed when appropriate.

Finally, the data for the Maryland T beams is treated as two distinct sets. In the original design reference is made to upper and lower, salted and unsalted Maryland T beams. Prior testing had shown that the level of contamination was remarkably close for both the upper and lower T beams. Since the primary distinction is salted and unsalted, the data for all Maryland beam samples was recoded using salted and unsalted as grouping variables. This recoded data was used in all ANOVA'S. Data using the original four category grouping for the Maryland T beams is shown in appendix 1.

To determine the influence that these factors (coating system, surface preparation, site, substrate, and contamination level) have on the outcome of the experiment, three approaches are taken:

- Inspection of the rating data for general trends.
- Correlation analysis to show strength of linear relationships (this is useful when numerical factors such as contamination level are examined).
- ANOVA to establish the influence of factors which are linear or non-linear.

2. Effect of Substrate

We begin our analysis by examining the influence of the substrate contamination level and substrate configuration on coating performance.

As discussed in section A, the following substrates were included:

- New A 588 mill scale covered steel.
- Several categories of previously exposed weathering steel from bridge structures in two countries and four geographical locations.

The substrata varied both in their configuration (i.e., shape, gauge, orientation) and in the level of salt contamination (due to previous exposure). Each of these aspects will be examined.

Substrate Contamination Level

From other work conducted by SSPC on behalf of the FHWA it is known that the level of surface contamination is critically dependent on several factors including:(4)

- The position of the structural element on a bridge.
- The surface preparation employed.
- The extent of contamination by deicing salt or other pollutants.
- The surface of the structural element examined, i.e., a web surface is often, though not always, less highly contaminated than a flange surface.

In the experimental design for this program specimens were used which had been deliberately subjected to frequent spraying with salt solutions. These were called salted Maryland T pieces. As internal controls to these specimens we used unsalted Maryland T pieces, these had been subjected to exterior mild exposures. Though frequently washed with potable water spray, they were not subjected to salt water exposure. Other T specimens included pieces of steel taken from actual bridge sections, which originated in Ontario and Louisiana. New A 588 steel plates, which are flat panels, were employed as the control. Other flat panels consisted of specimens from real bridge steel originally exposed in New Jersey and Ontario respectively.

From the previous work in this study, levels of surface contamination were found to be fairly uniform on each of the five T surfaces analyzed on a multiple surface specimen. Thus a single figure is reported in table 3 for the level of contamination for each type of specimen.[1] This is further discussed in the section titled "Substrate Configuration."

Estimates of surface contamination are given in table 3. These are based on conversions of conductivity measurements made upon swabbing or boiling samples taken from a representative number of each specimen category.[1] Boiling retrieval was typically employed with flat panel sections only. For the conversion it is assumed for simplicity that all the ionic species are acting as chloride ions.

Because of inefficiencies in the swabbing retrieval method and inaccuracies caused by the assumption that all ionic material is chloride, the quoted levels of contamination may be lower or higher than stated in table 3.[4]

The specimens used in this project have estimated chloride levels between 2 $\mu g/cm^2$ to 150 $\mu g/cm^2$. The levels of contamination can also be roughly subdivided into three categories:

- Salt Level 1: 2 to 12 $\mu g/cm^2$.
- Salt Level 2: 25 to 50 $\mu g/cm^2$.
- Salt Level 3: 100 to 150 $\mu g/cm^2$.

Two approaches are used to evaluate the influence of surface contamination on coating performance. The first is to determine the correlation between the estimated salt levels and the rust ratings for the various coating systems.

For each coating system the average rust rating (based on two replicates) is plotted versus the estimated salt level, and a correlation coefficient is computed. A correlation of -1 indicates 100 percent correlation (negative sign because a higher salt content results in a lower rust rating), and 0 indicates complete lack of correlation.

The second approach was taken on the Maryland T sections only. These were divided into two sets. One set was subjected only to mild natural exposure, the other was deliberately contaminated with chloride ion. Because this provides a matched set prepared under identical conditions except for salt content, comparisons of the rusting data will provide valuable insight. Conclusions from this approach are presented in the section on ANOVA studies and are based on data from all sites except Louisiana (here no Maryland T sections were exposed). The correlations from this set are shown in table 4 as data set number 4.

Table 4 gives a summary of the correlation between paint system performance and substrate contamination level for each site. For these studies the data was analyzed separately for each site to eliminate site differences as variable. Not all types of substrates or surface preparations were examined at each site. Hence, the number of data points analyzed differs among the sites. For example, at the Louisiana bridge site the data included 2 surface preparations, 3 substrates and 6 paint systems for a total of 36 points in the correlation plot. In the case of Kure Beach and the Pennsylvania bridge site, two correlations are shown. The first reflects the influence of salt contamination when power tool cleaned specimens are included in the data set, and the second is for blast cleaned specimens only. The correlations which included power tool cleaning contained the greatest range of salt level, as power tool cleaning resulted in

Table 4. Correlations of rust rating with salt level.

Set No.	Site[2]	Surface Preparation[2]	Specimens Used[2]	No. of Cases	Coating Systems[1]						
					1	2	3	4	5	6	Average Rating
1	PA	DB,WB,PT	A588,MTS,ONTCOV	108	-0.66[3]	-0.99	-0.72	-0.48	-0.94	-0.21	-0.58
2	Kure	DB,WB,PT	A588, MTS	60	-0.99	-0.89	-0.94	-0.93	-0.97	-0.27	-0.92
3	PA	DB,WB	A588, MTS, MTU, ONTCOV	96	-0.99	-0.85	-0.85	-0.95	-0.88	-0.41	-0.87
4	Kure	DB,WB	MTS, MTU	48	-0.75	-0.74	-0.66	-0.26	-0.63	-0.24	-0.48
5	MI	DB,WB	A588, MTS, MTU	72	-0.71	-0.40	-0.93	-0.35	-0.60	0.12	-0.72
6	LA	DB,WB	A588, LAT, ONTANG	72	0.52	-0.31	-0.68	-0.43	-0.27	-0.47	-0.43
7	Neville	DB,WB	A588, MTS, MTU, ONTANG, ONTCOV, NJBR	144	n/a[4]	n/a	-0.77	n/a	n/a	-0.79	-0.96
8	All Sites	DB,WB	ALL SAMPLES	288	0.04	-0.48	-0.36	-0.09	-0.09	-0.21	-0.20

[1] Refer to table 1 for decriptions of coating systems.

[2] Refer to table 3 for translation of codes.

[3] Linear correlation coefficient for coating system 1.

[4] The notation n/a shows no correlation was observed.

Key

- Statistically Significant at the 90 % Level
- Statistically Significant at the 95 % Level
- Not Statistically Significant

the highest level of salt on the substrate. For all other sites one correlation alone is shown, followed by a general correlation reflecting all sites. Each rust rating was the average of two replicates. For the multiconfiguration T's and angles, an overall rust rating of the five surfaces was assigned for each replicate. An analysis of the differences among the five surfaces is given in section 1. The data derives from average rust ratings, shown in table 3.

The conclusions are as follows:

- Paint system performance is more sensitive to salt contamination level when surfaces are cleaned by power tools.
- Paint system 6 (water-borne zinc) performed poorly with all methods of surface preparation regardless of residual level of salt contamination.
- The significance of correlation between rust rating and salt contamination level for paint systems 1 to 5 is improved at the Pennsylvania site when only blast cleaning methods are examined (i.e., power tool cleaning is excluded); it decreased at Kure Beach.
- The performance of paint systems 2 and 3 is significantly dependent on salt level of all sites combined.
- All systems except number 6 show some dependence on substrate salt contamination at at least one site.

Each rust rating was the average of two replicates for the multiconfiguration T's and angles. An overall rust rating of the five surfaces was assigned for each replicate. An analysis of the differences among the five surfaces is given in the section on substrate configuration. A typical plot illustrating the dependence of paint performance on salt contamination is shown in figure 5. Two sets of data are plotted, that for paint system 2 performance, which shows a linear dependence on salt concentration, and that for second the averaged performance of paint systems 1 to 6, showing a logarithmic dependence on salt concentration.

Substrate Configuration

It was of interest to determine whether the deterioration of the coatings was linked to the sample configuration. Several of the samples consisted of angles or T specimens cut from bridge steel sections. Rust ratings were recorded separately for each of the five flat surfaces of the T's (see figure 3). Substrate configuration might affect the outcome of the exposure for several reasons:

- The top of the bottom flange surface may be more highly contaminated with salt after cleaning than the other surfaces, due to previous exposure. However, an examination of residual chloride levels on exposed beam segments showed little difference between web and flange.

- The top of the bottom flange or lower portion of adjacent web might become more highly contaminated after exposure due to salt dripping from above. Salt splashing from below could similarly contaminate the bottom of the bottom flange.

- A flange or web surface might be subject to greater physical stress after exposure due to physical damage.

- Inside corners of I-beams or stiffeners might be more difficult to clean properly.

Any configuration-dependent paint performance would be expected to be shown in the average ratings for the multiple surface panels (table 5). For all paint systems the average rust rating on each surface is nearly identical. Case specific instances may be noted in which the differences observed from one surface to another are substantial. To examine if these and other smaller observed differences are significant requires an analysis of variance. This is presented later.

3. Effect of Exposure Location

The exposure site is an important variable affecting coating performance. Certain sites are acknowledged to be more severe than others. Based on prior exposure studies it would be expected that the ratings for identical specimens would be higher at Neville Island than at the Kure Beach 80-ft (25-m) lot.

An examination of coating performances in table 3 indicates that certain sites are more severe than others. Based on the rust data, the Louisiana site is the most severe, followed by Kure Beach. The Pennsylvania and Michigan exposure performance data is quite similar, while that for Neville Island indicates that it is the least severe.

Average scribe ratings are shown in table 6. From this table the average scribe rating for systems 1 to 6 on the control substrate is calculated to be Kure Beach 4.75, Pennsylvania site 2.67, Neville Island 1.41, Michigan 1.04, and Louisiana 0.92. This is a radically different order of site severity as compared with that obtained from the comparative rust data.

To assess whether the differences in ratings for each site with each paint system are significant requires an analysis of variance. The ANOVA results for rusting data are reproduced later in this report.

4. Effect of Surface Preparation

Three surface preparations were examined in this study:

- Wet abrasive blasting.
- Dry abrasive blasting.
- Power tool cleaning.

Table 5. Average rust ratings for multi-surface panels.

Site [1]	Specimen Type [1]	Surface Preparation [1]	Surface 1 [2]	Surface 2 [2]	Surface 3 [2]	Surface 4 [2]	Surface 5 [2]
Kure	MTS	Dry	8.86	8.64	8.16	8.33	8.19
	MTS	Wet	8.61	9.00	8.73	8.90	8.40
	MTS	All Blast	8.73	8.82	8.45	8.61	8.29
	MTS	P.Tool	6.08	7.36	7.42	8.31	6.33
	MTU	Dry	9.57	9.67	9.29	9.19	9.31
	MTU	Wet	9.31	9.25	8.97	9.12	8.89
	MTU	All Blast	9.44	9.46	9.13	9.15	9.10
Kure	All	Overall	8.56	8.83	8.55	8.78	8.28
LA	LAT	Dry	8.20	8.30	8.70	8.60	8.40
		Wet	8.08	8.83	8.75	8.58	7.67
		All Blast	8.14	8.59	8.73	8.59	8.00
	ONTANG	Dry	8.17	8.67	8.67	8.67	8.50
		Wet	8.00	8.58	8.33	8.25	7.92
		All Blast	8.08	8.63	8.50	8.46	8.21
LA	All	Overall	8.11	8.61	8.61	8.52	8.11
MI	MTS	Dry	9.31	9.38	9.78	9.11	9.92
		Wet	9.44	8.85	9.64	9.16	9.78
		All Blast	9.38	9.12	9.71	9.13	9.85
	MTU	Dry	9.70	9.53	9.88	9.56	9.92
		Wet	9.69	9.58	9.73	9.75	9.92
		All Blast	9.70	9.55	9.80	9.65	9.92
MI	All	Overall	9.54	9.34	9.76	9.39	9.88
PABR	MTS	Dry	9.42	9.34	8.88	9.21	8.69
		Wet	9.12	9.09	8.81	9.24	8.99
		All Blast	9.27	9.21	8.85	9.23	8.84
		P.Tool	7.36	8.44	8.19	8.98	8.36
	MTU	Dry	9.56	9.74	9.41	9.63	9.36
		Wet	9.54	9.39	9.22	9.41	9.54
		All Blast	9.55	9.56	9.31	9.52	9.45
PABR	All	Overall	9.05	9.22	8.92	9.30	9.01
All	All	Overall	8.82	9.01	8.92	9.01	8.79
Average per surface			8.85	9.02	8.96	9.01	8.83

[1] Refer to table 3 for decriptions of site, surface preparation, and specimen codes.

[2] Surfaces 1 and 2 are web sections, surface 4 is the underside of the flange, surfaces 3 and 5 are the upper flanges.

of these factors, it is essential that an ANOVA be performed on the ratings from the different exposure sites. This analysis of variance can be performed separately for rusting and scribe data.

Factors examined for both rust and scribe data were:

- Differences among coating system performance.
- Surface preparation.
- Site severity.
- Effect of substrate salt contamination and configuration.

Several different ANOVA's were run on selected subsets of the full data. The data sets were different for each ANOVA. The selection of data to be used in each ANOVA was done so that all ANOVA's were based on full factorial data sets. Further, each data set is intended to provide an understanding of the relative importance of the principal factors permeating the experimental design in deciding the outcome of the exposure studies. The factors incorporated into each ANOVA data set are outlined in table 7. An example of a data set used in calculating scribe ANOVA # 3 is given in table 8.

Several key pieces of information can be obtained from ANOVA tables in appendix 2. ANOVA will indicate whether a factor such as surface preparation or exposure site has a significant effect on the quantity of interest (i.e., rust or scribe rating). If a factor is significant, an analysis can be done to determine relative rankings and significance of difference between any two sub-factors (e.g., 2 sets). Thus, ANOVA provides an estimate of significant mean differences between like sets of data. A value can be computed, appendix 2, called the critical range (CR_t). The critical range for significant mean differences are computed using the formula for Duncan's Multiple Range Test and indicate the margin of difference required to be statistically significant at 95 percent probability level.

Two means must differ by at least the size of the critical range before they are held to be significantly different from one another. In addition, one can compute the extent to which a factor affected the overall analysis or rating. These estimates of factor importance and critical ranges, used for deciding if two means are significantly different, are shown in table 9. Relative performance of paint systems, substrate worthiness, site severity and surface preparation benefits are all based on the significant difference criterion. The method by which these coefficients are obtained is described in appendix 2. ANOVA's such as these, which include replicate data, also provide estimates of the standard deviation of the measurement.

A considerable amount of data output was generated for each ANOVA. A typical printout from scribe ANOVA 3 is shown in table 10. Only certain portions of this output need concern us. They are specifically the mean square error (known as the variance) from each ANOVA, the computed values for the critical ranges, and the percent of variance attributable to a factor. These are summarized in appendix 2.

It is clear from table 9 that when a large data set is used, with a larger numbers of samples, the critical range for a significant mean difference is usually smaller. To a first approximation, these lower critical range values may be used to establish the significance of

Table 7. Parameters examined in ANOVA studies.

NO	PROPERTY	COATING SYSTEMS [1]	SURFACE PREP'NS [2]	SPECIMEN TYPES [2]		SITES [2]		TOTAL PANELS [3]	COMMENTS AND EFFECT(S) EVALUATED
1	RUST	6	2	3	A588,MTS,MTU	4	NEV,MI,PABR,KURE	288	GENERAL ANOVA
2	RUST	6	2	2	MTS,MTU	4	NEV,PABR,MI, KURE	[4] 720	MULTIPLE SURFACE SPECIMENS
3	RUST	6	2	1	A588	5	NEV,MI,LA,PABR, KURE	120	SITES & COATINGS ON NEW STEEL
									NEW STEEL
4	RUST	7	2	3	A588,MTS,MTU	3	NEV.PABR,KURE	252	CTG SYSTEM 7
5	RUST	7	2	4	A588,MTS,MTU, ONTCOV	2	NEV,PABR	224	CTG SYSTEM 7
6	RUST	6	3	1	MTS	2	PABR,KURE	72	POWER TOOL CLEAN.
7	RUST	6	3	3	A588,MTS,MTU	1	PABR	108	POWER TOOL CLEAN.
1	SCRIBE	6	2	1	A588	5	KURE,LA,MI,NEV,PABR	120	SITES & COATINGS ON NEW STEEL
2	SCRIBE	7	2	2	A588,ONTCOV	2	NEV,PABR	112	SPECIMEN TYPE, SYSTEM 7 AND SITE
3	SCRIBE	6	3	2	A588,ONTCOV	1	PABR	72	POWER TOOL CLEAN, SPECIMEN TYPE

[1] Refer to table 1 for coating system descriptions.

[2] Refer to table 3 for descriptions of surface preparation, specimen, and site codes.

[3] Computed by multipling number of coating systems by number of surface preparations by number of specimen types by number of sites by 2 (number of replicates).

[4] Each specimen contained five individual surfaces.

Table 8. Sample ANOVA data set based on scribe ANOVA #3.

PAINT SYSTEM[1]	SURFACE PREPARATION[2]	SPECIMEN[2]	Scribe ratings in 1/32" (0.8mm)	PAINT SYSTEM[1]	SURFACE PREPARATION[2]	SPECIMEN[2]	Scribe ratings in 1/32" (0.8mm)
SYS1	DRY	ONTCOV	1	SYS4	DRY	ONTCOV	3
SYS1	DRY	ONTCOV	1	SYS4	DRY	ONTCOV	1
SYS1	WET	ONTCOV	1	SYS4	WET	ONTCOV	1
SYS1	WET	ONTCOV	1	SYS4	WET	ONTCOV	1
SYS1	P.TOOL	ONTCOV	1	SYS4	P.TOOL	ONTCOV	8
SYS1	P.TOOL	ONTCOV	1	SYS4	P.TOOL	ONTCOV	8
SYS1	DRY	A588	6	SYS4	DRY	A588	4
SYS1	DRY	A588	1	SYS4	DRY	A588	3
SYS1	WET	A588	24	SYS4	WET	A588	1
SYS1	WET	A588	16	SYS4	WET	A588	1
SYS1	P.TOOL	A588	12	SYS4	P.TOOL	A588	32
SYS1	P.TOOL	A588	20	SYS4	P.TOOL	A588	32
SYS2	DRY	ONTCOV	0	SYS5	DRY	ONTCOV	0
SYS2	DRY	ONTCOV	0	SYS5	DRY	ONTCOV	1
SYS2	WET	ONTCOV	1	SYS5	WET	ONTCOV	1
SYS2	WET	ONTCOV	1	SYS5	WET	ONTCOV	1
SYS2	P.TOOL	ONTCOV	0	SYS5	P.TOOL	ONTCOV	8
SYS2	P.TOOL	ONTCOV	1	SYS5	P.TOOL	ONTCOV	1
SYS2	DRY	A588	0	SYS5	DRY	A588	1
SYS2	DRY	A588	0	SYS5	DRY	A588	1
SYS2	WET	A588	1	SYS5	WET	A588	1
SYS2	WET	A588	0	SYS5	WET	A588	1
SYS2	P.TOOL	A588	0	SYS5	P.TOOL	A588	8
SYS2	P.TOOL	A588	0	SYS5	P.TOOL	A588	6
SYS3	DRY	ONTCOV	0	SYS6	DRY	ONTCOV	1
SYS3	DRY	ONTCOV	0	SYS6	DRY	ONTCOV	1
SYS3	WET	ONTCOV	0	SYS6	WET	ONTCOV	1
SYS3	WET	ONTCOV	1	SYS6	WET	ONTCOV	1
SYS3	P.TOOL	ONTCOV	8	SYS6	P.TOOL	ONTCOV	2
SYS3	P.TOOL	ONTCOV	4	SYS6	P.TOOL	ONTCOV	3
SYS3	DRY	A588	0	SYS6	DRY	A588	0
SYS3	DRY	A588	0	SYS6	DRY	A588	1
SYS3	WET	A588	0	SYS6	WET	A588	1
SYS3	WET	A588	0	SYS6	WET	A588	1
SYS3	P.TOOL	A588	6	SYS6	P.TOOL	A588	6
SYS3	P.TOOL	A588	16	SYS6	P.TOOL	A588	2

[1] Refer to table 1.

[2] Refer to table 3

Table 9. Summary of findings from ANOVA's

ANOVA [1]	RUST 1	RUST 2	RUST 3	RUST 4	RUST 5	RUST 6	RUST 7	SCRIBE 1	SCRIBE 2	SCRIBE 3
COATING SYSTEM DIFFERENCES [2]	6«4≈3<2≈1≈5 [3] CRt=0.11 [4]	6«1≈3≈2≈4≈5 CRt=0.17	6«4<5=3≈1≈2 CRt=0.18	6«4≈3≈2≈1≈5<7 CRt=0.13	6«1≈3=2≈4≈5≈7 CRt=0.16	6«2≈4<3=5≈1 CRt=0.61	6≈4«2<1≈3≈5 CRt=0.31	4<3<2≤5≈1≈6 CRt=1.05	1≤4<6≈5≈2≈7=3 CRT=0.72	4≈1<3≈5≈6≈2 CRt=1.96
PERCENT VARIANCE EXPLAINED [5]	45%	35%	37%	46%	37%	31%	17%	55%	18%	17%
SITE DIFFERENCES	KURE<PABR<MI,NEV CRt=0.09	PABR«NEV CRt=0.10	LA«KURE≤MI≤PABR<NEV CRt=0.16	KURE«PABR«NEV CRt=0.08	PABR«NEV CRt=0.08	PABR«NEV CRt=0.33	N/A	MI«KURE≈NEV≈LA≈PABR CRt=0.95	PABR<NEV CRt=0.37	N/A
PERCENT VARIANCE EXPLAINED	14%	11%	32%	12%	10%	8%	n/a	22%	1%	n/a
SPECIMEN DIFFERENCES [5]	MTS«MTU«A588 CRt=0.08	MTS«MTU«ONTCOV≈A588 CRt=0.14	N/A	MTS«MTU«A588 CRt=0.08	MTS«MTU«ONTCOV≈A588 CRt=0.12	N/A	MTS«MTU<A588 CRt=0.21	N/A	ONTCOV«A588 CRt=0.37	ONTCOV«A588 CRt=1.05
PERCENT VARIANCE EXPLAINED	9%	11%	n/a	9%	9%	n/a	4%	n/a	4%	8%
SURFACE PREPARATION DIFFERENCES [5]	WET≈DRY CRt=0.06	WET≈DRY CRt=0.1	WET≈DRY CRt=0.1	WET<DRY CRt=0.06	WET≈DRY CRt=0.08	P.TOOL«WET≈DRY CRt=0.41	P.TOOL«WET≈DRY CRt=0.21	DRY<WET CRt=0.58	WET≈DRY CRt=0.37	P.TOOL«WET<DRY CRt=1.31
PERCENT VARIANCE EXPLAINED	0%	0%	0%	0%	0%	11%	8%	5%	0%	18%

[1] Refer to table 7 for ANOVA parameters.
[2] Refer to table 1 for coating system description.
[3] Notation: <<: much worse than; <: worse than; ≈: approximately equal; = : indistinguishable.
[4] CR_t is the critical range for signifcant difference between two ratings.
[5] Refer to table 3 for descriptions of surface preparations, specimen, and site codes.

Table 10. Sample ANOVA output based on scribe ANOVA # 3.

ANOVA table for a 3-factor Analysis of Variance on $_1$:Y YR4

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
SPECIMEN (A)	1	268.347	268.347	55.361	.0001
SURFPREP (B)	2	589.361	294.681	60.794	.0001
AB	2	164.361	82.181	16.954	.0001
PAINTSYS (C)	5	560.903	112.181	23.143	.0001
AC	5	402.903	80.581	16.624	.0001
BC	10	707.972	70.797	14.606	.0001
ABC	10	369.639	36.964	7.626	.0001
Error	36	174.5	4.847		

There were no missing cells found.

The AB Incidence table on $_1$Y: YR4

	SURFPREP:	DRY	WET	P.TOOL	Totals:
SPECIMEN	ONTCOV	12 .75	12 .917	12 3.75	36 1.806
SPECIMEN	A588	12 1.417	12 3.917	12 11.667	36 5.667
Totals:		24 1.083	24 2.417	24 7.708	72 3.736

Table 10. Sample ANOVA output based on scribe ANOVA # 3 (continued).

Page 1 of the AC Incidence table on $_1$Y: YR4

	PAINTSYS:	SYS1	SYS2	SYS3	SYS4	SYS5
SPECIMEN	ONTCOV	6 1	6 .5	6 2.167	6 3.667	6 2
SPECIMEN	A588	6 13.167	6 .167	6 3.667	6 12.167	6 3
Totals:		12 7.083	12 .333	12 2.917	12 7.917	12 2.5

Page 2 of the AC Incidence table on $_1$Y: YR4

	PAINTSYS:	SYS6	Totals:
SPECIMEN	ONTCOV	6 1.5	36 1.806
SPECIMEN	A588	6 1.833	36 5.667
Totals:		12 1.667	72 3.736

Table 10. Sample ANOVA output based on scribe ANOVA # 3 (continued).

Page 1 of the ABC Incidence table on $_1$Y: YR4

	SURFPREP:	DRY					
	PAINTSYS:	SYS1	SYS2	SYS3	SYS4	SYS5	SYS6
SPECIMEN	ONTCOV	2 1	2 0	2 0	2 2	2 .5	2 1
	A588	2 3.5	2 0	2 0	2 3.5	2 1	2 .5
Totals:		4 2.25	4 0	4 0	4 2.75	4 .75	4 .75

Page 2 of the ABC Incidence table on $_1$Y: YR4

	SURFPREP:	WET					
	PAINTSYS:	SYS1	SYS2	SYS3	SYS4	SYS5	SYS6
SPECIMEN	ONTCOV	2 1	2 1	2 .5	2 1	2 1	2 1
	A588	2 20	2 .5	2 0	2 1	2 1	2 1
Totals:		4 10.5	4 .75	4 .25	4 1	4 1	4 1

Table 10. Sample ANOVA output based on scribe ANOVA # 3 (continued).

Page 1 of the BC incidence table on $_1$Y: YR4

	PAINTSYS:	SYS1	SYS2	SYS3	SYS4	SYS5
SURFPREP	DRY	4 2.25	4 0	4 0	4 2.75	4 .75
	WET	4 10.5	4 .75	4 .25	4 1	4 1
	P.TOOL	4 8.5	4 .25	4 8.5	4 20	4 5.75
Totals:		12 7.083	12 .333	12 2.917	12 7.917	12 2.5

Page 2 of the BC incidence table on $_1$Y: YR4

	PAINTSYS:	SYS6	Totals:
SURFPREP	DRY	4 .75	24 1.083
	WET	4 1	24 2.417
	P.TOOL	4 3.25	24 7.708
Totals:		12 1.667	72 3.736

Table 10. Sample ANOVA output based on scribe ANOVA # 3 (continued).

Page 3 of the BC Incidence table on $_1$Y: YR4

	SURFPREP:	P.TOOL				
	PAINTSYS:	SYS1	SYS2	SYS3	SYS4	SYS5
SPECIMEN	ONTCOV	2 1	2 .5	2 6	2 8	2 4.5
SPECIMEN	A588	2 16	2 0	2 11	2 32	2 7
Totals:		4 8.5	4 .25	4 8.5	4 20	4 5.75

Page 4 of the BC Incidence table on $_1$Y: YR4

	SURFPREP:	P.TOOL	Totals:
	PAINTSYS:	SYS6	
SPECIMEN	ONTCOV	2 2.5	36 1.806
SPECIMEN	A588	2 4	36 5.667
Totals:		4 3.25	72 3.736

mean differences not evaluated directly in any of the 10 ANOVA's performed. You could apply the calculated CR_t values to all averaged results of rust ratings and scribe undercutting shown previously in tables 3 and 6. Each critical range suggested below may not derive from the same ANOVA. For instance, the CR_t values for rusting were derived from ANOVA's 1, 4, 1, and 1 for coating system, surface preparation, site severity, and specimen identity, respectively. In each case, the number of cases used in determining the CR_t value is the largest possible. Scribe critical values were selected in a similar fashion.

An interpretation of critical range is given for rust rating of coating system for which the critical range is 0.11. Consider three coatings with the following mean rust ratings (Coating A = 9.5, Coating B = 9.2, Coating C = 9.1). Coating A is statistically better than Coating B (at the 95 percent confidence level) because the difference is 0.11 or greater. Coating B is not statistically better than Coating C because the difference is only 0.1 rust units.

For rusting, the appropriate critical ranges are:

- Coating System: 0.11 rust units.
- Surface Preparation: 0.06 rust units.
- Site Severity: 0.08 rust units.
- Specimen Identity: 0.08 rust units.

For scribe undercutting, the lower critical ranges are:

- Coating System: 0.72 x 1/32 in (0.75 mm).
- Surface Preparation: 0.37 x 1/32 in (0.75 mm).
- Site Severity: 0.37 x 1/32 in (0.75 mm).
- Specimen Identity: 0.37 x 1/32 in (0.75 mm).

In table 11 a ranking of the factors from exterior exposure is given using the critical ranges above when applied to data from tables 3 and 6, respectively. Such an approach is of course only an approximation. The ANOVA's summarized in table 7 were selected to answer specific questions about aspects of the entire experiment. These ANOVA's will now be considered in series.

- Rust ANOVA 1 is an attempt to examine several factors at four sites. Only the Maryland T specimens and A 588 specimens are examined. No power tool cleaning data is used.

- Rust ANOVA 2 examines the influence of substrate configuration on rusting.

- Rust ANOVA 3 looks at the differences between all sites. To accomplish this aim, only the data from the control specimens can be used. Rust ANOVA 3 can be directly compared with scribe ANOVA 1.

- Rust ANOVA 4 and 5 examine the relative performance of systems 1 through 7. In ANOVA 4 this is done using the same specimen sets as ANOVA 1, but only at three sites, while the specimen types are expanded in ANOVA 5 to include the Ontario cover plates, the sites being reduced to only two.

- Rust ANOVA 6 examines the influence of power tool cleaning at two sites, Kure Beach and Pennsylvania bridge, on A 588 steel only.

- Rust ANOVA 7 also looks at the influence of power tool cleaning but restricts the analysis to the Pennsylvania site alone, yet examines three specimen types.

- Scribe ANOVA 1 is comparable with rust ANOVA 3. Scribe ANOVA's 2 and 3 are similar in intent to rust ANOVA's 6 and 7. Data from Neville Island has to be used for the second site in scribe ANOVA 2.

Table 11. Rankings of factors from exterior exposure.

Rust Rating Results	Scribe Undercutting Results
Coating Systems: 7> 2,5,1,3 > 4 >> 6[1,2]	Coating Systems: 7,2 ≥ 3,6 >5 > 1 > 4
Surface Preparation: Dry = Wet >> P.Tool	Surface Preparation: Wet,Dry > P. Tool
Specimen:[3] NJBR > OntCov > A 588 > Ont Ang > MTU > MTS > LATS	Specimen: OntCov, NJBr > OntAng > A 588
Site: NEV > MI, PA > Kure > LA	Site: LA, MI > NEV >> PA >> Kure

1 Refer to table 1 for description of coating systems.
2 Notation: >> indicates much better than; > indicates better than; coating systems separated by a comma are statistically equivalent.
3 Refer to table 3 for descriptions of site, surface preparation, and specimen codes.
4 System 8 was not included because only a small number of samples were tested, and these were at the most benign exposure site.

For each ANOVA, rankings of specific factors have been performed. These rankings use the critical range values for significant mean differences appropriate to each individual ANOVA. As a result, the summary of the analyses in table 8 will frequently show ranking reversals from ANOVA to ANOVA. Key points arising from the analyses include the following:

- The factors in these analyses are always more influential in determining the variance in rusting data than scribe undercutting, with the exception of rust ANOVA 2.

- Coating system identity always accounts for the majority of the variance in observed results.

- Site is generally the next most significant factor in deciding the outcome of the experiment.

- Specimen type is often influential in determining the rating given to each sample, but less so than site or coating system.

- Surface preparation is always influential when power tool cleaned specimens are included in the data set(s). When wet and dry blast cleaning is considered alone, the degree to which surface preparation affects experimental outcome is extremely small.

- The degree to which surface contamination influences a rating can be seen from data such as rust ANOVA 1, 4, and 5. These show clear differences between the Maryland salted and unsalted T specimens. This corroborates our prior correlation analyses.

- There are significant reversals in site severity going from rust ANOVA 3 to scribe ANOVA 1.

It is important to point out one significant variable from the rusting and scribe undercutting data used in the analyses. Only at the Louisiana site were all ratings performed by State highway personnel. All other ratings were performed by SSPC personnel. This could have a significant effect on the outcome of the experiment. Rust ratings are qualitative in nature, thus the severe ratings given at the Louisiana site could reflect operator bias. This is underscored by the ratings given for scribe undercutting. Being quantitative, these ratings are less likely to incorporate a large operator bias. The switch, which is seen in rankings of sites when rust then scribe undercutting is used as the criterion of performance, would be explained by such operator dependence.

Rust ANOVA 2 examines sample configuration, a criterion which is not observable in any of the other data sets. A total of 720 cases were examined with five cases per sample panel, one for each surface. The data could also be stratified using the common factors summarized in table 7. The influence of all common factors in determining variance within the rust ANOVA 2 data set is significantly lower than with any comparable ANOVA, such as rust ANOVA 1. This may reflect the variegated nature of the data. It implies there is wider variation from surface to surface than from site to site. Using the same methods employed to determine the CR_t and the percentage influence factors, one can give some measure of the influence of configuration itself on the experimental outcome. The degree to which the rust ratings for multiple surface specimens is influenced by configuration is surprisingly small. With a contribution to total variance near zero, the critical range value for a significant mean difference is 0.26. Thus, if the average rating for surface 1 differs from that of the other surfaces by more than 0.26 rating points, the two surfaces are significantly different.

Inspection of the mean values for each surface depicted in table 5 shows none are noticeably different. For individual cases such as power tool cleaned Maryland salted beams at Kure Beach, large and significant differences are observed. There are many such case-specific instances where certain surfaces are significantly worse than others. We must then reconcile the low contribution to overall variance directly attributable to surface identity with the large number of observed instances of significant surface differences. In simple language the ANOVA would indicate an underlying pattern of behavior if one or more of the five surfaces was consistently worse than the rest. What is obvious from table 5 is that no one surface is consistently worse than any other. True, the surface variability is quite noticeable, but it is randomized throughout the data set.

Examining striking instances of surface to surface difference is equally confusing because the surfaces are unique. In the cited instance of the power tool cleaned specimens at Kure Beach, the lower rated 1 and 5 surfaces are a web and upper flange surface, respectively, on opposite sides of the T section.

7. Overall Conclusions

The general indications from the field results is that there are several coating systems which a bridge engineer may specify to counteract aggressive corrosion of a weathering steel structure. Certain of the currently favored high technology coating materials show good performance, but it is of interest that the older lead containing alkyd system provided excellent protection to the A 588 test pieces, even under severe environmental conditions.

The most unexpected results are those for the water borne inorganic zinc-rich system, (number 6). It is worthwhile considering whether the results obtained are primarily a reflection of the coating or the influence of external factors. It is suspected that the poor performance of system 6 is in part due to application having taken place while the ambient temperatures were in the mid-90 °F (mid-30 °C) range. The substrate temperature was not greater than 125 °F (52 °C), yet it may still have been high enough for all the water to evaporate from the coating before curing of the silicate vehicle. The high temperatures may also have contributed to poor coverage of the primer over the narrow pits typical of corroded A 588 steel. This could favor future failure by rusting of the finished system. System 4, the surface tolerant epoxy system, also exhibited poor performance. It was most evident when applied to power tool cleaned surfaces. This is consistent with previous data.

Rankings of the coating systems have been developed using either rust or scribe as the measure of degradation. One can obtain a simple combined ranking by ordering the paint systems according to their rank by each parameter, then appending a score based on the position in the rank, from 1 to n. Summing both ranking numbers gives the overall ranking for each paint system. The results of this treatment are shown in table 12. System 8 is excluded from this table as an insufficient number of samples of this system were exposed for value of comparison.

Table 12. Overall rankings of coating systems from field data.

Coating System [1]	Average Rust	Ranking [2]	Coating System	Average Scribe	Ranking	Coating System	Overall Score [3]	Overall Ranking
7	9.99	1.0	7	0.06	1.5 [4]	7	2.5	1
2	9.63	3.5	2	0.3	1.5	2	5.0	2
5	9.59	3.5	6	1.2	3.5	3	7.0	3.5
1	9.55	3.5	3	1.6	3.5	1	7.0	3.5
3	9.52	3.5	5	2.2	5.5	5	9.0	5
4	9.12	6.0	1	2.8	5.5	6	11.5	6
6	8.12	7.0	4	5.2	7.0	4	14.0	7

1 Refer to table 1 for description of coating systems
2 Coating systems are ranked from best (top) to worst (bottom).
3 Overall score is the sum of rust and scribe ratings.
4 Derived by averaging ranking of systems with identicial ratings (e.g., average of 1 and 2 or 2, 3, 4, and 5).

Surface Preparation

The coating systems performed approximately the same over wet and dry blasting. Power tool cleaning to bare metal gave significantly inferior rust and scribe rating. Power tool cleaning is not a suitable method for cleaning A-588 steel exposed and corroded in chloride contaminated environments.

Sites

Conflicting information derives from evaluation of site severity based on rust or scribe data. For both, Kure Beach is one of the most severe sites. As explained above, the substantially worse average rust ratings recorded at the Louisiana site may reflect differences in the severity of ratings assigned by different operators. The rust ratings by SSPC personnel may be systematically higher than those by the Louisiana DOTD personnel who performed the ratings at the Louisiana bridge site. The ratings based on scribe, which is less subject to operator bias, clearly show that Kure Beach is the most severe location, followed by the Pennsylvania site. All other sites are nearly equal or statistically indistinguishable from one another.

From rusting data, with the exception of the data from Louisiana, the most severe site is Kure Beach, which is more severe than the Michigan bridge, the Pennsylvania bridge, and the Neville Island sites, respectively. The degree of difference due to site is always closer to or greater than the critical range than it is in the case of scribe undercutting. These rankings are shown in table 11.

Specimens and Surface Contamination

The selection of different specimens allows one to determine the effect of substrate contamination (information about substrate configuration is also derived). A full summary of the relative suitability of each surface for good coating performance can be seen in table 11.

The ranking of the system performances based on rusting indicates that geographical locations such as Ontario have steel surfaces which can be coated for maintenance with many of the paint materials examined in the study. Other substrata would require greater care in surface preparation and the selection of higher performance coating systems, among these problematic surfaces are all the T specimens examined. This may primarily be due to the intrinsically higher surface contamination noted on these specimens. In instances where substantial contamination is suspected, a zinc-rich coating based on an ethyl silicate formulation or any of the organic zinc coatings employed in the study would be appropriate primers. In all instances, appropriate finish coat(s) would be either two-component epoxy or urethane coatings.

Initial coating of new A-588 is a good measure to take if the exposure environment is expected to be severe (e.g., exposed to leaky joints).

III. COMPARING FIELD AND LABORATORY DATA

A. SUMMARY OF LABORATORY EVALUATIONS

From the laboratory evaluations an overall ranking of tested coating systems was produced as shown in table 13. It is informative to compare the results derived from these short-term laboratory screening tests with those obtained in the field evaluations. A complete comparison cannot be made because two new coatings systems, the water-borne zinc silicate system and the low VOC ethyl silicate inorganic zinc system (untested in the laboratory), were entered in the field phase. Also, three coating systems were excluded from the field trials because of poor performance in the screening tests. These were the polar wax coating, a duplicate urethane system, and a duplicate organic zinc based system. In part this was done for economy of scale. That is when two systems of the same generic type were included in laboratory testing. Only the better performer in the screening tests was used in the field evaluations. In the case of the wax-based coating, elimination from field evaluation was due to poor performance in the laboratory screening tests. Based on comparative results with other poorly performing laboratory candidates used in field trials, this may not have been a valid response.

In the laboratory screening the high technology coatings won hands down. The traditional alkyd coating and the new polar wax coatings performed relatively poorly in all corrosion tests. Over blasted surfaces the zinc-rich coatings generally performed well, the exception being one of the zinc-rich urethane coating system.

In the laboratory study the inorganic zinc/vinyl system exhibited poor resistance to blistering in the salt fog exposures. In the field exposures such failure was not replicated, nor was it expected to be, as failure by blistering is rare in exterior exposures for any system. Moreover, the failure could also be ascribed to a portion of the system. Experience has shown blistering of topcoated inorganic zinc coatings to occur between the inorganic zinc and the topcoat without interruption of the protection afforded by the zinc primer to the surface. Comparing the performance of this system in field exposures with that in the short-term tests also demands a reevaluation of the sensitivity of this system to substrate contamination. From the laboratory work described in the interim report, the inorganic zinc vinyl system could be considered sensitive to levels of chloride as low as 7×10^{-4} gr/in^2 (7 μg/cm^2), (based on salt fog testing). The new results from outdoor exposures would support a sensitivity threshold at the higher level of 3×10^{-3} to 5×10^{-3} gr/in^2 (30 to 50 μg/cm^2).

B. CORRELATIONS BETWEEN LABORATORY AND FIELD RANKINGS

In the field tests the best overall performance was given by the thermal spray zinc. This is in agreement with the results of the laboratory screening tests. The bulk of the high technology coatings performed closely to the levels expected from the lab tests.

The alkyd coating system, number 1, outperformed many of these high technology coatings when tested in the field. This would not have been predicted on the basis of the laboratory tests, but is in accordance with the cited performance for similar low technology alkyd systems when applied by highway agencies to weathering steel structures.

The strong performance of the alkyd system in the field brings into question the validity of the screening procedure. The polar wax coating system was excluded from field testing because of poor performance in the laboratory testing, especially in salt spray exposures. It should be pointed out that separate testing of similar systems on corroding weathering steel transmission tower joints indicated the field suitability of this system for protection of A 588 substrata. This is by no means a minor point, for both the alkyd system and the polar wax system are clearly ideal for application in areas where blast cleaning cannot be readily achieved. If performance based on short-term tests was the primary criterion for design of the outdoor exposure tests the alkyd systems might also have been deleted from the test matrix for field evaluation. This episode might underscore the shortcomings of placing too much faith in short-term monotonic laboratory testing.

Comparisons of laboratory system rankings for respective generic types of coatings (shown in table 13) indicates considerable variation. These rankings depend on the test method used in the laboratory evaluation.

In salt spray testing the worst performing coatings are the equivalents of field systems 1, 2, 3, and 4. This result is not borne out for field exposures in the case of systems 1, 2, and 3 (see table 12).

As shown in table 3, system 4 did perform poorly in field on power tool cleaned surfaces but was a strong performer on similar substrates in salt spray testing. Clearly salt spray testing was not predictive of actual field performance expectations.

Examination of the rankings produced with immersion testing in the laboratory reveals that system 4 was one of the worst performers on highly contaminated steel. All laboratory failures in immersion testing were through blistering, a mode of failure not seen in field exposures.

Table 14 summarizes the relative rankings of companion systems in laboratory and field testing in terms of the three types of laboratory test environment and the three ranges of chloride contamination of field exposed steel. Below the rankings is the correlation matrix of this ranked data (table 15). Note that four cases with missing values were deleted in generating this table. The overall conclusions from these tables are:

- Rankings based on rusting in the field (at different chloride levels) are well correlated with one another.
- Rankings from field rust data and field scribe data are poorly correlated.
- Rankings between laboratory testing and field exposure are very poor.
  - Field rust rankings and immersion rankings are inverted.
  - ASTM B-117 (salt spray) rankings are nearly inverted from field rust rankings.

Table 13. Summary of laboratory coating performance evaluations.[1,2]

Branch[3]	Test[4]	Parameter[5]	Substrate[6]	Surf. Prep.[7]	Coating Rankings[8]
A	Salt Spray	Rust	MS > HCL	DB > WB	(5, 6) ≥ 4 > (2,3A, 3B)
A	Salt Spray	Blister	MS > HC	WB > DB	(3A, 3B, 5) > 4 > (2, 6)
A	Immersion	Rust	No Failures	- - - - - - - - - -	- - - - - - - - - - - - -
A	Immersion	Blister	MS > HCL	WB > DB	(2, 3B) ≥ (3A, 5) > (4, 6)
A	UV-Con/F-T	Rust/Blister	No Failures	- - - - - - - - - -	- - - - - - - - - - - - -
B	Salt Spray	Rust	LCL > HCL	PT > HT	4 > 6 > 1 > 7
B	Salt Spray	Blister	LCL > HCL	PT > HT	4 > 6 ≥ 1
B	UV-Con/F-T	Rust	LCL >> HCL	PT >> HT	4 > 6 > 1 > 7
B	UV-Con/F-T	Blister	LCL >> HCL	PT >> HT	(1, 4, 7) > 6
C	Salt Spray	Rust	MS > LCF > HCF ≥ HCL	(DB, WB) > P	4 > 3A >> 1
C	Salt Spray	Blister	(MS, LCF) > (HCL, HCF)	WB > DB > P	3A > 4 >> 1
D	Salt Spray	Rust/Blister	No Failures	- - - - - - - - -	- - - - - - - - - - - - - -
D	UV-Con/F-T	Rust/Blister	No Failures	- - - - - - - - -	- - - - - - - - - - - - - -

1 Detailed data and discussions given in Reference x.

2 Explanation of symbols
- X ≥ Y indicates that coating or treatment X was slightly better than Y.
- X > Y indicates that X was significantly better than Y.
- X >> Y indicates that X was much better than Y.
- Based on data from tables 6, 7, and 8

3 Test branches designed as follows
- A Blast cleaned steel, 6 coating systems
- B Non-blast cleaned steel, 4 coating systems
- C Field vs. lab corroded steel, 4 substrates, 3 coating systems
- D Thermal spray coating vs. organic zinc-rich coating

4 See appendix 3 for details.

5 Rust rated according to ASTM D610/SSPC-VIs 2; blistering rated according to ASTM D714.

6 Key:
- MS (millscale), new A-588 steel.
- HCL (high-chloride laboratory) panels exposed to 100 cycles in salt spray cabinet prior to surface preparation.
- HCF (high-chloride, field) specimens obtained from Michigan or Ontario, having high levels of chloride contamination.
- LCF (low-chloride, field) specimens from New Jersey Turnpike, low levels of chloride contamination.

7 Key:
- DB dry blast (medium abrasive)
- WB wet abrasive blast
- PT power tool cleaning using heavy duty roto-peen and non-woven discs
- HC hand tool cleaning using wire brush

8
- System 1: lead oil alkyd (2-coat)
- System 2: inorganic zinc/vinyl
- Systems 3A & 3B: zinc-rich epoxy polyamide/high build epoxy
- System 4: high solids epoxy mastic/acrylic epoxy
- System 5: moisture-cured zinc-aluminum urethane/high-build epoxy
- System 6: zinc-rich urethane/urethane
- System 7: petroleum wax primer/topcoat
- System 8: thermal spray zinc

Table 14. Rankings and correlations of coating systems from field and laboratory data.

Rank	Relative Field Ranking Low or Medium Cl [1]	Relative Field Ranking High Cl	Relative Ranking B117 Rust [2]	Relative Ranking Immersion [3]	Relative Ranking UV-Con[3]-T
1	System 7 [4]	System 7	System 7	System 7	System 7
2	System 2	System 2	System 5	System 2	System 1
3	System 3	System 5	System 4	System 3	System 4
4	System 5	System 1	System 2	System 5	
5	System 1	System 3	System 3	System 4	
6	System 4	System 4	System 1	System 1	
7	System 6	System 6			

Correlations	Field Ranking Low or Med Cl	Field Ranking High Cl	Ranking B 117 Rust	Ranking Immersion
Field Ranking High Cl	0.954			
Ranking B 117 Rust	-0.397	-0.655		
Ranking Immersion	-0.923	-0.996	0.721	
Ranking UV-Con/F-T	-0.596	-0.327	-0.5	0.24

[1] Rankings based on averages of final rusting data.

[2] See text for description of chloride levels and ranges.

[3] Refer to appendix 3 of reference 1 for description of laboratory tests.

[4] Refer to table 1 for description of coating systems.

[5] Linear correlation coefficient.

Table 15. Recommended coating systems for new and existing weathering steel bridges.

EXPOSURE CONDITION	CONDITION OF STEEL: New A 588	Aged Non-Corroded[1]	Aged Corroded[2]
Mild/Moderate[3]	SP 10/IOZ/EP[5]	SP 10/IOZ/EP/PU[6]	SP 10/IOZ/EP/PU
	SP 10/OZ(E)/EP	SP 10/OZ(E)/EP/PU[6,7]	SP 10/OZ(E)/EP/PU
	SP 10/OZ(U)/EP	SP 10/OZ(UP)/EP/PU[6,7]	SP 10/OZ(U)/EP/PU
	SP 10/TSZ	SP 10/EM/PU[6,7]	
	SP 10/OA(ZnO)/A[7]	SP 10/OA(CaSO)/A[7]	
Severe[4]	SP 10/IOZ/EP/PU	SP 10/IOZ/EP/PU	SP 10/IOZ/EP/PU
	SP 10/OZ(E)/EP/PU	SP 10/OZ(E)/EP/PU	SP 10/OZ(E)/EP/PU
	SP 10/OZ(U)/EP/PU	SP 10/TSZ/EP	SP 10/TSZ/EP
	SP 10/TSZ/EP		

1 < 30 μg/cm² of chloride by swabbing method after abrasive blasting.
2 > 50 μg/cm² of chloride.
3 Structures not subject to conditions in note 4.
4 Structures or zones which receive deposit of salt and high humidity, or frequent wet/dry cycling.
5 Codes:

IOZ	=	inorganic zinc (ethyl silicate)
EP	=	epoxy polyamide
PU	=	polyurethane (aliphatic)
OZ(E)	=	organic zinc (epoxy polyamide)
OZ(U)	=	organic zinc (moisture-cured urethane)
EM	=	high solids good wetting epoxy (epoxy mastic)
TSZ	=	thermal spray zinc
OA(CaSO)	=	oil alkyd (calcium sulfonate) (two coats)
OA(Zinc)	=	oil alkyd (zinc oxide) (two coats)
A	=	alkyd
SP 10	=	SSPC-SP 10, Near-White Blast
SP 6	=	SSPC-SP 6, Commercial Blast
SP 11	=	SSPC-SP 11, Power Tool Cleaning to Bare Metal

6 Polyurethane topcoat may not be needed except for aesthetic purposes
7 A commercial blast (SSPC-SP 6) may be acceptable in place of near-white (SSPC-SP 10) for these systems.

- Only UV-CON freeze-thaw rankings show partial agreement with field scribe rankings, but the sample size is very small.

- The laboratory tests correlated very poorly with exterior rust resistance and undercutting.

C. DISCUSSION

The laboratory tests had very limited value in predicting exterior rust and undercutting resistance. Some coating systems which showed poor performance in short-term laboratory exposures were included in the field exposure experimental design. They subsequently showed performance superior to that which would have been projected from the laboratory screening tests. Specific examples of such anomalies include the three coat oil-alkyd system (number 1), which showed superior rusting resistance in field testing, and the inorganic zinc/vinyl system, (number 2), which showed superior field performance for both rusting and scribe undercutting.

Several coating systems were rejected from the field evaluation experimental design, in part because of poor performance in the screening procedures used in the laboratory tests, partly to limit the size of the experiment. Rejected coatings included a second urethane coating, system 6 in the laboratory screening tests, a polar wax coating and a second candidate epoxy zinc-rich system. The field exposure data for these materials would have been valuable

Great emphasis is placed in this report, and in the revised guidelines, on the data from the field evaluations. The maxim, that the only proven valid test for bridge coatings is exposure at representative outdoor sites, is not contestable. What remains in question is the validity of such short term field exposure testing.

After 4 years there was not a marked difference among the coatings based on average rust rating or scribe undercutting. Through the use of ANOVA, attempts have been made to quantify the minimum difference between performance of different systems. Where the observed differences in performance do not exceed a minimum gap size for either rusting or scribe undercutting, the systems are held to be equivalent in performance. Note, systems may be numerically different without being demonstrably different when tested in this fashion.

It may be argued that prolongation of the field exposures would result in a reduction in the number of apparently equal systems. Another tactic would have been to increase the number of repeat specimens for each experimental factor. Previous work by SSPC for the National Shipbuilding Research Program has clearly shown that earlier system performance discrimination can be achieved with larger sample sets.[9] Nevertheless, the 4-year data in conjunction with other test data and field experience, allow certain conclusions and recommendations regarding specific systems for different conditions.

IV. CONCLUSIONS & RECOMMENDATIONS

A. GENERAL CONCLUSIONS

The study accomplished the aims set out in the original proposal. Means by which one can determine the degree of corrosive distress of A 588 structures were established, based upon analysis of saline contaminants present on an exposed structure. In general the extent of corrosion was correlated with the concentration of saline contaminants.

Effective means for preparation of corroded A 588 surfaces were evaluated. The compatibility of the prepared surfaces with various candidate coating systems was investigated. Based on the results there is no significant difference between wet abrasive blasting or dry abrasive blasting. Either surface preparation method can remove sufficient contamination to permit one of several high performance coating systems to provide long-term protection to the structure. The use of power tool cleaning of corroded areas on a structure is not recommended for the candidate systems evaluated. The extra effort and expense entailed in using a high performance coating system on an abrasive blast cleaned substrate is justified.

From these studies a set of guidelines for painting weathering steel bridges has been developed. (They are reproduced in appendix 1.)

B. USE OF GUIDELINES FOR PAINTING WEATHERING STEEL BRIDGES

The most valuable output from this study are the guidelines for painting weathering steel bridges contained in appendix 1. The guidelines are an updated version of a set of interim guidelines issued with the interim report on this project.[1]

The guidelines are intended to assist bridge engineers in establishing and implementing procedures for corrosion protection and maintenance of weathering steel bridges. Emphasis is placed on existing structures, particularly those with severe chloride contamination or corrosion damage. The need for preventative maintenance of other structures is also addressed.

In using the guidelines, the bridge engineer should decide in which of three categories the affected structure should be placed. The categories are: existing A 588 steel with high chloride contamination; existing A 588 steel low chloride contamination; or new A 588 steel. Further, the bridge engineer should be aware of the prevailing or anticipated service conditions the structure will see. Factors such as the extent of rainfall and use of deicing salts will have to be considered. Finally, a judgement must be made about deferring maintenance or making immediate implementation of a corrective plan of action.

Whichever classification is used, the bridge engineer must recognize that the variety of service environments or initial conditions that may be faced is inevitably greater than the number described in the guidelines.

Based on the set of combined factors, which the bridge engineer uses to describe the structure (i.e., condition, service and maintenance requirements), a menu of options is given. These constitute the preferred maintenance prescription for the described condition(s).

C. RECOMMENDATIONS FOR COATING SYSTEM SELECTION

1. Classification Schemes

The recommendations for coating systems are based on the classification of the steel condition and the exposure conditions, as follows:

Field Conditions:

- New A 588.
- Noncorroded, weathered A 588 (low chloride).
- Corroded, weathered A 588 (high chloride).

The extent of corrosion may be determined by measuring the chloride level (preferred) or by observation. Chloride levels can be measured by swabbing/extraction techniques on a surface after blast cleaning. Chloride measured above 5×10^{-3} gr/in^2 (50 μg/cm^2) is considered highly chloride contaminated. Levels below 3×10^{-3} gr/in^2 (30 μg/cm^2) are classified as low chloride, levels between 3×10^{-3} and 5×10^{-3} gr/in^2 (30 and 50 μg/cm^2) are considered marginal. Other evidence of high corrosion are heavy continued scaling of the surface layers, visual evidence of salt deposits and evidence of leaks from joints or vehicle splashing.

2. Bridge Exposure Conditions

- Severe: These are structures or zones which receive deposits of salt and high humidity or long-term wet conditions.

- Mild/Moderate: These are structures not subject to the conditions for a severe exposure. NOTE: A noncorroded substrate would be present in a severe environment if the structure had only been exposed to the severe conditions (i.e., leaky joints) for a short period or if it had received some other protection (e.g., temporary coating).

3. Coating Systems

a. Shop Painting of A 588 Steel

The systems recommended are as follows:

- Inorganic zinc, organic zinc-rich system (epoxy or urethane zinc-rich primer) and thermal spray zinc system. Depending on whether the steel is to be exposed to severe or mild/moderate conditions, an additional protective topcoat or sealer may be required. Additional details are given in appendix 1.

b. Low Chloride Existing Steel

For a severe exposure environment, the recommended systems are inorganic zinc system (three coats), epoxy organic zinc system (three coats) or thermal spray zinc system with seal coat. For a mild/moderate zone, additional systems recommended are organic zinc urethane system, high-solids epoxy mastic system, and inhibitive oil alkyd systems. All the others require at least a near-white blast.

c. High Chloride Existing Steel

For the severe exposure zone, the same three systems are recommended as for the above (i.e., inorganic zinc, organic zinc epoxy, or thermal spray zinc systems).

For a mild/moderate zone, systems include epoxy mastic, polyurethane (minimum near-white blast) and inhibitive oil-alkyd systems (minimum commercial blast).

d. Surface Preparation

Abrasive blasting remains the method of choice for practical large scale surface preparation. The current study concludes that wet and dry blasting result in essentially equal coating performance. This is particularly important, for it means that effective methods for reducing residual chloride contamination are available which do not dramatically reduce coating system choices.

Power tool cleaning to bare metal is not an effective means for preparing previously exposed A 588 steel when high levels of chloride contamination are present. Cleaning to SSPC-SP 11 remains a worthwhile means of surface preparation for localized sections of low chloride contaminated steel, or new A 588 steel. It is not recommended for use with new A 588 steel if excessive chloride exposure is expected.

More complete details of system and surface preparation recommendations can be found in Appendix 1, Guidelines for Painting of Weathering Steel Bridges.

D. RECOMMENDATIONS FOR FURTHER EXTERIOR EXPOSURES

1. Current Exposures

It is recommended that consideration be given to conducting an evaluation of the performance of the coatings placed at an existing corrosive site in future years. Evaluations could be restricted to the Pennsylvania bridge site which is a reasonably aggressive location where the full range of coatings and surface preparation conditions was exposed. This would provide the quickest feedback of results without compromising the overall integrity of any conclusions. Updated evaluations could be made at 2- to 3-year intervals. This will be particularly helpful in assessing the true value of metallizing as an option for protection of A 588 structures in severe environments.

An alternative to the above would be continued exposures at all sites in the current experimental design. With the cooperation of State highway personnel future examinations of the exposed specimens could take place after the fifth or sixth year of exposure, though longer periods might be needed at some locations.

2. Case Histories from Painted Weathering Steel Structures

State highway transportation organizations should be encouraged to furnish data on painting of weathering steel bridges to the FHWA and SSPC. The type of data that might be delivered could include:

- Costs for spot repairs of coated weathering steel and painting of entire structures.

- Type of surface preparation employed, including details of abrasive used, finish achieved prior to application, e.g., SSPC-SP 10 Near White Metal Blast Cleaning, and surface profile achieved.

- Generic description of coating system, including dry film thicknesses of coating system components, and method of application.

- Condition of steel before application, i.e., degree of rusting or pitting, extent of salt contamination and deicing salt use, temperature and relative humidity at time of application.

- Performance history of installed system based on regular inspections of painted structure. Extent of rusting or degree of undercutting would be useful information, which could be reported either based on standard American Society for Testing and Materials (ASTM) practices such as ASTM D 610 for rusting, or on the basis of percent area affected. Photographs showing structures inspected would be invaluable.

A standard form for recording the data could readily be prepared based on existing SSPC or ASTM documents.

3. Field Case Histories from Michigan DOT

Since 1984 Michigan DOT has used the coating specification summarized above for protection of some 65 previously uncoated weathering steel bridges. A wealth of case history data on the performance benefits of competitive systems continues to be acquired by State highway personnel. Based on preliminary data, Michigan DOT projects a 30 to 40 year life span for most of these coating installations. They expect to specify the same system for maintenance painting of the remainder of the 600 uncoated A 588 bridges affected by a wet, salt-laden environment.

E. RECOMMENDATIONS FOR IMPROVING SHORT-TERM TESTING

To improve the correspondence between short-term laboratory screening tests and eventual field performance the following are suggested:

- The testing regimen should reflect eventual service requirements. This may include knowledge of such factors as time of wetness, temperature extremes, exposure to sunlight, rainfall and typical components of rust product. This effectively precludes dependence on salt fog testing in accordance with ASTM B 117.

- Laboratory tests should incorporate cyclic elements such as periods of drying, exposure to ultra violet radiation, and the use of a corrosive salt mixture close to that found in service.

- Replicate laboratory screening tests and field evaluations, using the same combinations of specimens and coating samples in both. This should improve comparisons made between the two and could potentially shorten the overall testing cycle. Preliminary qualification could be made based on an improved short term laboratory testing regimen, final qualification coming from the field exposure results.

- Require larger numbers of samples be used in either field or laboratory evaluations, this permits earlier determination of coating failures. NOTE: If five or fewer repeat specimens per coating are used, field evaluations demand longer periods of exposure, often up to 10 years.

- Demand the use of statistical evaluation of results for either form of coating evaluation program. Appropriate tests include correlation analysis and ANOVA

- Make this type of experimental design requirement a part of future research proposal requests, i.e., spell out how long you expect the field exposures to last or what degree of statistical probability you would like for the derived answers. Tests exist by which one can determine the optimum sample size for a specific set of statistical requirements.

APPENDIX 1
GUIDELINES FOR PAINTING OF WEATHERING STEEL BRIDGES

INTRODUCTION

These guidelines are intended to assist highway bridge and maintenance engineers in establishing and implementing procedures for corrosion protection and maintenance painting of weathering steel bridges. The emphasis is on structures with severe corrosion damage or chloride contamination, but also addressed is the need for preventative maintenance of weathering steel bridges. These guidelines are an updated version of the interim guidelines first issued within the interim report for this project. They also reflect the guidelines issued as a technical advisory, # T 5140.22, by the FHWA on October 3, 1989.[3] The guidelines address two principal questions:

- What type of remedial actions are recommended and under what conditions?
- What are the procedures and criteria for achieving the required level of performance?

A. SELECTING REMEDIAL ACTION (MAINTENANCE OPTIONS)

The primary goal of maintenance is to ensure the structural integrity and safety of the bridge. A secondary objective is to provide a level of aesthetics because of the bridge's public nature and to retain the public confidence in bridges.

It is well documented that corrosion damage of carbon steel bridges has resulted in substantial structural deficiencies, loss of critical strength, and even failure. For weathering steel bridges, it is assumed that unmitigated corrosion of joints and other critical areas can also affect their structural integrity and safety.

Most maintenance programs require tradeoffs between the optimal level of maintenance and the level which can be afforded and justified within the current budget.Unfortunately this approach can be more expensive in the long term.

The maintenance engineer has four basic choices of action regarding protection of weathering steel bridges:

- No Action: This decision may assume that no structural deficiencies will become manifest within a 2-year period. The decision may be based on a thorough analysis that the structure does not need maintenance, or it may signify that other structures are in much greater need of immediate action.
- Protect Corroded or Damaged Areas Only (preventative maintenance): This decision is based on the determination that certain areas of the structure (e.g. in the vicinity of deck joints) are in much worse condition than the other areas of the structure which are not subject to leakage of deicing salts. This option requires the identification of the areas requiring maintenance.

- Protect Entire Structure: In this case, the weathering steel bridge is treated much like a carbon steel bridge, although there may be a need to use special techniques or materials in the coating process.

- Preventative Maintenance (non-painting): This option includes measures to limit the exposure to deicing salts (e.g., by cleaning drains and scuppers or better-sealing materials) or to treat the surface to prevent the corrosive action of the salts (e.g., periodic washing or special chemical treatments).

1. Types and Sources of Data

The decision should be based on a well developed database. The major sources of data include the following:

- Biennial Bridge Inspection: Safety inspections are conducted every 2 years on all weathering steel bridges. Inspectors record instances of broken bolts, damaged members, and excessive corrosion and scaling. However, there is substantial confusion and lack of agreement on what the acceptable levels of corrosion scale or surface roughnesses are. In some cases, it may be necessary to remove corrosion scale by blast cleaning or power tool cleaning to determine section loss or pitting. This is not part of a routine bridge inspection. Therefore, if significant corrosion or pitting is suspected, a special inspection when cleaning may be required.

- Bridge Data: Relevant information that is readily available is as follows: age of bridge; level of salt usage (both under and over the bridge); type of construction (e.g., rolled beam, box girder, plate girder, truss); configuration (e.g., stiffeners, angles, types and number of joints); traffic type (e.g., trucks) and volume; accessibility for rigging; size and gauge of steel; and exposure environment (e.g., degree of salting, rainfall, humidity, pollution, winds, temperature). These factors affect the degree of exposure of the bridge to corrosive agents and the likelihood that chlorides and moisture will result in accelerated corrosion. For example, Michigan DOT has shown that certain pin and hanger connections and sheltered areas of a bridge (i.e., "tunnel effect") can greatly accelerate the corrosion and pitting.

- Special Corrosion Inspection: This is a nonroutine inspection to examine the joints and other components for pitting, loss of section, or chloride penetration. It often requires special equipment to dismantle assemblies (e.g., pin and hanger connection) or to abrasive blast clean salt-exposed areas to examine pitting and metal loss. Dismantling joints is normally required only when there is suspicion of reduction in structural strength. However, examination of pitting and chloride contamination can yield valuable information on the type of cleaning and painting needed.

2. Analyzing Available Data

The maintenance decision depends on the agency's policy of maintenance and its perception of the condition and continuing risks from chloride corrosion, as well as the various factors enumerated above. One major, controversial question is the ultimate corrosion rate of unprotected weathering steel and its effect on fatigue life. The original literature from the steel industry indicated that the initially high corrosion rates would flatten out to a rate on the order of one quarter that of carbon steel. Recent studies by Michigan DOT and the University of Maryland indicated that, under conditions of extended exposure to chloride or moisture, the rates do not level off and may occur at 1 mil (25 microns) per year or greater for extended time periods. One recommendation is for agencies with structures suspected of high corrosion rates to institute regular monitoring of section thicknesses and its effect on fatigue life. It is also recommended to regularly evaluate the exposure environment.

Following are some factors that favor the various maintenance options.

a. No Maintenance Option (includes deferring maintenance painting)

- Little or no chloride deicing salts used, and absence of marine environment.
- Non-leaking joints, the absence of joints, very light traffic.
- Dry climates, rural areas, no prolonged wet conditions.
- Open structure, with minimal angles, joints, and faying surfaces (e.g., box girders at 20 ft (6 m) or more above roadway).
- Inspection indicates very little corrosion (e.g., intact mill scale) or very light, small-grained scale on top flange and other locations.
- Long term maintenance program includes future painting plans.
- Note: Reference FHWA Technical Advisory 5140.22 for guidance.

b. Paint Corroded Areas Only

- Evidence of severe localized corrosion, including heavy salt deposits.
- Little salt spray exposure from below (e.g., no truck traffic or high clearance, light traffic, or non-highway [e.g., river] crossing).

  NOTE: In the presence of extensive truck spray, it may be more prudent to paint the entire structure rather than the corroded areas only because of the difficulty of isolating the high corrosion areas (see next option).

- Loose scale continues to develop in localized areas even after 5 or more years, evidence of scale loss.

- Configuration presents areas that tend to collect moisture and debris, and which are not readily cleaned by rain and are not readily accessible to drying conditions.

c. Paint Entire Structure

- Corrosion and scale evident in many parts of structure (e.g., evidence of salt running along the entire bottom flange, or salt spray from traffic on bottom of flange).

- Humid or salt-laden environment (e.g., near salt marshes, bays, or coastal areas).

- Aesthetics important (e.g., desirable to have uniform appearance of the entire bridge).

- Difficult to isolate corrosion-prone areas.

- Rigging and mobility cost very high so that it would not be cost-effective to paint entire bridge.

- Corrosion rate data indicates that eventually entire structure will require painting to perform safely for its design life.

d. Preventative Maintenance (non-painting)

- Cleaning and providing adequate drainage for drains, scuppers, dams: This option is favored when such improvements can achieve major reductions in accumulation or distribution of moisture and chlorides into joints or along flanges.

- Surface Chemical Treatment: Examples include benzoic acid, phosphoric acid and tannic acid. The results from the Louisiana State study indicate that this technique is helpful but may not be cost effective.[10]

- Periodic Washing with Water: There is some evidence that such a procedure is effective in reducing the corrosion rate. It is one of the approaches favored in the FHWA technical advisory. Results of the SSPC study, however, indicate that low pressure water jetting cannot remove chlorides embedded in the steel. This approach could require relatively .frequent washing with copious amounts of water. No economic studies have been undertaken on cost-effectiveness of this strategy.

3. Discussion

Many of the above factors are subjective and cannot be precisely measured or defined. Consequently there is a variety of practices and opinions by different State agencies and other interested parties.

B. OPTION 1: PROTECTIVE COATINGS ON CORRODED AREAS ONLY

The most susceptible areas of a structure are the areas beneath open joints where leakage can occur. It should be assumed that eventually all joints will leak, so the treatment should be applied to all areas subjected to joint leaking. In addition, there is an area adjacent to the joints which should also be protected because of the tendency of running water to carry salt to these areas. This ranges from about 6 to 10 ft (2 to 3 m) on either side of the joints, and generally includes the entire web and flange area. As with any protective coating system, it is necessary to consider the following components of the system: surface preparation, application techniques, coating materials, film thickness and quality control.

1. Surface Preparation

a. Cleaning Methods: This study and other investigations indicate that abrasive blasting is mandatory for cleaning corroded weathering steel. Power tool cleaning to bare metal (SSPC-SP 11), while capable of removing most rust and mill scale, leaves an unacceptably high level of chloride and other corrosion products in the pits, which, in both laboratory and field testing, resulted in a substantially reduced coating lifetime for the major coating types recommended. Accelerated laboratory and 4-year field evaluations indicated that either dry or wet blasting will provide equivalent coating performance.

Should wet abrasive blasting be specified, the SSPC laboratory results also indicated that medium sand (e.g., 20/40 mesh) is optimal for contaminant removal, although Michigan DOT favors a finer abrasive (e.g., staurolite). One approach in wet blasting is to use the minimum amount of water (for dust control) during the early stages but to conduct a final cleaning with larger volumes of water or pure water at about 200 psi (1400 KPa) to remove the soluble salts. Alternate cleaning techniques such as dry blasting followed by pressurized rinse (e.g., 200 psi [1400 KPa]), dry blasting followed by steam cleaning, or pressurized water jetting with abrasive injection may give equivalently clean results, but at much slower and less productive rates than wet abrasive blasting.

b. Production Rates: Wet abrasive blasting is usually slower than dry blasting, possibly 75 to 90 percent of the production rate at best. The difficulty in removing the wet sand may further reduce the productivity. Blast cleaning of weathering steel requires more energy than for comparable carbon steel. Various estimates are 20 to 40 percent additional effort required (e.g., additional time and abrasive). This is attributed to the tightly adherent corrosion scale on the weathering steel which covers 100 percent of the surface, whereas for carbon steel typically only relatively small portions are badly corroded and pitted.

c. Pressure: It is essential that contractor be required to use the proper pressure (90 psi {630 kPa] minimum, 110 to 115 psi [760 to 790 kPa] preferred) to give higher cleaning rates.

d. Abrasives: A hard, angular abrasive is recommended, with Mohs hardness of 6 minimum, conforming to the SSPC abrasive specification. The preferred size is 90 percent between 20 and 40 mesh. Examples include copper slag and low-dusting silica abrasives. An alternative is a 40/60 mesh staurolite.

e. Inhibitors: Because of questions about the effect on paint lifetime, it is recommended that no inhibitor be used. A small amount of light flash rusting (golden color) is not considered highly detrimental. On the other hand, if a dark blackish or bluish corrosion product appears, this is probably evidence that there is substantial soluble salt remaining on the surface, and that additional cleaning may be required. (See discussion on soluble salts.)

f. Assessing Surface Cleanliness: Prior to painting, the surface should be evaluated for visual and chemical cleanliness as follows:

i. Visual Cleanliness: No rust, mill scale, or other foreign matter is permitted as stated in SSPC-SP 10. SSPC-Vis 1 should be used to assist in judging the cleanliness. Michigan DOT recommends holding the visual standard at a slight distance (12 in or 30 cm) from the surface to get the most accurate comparison.

ii. Chemical Cleanliness: If soluble salts are suspect, the area should be evaluated using SSPC or other field techniques for detecting soluble salts. The recommended parameter to measure is conductivity following swabbing of the surface with deionized water. This information can then be used to obtain an estimate of the amount of contamination present on the surface, expressed as chloride ion in gr/in^2 (grains per in^2) [$\mu g/cm^2$ (micrograms per cm^2)]. If the level of chloride contamination is 5×10^{-3} gr/in^2 (50 $\mu g/cm^2$) or greater, the surface should be recleaned. If the specific chloride concentration is less than 1×10^{-3} gr/in^2 (10 $\mu g/cm^2$), the surface is considered clean. Chloride levels between 1 and 5 $\times 10^{-3}$ gr/in^2 (10 and 50 $\mu g/cm$) indicate the surface is marginal. These acceptable and marginal chloride levels are based on results of the prior study on surface contaminants for the FHWA and the types of coating systems employed in the current study. Different values may apply if less sturdy coating systems are specified for use in maintaining a weathering steel bridge.

2. Application

a. Application Methods: The preferred method is conventional air spray because it allows greater control of the amount of paint applied. However, the selection should ultimately be based on the manufacturer's recommendations. Brushing may require special inspection to ensure that the proper film thickness is achieved.

b. Quantity of Paint: Because weathering steel is considerably rougher than carbon steel, it requires a substantially higher volume of primer; estimates range from 30 to 50 percent. The contractor should be made aware of this factor in bid negotiations.

c. Dry Film Thickness: For the primer, a 3-mil (75 micron) minimum DFT is recommended. The thickness gauge should be calibrated on bare weathering steel in accordance with SSPC-PA 2.

3. Coating Materials

a. Classification of Structures

Recommendations for coating systems are based on the condition of the structure and the severity of the exposure environment. The condition of the existing bridges is classified as low-chloride or high-chloride as discussed earlier. A third category (i.e., new A 588 steel) is also discussed for the convenience of those highway engineers considering shop painting of A 588 steel.

The exposure conditions are classified as mild/moderate or severe, based on the presence of corrosive factors. These include salt dripping, salt splashing, high humidity, frequent wet and dry cycling and other possible contaminants. A summary of the recommendations is given in table 15.

The principal recommended coating materials for a previously corroded area (subject to high chloride) are ethyl silicate inorganic zinc-rich coating systems, epoxy and polyurethane organic zinc-rich coating systems, and a thermal spray zinc system. Each of these systems is expected to provide long-term corrosion protection in the range of highway exposure environments encountered, including the most extreme corrosive conditions.

b Coating Materials for Corroded Steel in Severe Environment

1. Ethyl Silicate Zinc/Epoxy/Urethane

- Surface Preparation: SP-10 (see section 2).
- Primer: A two-component ethyl silicate solvent-borne inorganic zinc-rich coating.
- Second Coat: Two-component high-build epoxy polyamide, procured from the same manufacturer as that of the primer.

- Optional Topcoat: Two-package aliphatic urethane. For fascia girders, added protection or if aesthetics are important, this system can be applied.

Low-VOC versions of this system have shown excellent performance in a limited number of field trials.

A vinyl intermediate and topcoat is also considered an acceptable system from a performance basis, however, because of the high-solvent content, the vinyl coats are not expected to meet existing or proposed VOC level requirements.

2. Epoxy Zinc/Epoxy/Urethane

- Primer: Two-component epoxy polyamide zinc-rich coating.
- Second Coat: Two-component high build epoxy polyamide.
- Optional Topcoat: Two-component aliphatic urethane. This may be used for improved aesthetics or to provide additional protection in expected severe corrosion or mechanical damage areas.

3. Thermal Spray Zinc/Epoxy

- Primer: Thermally sprayed metallic zinc coating.
- Second Coat: Low-build (thin film) epoxy polyamide designed to provide an additional barrier over the zinc.
- Optional Topcoat: aliphatic polyurethane. This would be required primarily for aesthetic purposes.

c. Coating Materials for Corroded Zones in Mild/Moderate Environments

In addition to the above, there are several coating systems that have demonstrated good performance but are not as highly rated as the above three systems. These alternative coatings are recommended for all but the most severe exposure locations. These are as follows:

1. Urethane Zinc/Epoxy/Urethane

- Primer: Moisture-cured zinc-filled urethane.
- Intermediate Coat: Two-component high-build epoxy polyamide.
- Topcoat: Two-component aliphatic polyurethane.

2. High-Solids Epoxy Mastic/Polyurethane

- Primer: High-solids, high-build, good-wetting two-component epoxy coating (often described as "epoxy mastic").
- Topcoat: Two-component aliphatic polyurethane.

C. OPTION 2: FULL REPAINT

In some cases it will be possible to distinguish between the corroded and the non-corroded areas. The former will often consist of the joints and areas such as those along the top of the bottom flange where water runoff is present or the bottom of the bottom flange which is subjected to salt spray from trucks.

Surface Preparation of Corroded Sections: These should be prepared as described in Section B

1. Coating Systems for Corroded Steel in Severe Environmental Exposure

The systems recommended are identical to those described in Section B and include:

a. SSPC-SP 10
Ethyl silicate inorganic zinc primer
Epoxy polyamide intermediate
Aliphatic polyurethane topcoat

b. SSPC-SP 10 (see Section A below)
Epoxy polyamide zinc rich primer
Epoxy polyamide intermediate
Aliphatic polyurethane topcoat

c. SSPC-SP 10
Thermal spray zinc
Epoxy polyamide sealer

Guidelines on surface preparation are given in Section B.

2. Coating Systems for Non-Corroded Steel in Severe Exposure Environment.

The coating materials are the same as in C.1 above for corroded steel.

The preferred methods of surface preparation are dry blasting and wet abrasive blasting. From a performance standpoint, Power Tool Cleaning To Bare Metal (SSPC-SP 11) is acceptable; however, it is often too slow for general use. Pressurized water jetting without abrasive is also an acceptable technique for noncorroded areas which will be coated with the same systems noted below for hand tool cleaning. Hand tool cleaning can be an acceptable preparation method when only non-corroded sections are being prepared with this method and when these areas do not have any loose scale or dirt on them. Finally, the systems to be applied must be either a high solids epoxy mastic or a proven inhibitive oil alkyd (note: SSPC-Paint 25 is a candidate). In addition, the hand tool cleaning should not be used to prepare joint areas or other areas which may in the future be exposed to salt runoff or splash.

3. Coating Systems for Corroded Steel in a Mild/Moderate Environment

If the steel has become noticeably corroded or has a soluble chloride level of 50 $\mu g/cm^2$ the surface requires the same high-quality systems required for severe environments listed in C.1 above

4. Coating Systems for Non-Corroded Steel in a Mild/Moderate Environment

a. Coating Materials for Blast Cleaned Surfaces

All the systems recommended for corroded steel in a mild/moderate environment are also acceptable here. In addition, an oil-alkyd system as described below may be suitable. However, see note.

For the organic zinc epoxy urethane system and the epoxy mastic polyurethane system, it may be possible to substitute a commercial blast (SSPC-SP 6) for a near-white metal blast (SSPC-SP 10). In addition, the polyurethane topcoat for the three-coat inorganic or organic zinc systems may not be needed except for aesthetic purposes.

Oil-Alkyd/Alkyd

- Primer: Oil-alkyd coating with calcium sulfonate as inhibitive pigment (two coats). An alternative pigmentation with a proven track record such as zinc oxide (e.g., SSPC-Paint 25) may be substituted for the calcium sulfonate alkyd primer.
- Topcoat: Alkyd containing aluminum or other conventional pigmentation. For improved weatherability, a compatible silicone-alkyd may be used.

The system that was tested in this program was an oil-alkyd containing basic lead silico-chromate. This was selected because it had been commonly used by highway departments for many years and was a standard reference system. Because of restrictions on use of lead and chromate, this system is no longer recommended. The recommendations for using calcium sulfonate is based on field tests of this system on weathering steel utility towers, and other reported usage of it on bridges. The recommendation for SSPC-Paint 25 is based on documented long-term exterior performance on test panels applied to carbon steel.

NOTE: The FHWA strongly recommends considering life-cycle costs when selecting a protective coating system for A-588 bridges. Thus, it is normally advisable to select the best quality materials consistent with surface preparation achievable, as the material costs are typically 10 to 20 percent of the total costs of repainting.

b. Coating Materials for Non-Blast Cleaned Surfaces

For noncorroded steel in a mild/moderate environment, it may be possible to use power tool cleaning in place of abrasive blast cleaning.

As noted previously, the minimum surface preparation recommended for chloride contaminated weathering steel is SSPC-SP 6, Commercial Blast, with SSPC-SP 10 (Near White Metal Blast Cleaning). If a technique other than abrasive blast cleaning is used, the remaining chloride contamination level on the steel will often be in excess of 100 $\mu g/cm^2$ of chloride. The coating system which is expected to give the best performance over this type of surface is a good wetting oil alkyd similar to the system described above. Other systems (such as the epoxy mastic, the inorganic zinc, the epoxy zinc, and the urethane zinc) are NOT recommended for a non-blast cleaned surface.

For hand tool cleaned surfaces or pressurized water jetting, the suggested system is inhibitive oil alkyd (zinc oxide or calcium sulfonate). (See NOTE above.)

5. Application and Film Thickness:

The methods of application again include conventional air or airless spray. The former is preferred for joints and other confined areas, but most contractors prefer airless spray for the webs and other large areas because of its production rate.

The dry film thickness should be a minimum of 3 mils (75 microns) above the peaks (as measured by SSPC-PA 2) for the primers. The primer will require an additional 25 percent of material compared to similar surface areas over carbon steel because of the inherent roughness of the weathering steel.

Sources of Coatings

Inorganic zinc-rich coatings

- AASHTO M 300, Inorganic zinc-rich Primer.
- SSPC-Paint 29, Type I, "Zinc Dust Sacrificial Primer, Performance Based."

Inorganic zinc-rich coating systems.

- Florida DOT Qualified Products List (QPL).

Epoxy zinc-rich primer.

- SSPC-Paint 29, "Zinc Dust Sacrificial Primer, Performance-Based," Type II, Organic (epoxy).
- Louisiana DOTD Qualified Products List.

Epoxy zinc-rich coating system.

- Michigan DOT QPL.

Oil-alkyd primer

- SSPC-Paint 25, "Red Iron Oxide, Zinc Oxide, Raw Linseed Oil and Alkyd Primer."

Alkyd topcoat

- SSPC-Paint 104, "White or Tinted Alkyd Paint."

High-solids epoxy mastic coating

- Several DOTs (e.g., Pennsylvania, Connecticut, South Carolina) have established QPLs for epoxy mastic coatings.

Thermal spray zinc coating

- SSPC Coating System Guide 23, "Guide to Thermal Spray Metallic Coating Systems." (NOTE: This guide does not provide a materials specification but describes materials, application, and system properties.)

Other coating systems

For the other coating systems referenced (i.e., calcium sulfonate alkyd, urethane zinc-rich primer, epoxy [intermediate and topcoat] and urethanes), industry or government materials specifications or QPLs were not available. Some of these standards are in development by SSPC and some government agencies.

APPENDIX 2

DATA FROM EXTERIOR EXPOSURES AND STATISTICAL ANALYSIS

Raw Data from Field Evaluations

Tables 16 to 20 contain all the data for degree of rusting and extent of scribe undercutting from each of the five exterior exposure sites. Table 21 contains all the dry film thickness measurements for each of the samples prepared for the field evaluations, along with data for mean dry film thickness and standard deviations of each system component coat.

Statistical Analysis of Data from Field Exposures

From the prior discussion it is clear that a number of factors influence the outcome of the exposure experiments at each site. To gain a better understanding of the relative importance of these factors, an ANOVA was performed on the ratings from the different exposure sites. These ANOVA's were performed separately for rusting and scribe data.

Factors examined for both rust and scribe data were:

- Differences among coating system performance.
- Surface preparation.
- Site severity.
- Effects of substrate salt contamination and configuration.

This results in four categories of ANOVA data: entitled coating system ANOVA's ; surface preparation ANOVA's ; site ANOVA's; and specimen ANOVA's . These four categories are then replicated for both rusting and scribe undercutting data, resulting in a total of eight ANOVA categories. A summary of the results for each ANOVA category is depicted in tables 22 through 29.

Each of the ANOVA categories contains data from more than one ANOVA. Several different ANOVA's were run on selected subsets of the full data. The data sets were different for each ANOVA. Selection of data to be used in each ANOVA was done so that all ANOVA's were based on full factorial data sets. Further, each data set is intended to provide an understanding of the relative importance of the principal factors. The factors incorporated into each ANOVA data set were previously shown in table 7. Each data set has a unique analytical aim. The primary effect being examined is described in table 7 for each data set. The effect of the coating system and surface preparation is observed in each data set. Seven distinct data sets were created for the rusting data. Three ANOVA sets were created for the scribe data. A typical data set is shown in full in table 8.

The creation of several data sets eliminates the need to estimate factor influence when few specimens of a specific class or type were used. Partitioning of the total data into factorial subsets permits comparisons of "apples with apples."

Table 16. Raw rust and scribe data from Kure Beach site.

KURE BEACH 25 m LOT
MD Bottom T - SALTED
RUST RATINGS [4]

			11 MONTHS						23 MONTHS					
			SURFACE OF "T" SECTION [3]					OVER	SURFACE OF "T" SECTION					OVER
PANEL ID	PAINT CODE [1]	SURF PREP [2]	1	2	3	4	5	ALL	1	2	3	4	5	ALL
SRT	1	DRY	10	10	9.7	10	10	10	10	10	10	10	10	10
SRT1	1	DRY	10	10	10	9.7	10	10	10	10	10	9	10	9.3
SRU	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SRU1	1	WET	10	9.7	9.3	9.7	10	9.3	10	9.3	9.3	10	10	9.3
SRV	2	DRY	10	10	10	10	9	9.3	10	10	8	10	8	8.3
SRV1	2	DRY	10	10	10	10	10	10	10	10	8.3	10	8.3	9
SRW	2	WET	10	10	10	10	10	10	9	10	8	10	9	9
SRW1	2	WET	10	10	10	10	10	10	9	10	10	10	9	9
SRX	3	DRY	10	10	8.3	8	10	8	8	9	8	10	8	8
SRX1	3	DRY	10	10	9.3	10	9.7	9.3	10	9	9	10	10	9.3
SRY	3	WET	9	10	8.3	9	8	8	8	9.3	8	9	8	8
SRY1	3	WET	10	10	9.3	10	9	9.3	10	10	9	10	9	9.3
SRZ	4	DRY	9	9.3	10	9	9	9	8	9	10	8	8	8
SRZ1	4	DRY	9	9	8	8	8	8	8	8	7	7	7	7
SSA	4	WET	9	9	9	9	9	9	9	8	9	9	8	8
SSA1	4	WET	9	9	9	8	10	8.3	9	8	10	8	9	8
SSB	5	DRY	10	10	9	8	9	8	10	10	8	8	9	8
SSB1	5	DRY	10	10	9.3	10	9	9	8	9	10	9	8	8
SSC	5	WET	9.7	10	10	8.3	9	9	10	10	9	8	9	9
SSC1	5	WET	10	9.7	9	10	10	9	10	9	8	10	10	9
SSD	6	DRY	7	7	6	8	6	6	7	6	6	7	4	6
SSD1	6	DRY	7	7	6	8	6	6	7	6	4	7	6	6
SSE	6	WET	7	7	6	10	6	6	7	6	4	9	4	6
SSE1	6	WET	8	8	8	8.3	8	8	7	8	7	8	8	7
SSF	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SSF1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SSG	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SSG1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SSH	1	P.TOOL	10	10	9.7	9	9.3	9	9.7	9	9	8	8	8
SSH1	1	P.TOOL	10	10	10	10	10	10	10	10	10	10	10	10
SSI	2	P.TOOL	8	9	10	10	10	9	7	9	10	10	10	8
SSI1	2	P.TOOL	10	10	10	10	10	10	10	10	10	10	8	8.3
SSJ	3	P.TOOL	8	8.3	9	10	8	8	8	8	9	10	8	8
SSJ1	3	P.TOOL	10	10	8.3	10	9	9	10	10	8	9	9	9
SSK	4	P.TOOL	7	8	8	8	8	7	6	7	7	8	4	6
SSK1	4	P.TOOL	8.3	8	9	8	8	8	8	8	8	8	8	8
SSL	5	P.TOOL	9	10	9	9	9	9	6	9	9	9	8	7
SSL1	5	P.TOOL	9	9.7	9	9.7	9.7	9	8	10	9	9	9	8.3
SSM	6	P.TOOL	8	9	9	8	8	8	7	8	9	6	8	7
SSM1	6	P.TOOL	8.3	9	8	8	8	8	9	8	8	7	6	7

[1] Reference table 1.

[2] Reference table 3.

[3] Reference figure 3.

[4] Rust ratings per ASTM D 610, scribe ratings are in units of 1/32 in (0.8 mm).

Table 16. Raw rust and scribe data from Kure Beach site (continued).

KURE BEACH 25 m LOT
MD Bottom T - SALTED
RUST RATINGS

			35 MONTHS						47 MONTHS					
PANEL	PAINT	SURF	SURFACE OF "T" SECTION					OVER	SURFACE OF "T" SECTION					OVER
ID	CODE	PREP	1	2	3	4	5	ALL	1	2	3	4	5	ALL
SRT	1	DRY	10	10	9.3	9	10	9.3	10	10	9.7	8.3	10	9
SRT1	1	DRY	10	10	9.3	9	10	9	10	10	9.7	8.3	9.7	9
SRU	1	WET	10	9	9	10	10	9	10	10	9	9.3	10	9
SRU1	1	WET	10	9	10	9	10	9.3	10	9.3	9.3	9.3	9.7	9.3
SRV	2	DRY	9	8	8	9	8	8	9	8	8	9	7	7
SRV1	2	DRY	9.3	10	9	10	9	9	9.7	9.3	9.3	9	8.3	9
SRW	2	WET	9	9	8	9	9.3	9	8.3	8	8	9	9	8
SRW1	2	WET	8	10	10	8	8	8	8.3	9.7	10	8.3	8	8.3
SRX	3	DRY	8	8	8	8	9.3	8	8.3	8.3	8.3	8	9.3	8
SRX1	3	DRY	10	9	9	9	9	9	10	9	9	9	9	9
SRY	3	WET	8	9	8	9	8	8	8	9	8.3	9	7	8
SRY1	3	WET	9.3	10	9	10	10	9.3	9.3	10	9	10	9	9.3
SRZ	4	DRY	8	8	9	8	8	8	8	8.3	9	8	8.3	8
SRZ1	4	DRY	8	8	7	7	7	7	8	8	7	6	7	6
SSA	4	WET	9	8.3	9	9	9	8.7	9	9	8.3	9	8.3	8.3
SSA1	4	WET	8	9	9	8	9.3	8	8.3	9	9	8	9	8
SSB	5	DRY	10	9.7	9	8	8	8	10	9	8.3	8	8	8
SSB1	5	. DRY	9	8	8	9	10	8.3	9	9	8	9	10	8.3
SSC	5	WET	9	9.7	9	8	9	9	9	9.3	9.3	8	8.3	8.3
SSC1	5	WET	9	9.3	9	9.7	8	9	8.3	9.7	9	9.7	8.3	9
SSD	6	DRY	6	6	4	7	4	6	6	6	4	7	4	6
SSD1	6	DRY	6	6	4	7	4	6	6	6	4	7	4	6
SSE	6	WET	6	6	6	8	4	6	6	6	6	8	4	6
SSE1	6	WET	7	7	7	7	7	7	6	7	7	7	7	6
SSF	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SSF1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SSG	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SSG1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SSH	1	P.TOOL	8	8	8	8	7	8	6	7	6	8	6	6
SSH1	1	P.TOOL	10	10	10	10	10	10	10	10	10	10	10	10
SSI	2	P.TOOL	6	9	10	10	9	7	6	8	9	9.7	8	7
SSI1	2	P.TOOL	10	9	8	10	7	8	8	8	6	10	6	6
SSJ	3	P.TOOL	7	7	8	10	8	7	6	6	7	9	6	6
SSJ1	3	P.TOOL	9.3	9.3	8	9.3	10	8.3	9	9	7	9.7	8	7
SSK	4	P.TOOL	2	2	7	8	2	4	2	2	7	8	2	4
SSK1	4	P.TOOL	6	8	7	8	8	7	6	7	6	8	7	6
SSL	5	P.TOOL	4	8	7	8	8	6	4	7	7	6	6	4
SSL1	5	P.TOOL	6	9	8	8	8	7	6	8.3	8	8.3	7	7
SSM	6	P.TOOL	4	7	8	6	6	6	4	7	8	6	6	6
SSM1	6	P.TOOL	8	8.3	8	7	6	7	6	9	8	7	4	6

Table 16. Raw rust and scribe data from Kure Beach site (continued).

KURE BEACH 25 m LOT

MD Bottom T - UNSALTED

RUST RATINGS

			11 MONTHS						23 MONTHS					
PANEL ID	PAINT CODE	SURF PREP	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL
SUD	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUD1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUE	1	WET	10	10	10	10	10	10	9.3	10	10	10	10	10
SUE1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SUF	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUF1	2	DRY	10	10	10	10	10	10	10	9.7	10	10	10	10
SUG	2	WET	10	10	10	10	10	10	10	10	10	10	9.7	10
SUG1	2	WET	10	10	10	10	10	10	10	9.7	10	10	10	10
SUH	3	DRY	10	10	10	10	10	10	10	10	10	10	9.7	10
SUH1	3	DRY	10	10	10	10	9.7	10	10	9.7	10	10	9	9.7
SUI	3	WET	10	9	8.3	10	8	8.3	10	9	8	10	8	8
SUI1	3	WET	10	10	9	9.7	9	9	8.3	10	9	10	9	9
SUJ	4	DRY	10	10	9.3	10	9	9.3	10	10	9	10	9	9
SUJ1	4	DRY	10	10	9.7	10	10	10	10	10	10	10	9.7	10
SUK	4	WET	9.7	10	8.3	9	10	9	9.3	9.3	8.3	9	9	9
SUK1	4	WET	9	10	10	9.7	10	9.3	9	9.7	10	9	10	9
SUL	5	DRY	10	10	10	9	10	9.3	10	10	10	9	10	9.3
SUL1	5	DRY	10	10	10	9	10	9.3	10	10	10	9	10	9.3
SUM	5	WET	10	10	9	10	10	9.3	9	9.3	9	9.3	10	9
SUM1	5	WET	9	10	9.7	10	10	9.3	9	10	9	9	9	9
SUN	6	DRY	8.3	9	8	8	9	8	8	8	7	6	8	7
SUN1	6	DRY	8	9	8	8	8	8	8	8	7	6	8	7
SUO	6	WET	8	9	8	9	7	8	8	8.3	7	8	6	7
SUO1	6	WET	10	8	6	8	8	8	9	7	6	7	7	7
SUP	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUP1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUQ	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SUQ1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10

Table 16. Raw rust and scribe data from Kure Beach site (continued).

KURE BEACH 25 m LOT
MD Bottom T - UNSALTED

RUST RATINGS

			35 MONTHS						47 MONTHS					
PANEL	PAINT	SURF	SURFACE OF "T" SECTION					OVER	SURFACE OF "T" SECTION					OVER
ID	CODE	PREP	1	2	3	4	5	ALL	1	2	3	4	5	ALL
SUD	1	DRY	10	10	10	9.3	10	10	10	9.7	10	9.3	10	9.7
SUD1	1	DRY	10	10	10	9	10	9.3	10	10	10	9	10	9.3
SUE	1	WET	9.7	10	10	10	10	10	10	10	10	9	10	9.3
SUE1	1	WET	10	10	10	9.7	9.7	10	9.7	10	10	9	10	9.3
SUF	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUF1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUG	2	WET	9.7	10	10	10	10	10	10	9.7	10	9.7	9.3	9.3
SUG1	2	WET	10	10	10	10	9.7	10	10	9.3	9.3	10	9.3	9.3
SUH	3	DRY	10	10	9.3	10	9.3	9.7	10	10	10	10	9.7	10
SUH1	3	DRY	10	9.7	10	10	9.7	10	10	10	10	10	9.7	10
SUI	3	WET	9.3	9.3	8	10	8	8	9	9	8	10	8	8
SUI1	3	WET	9	8.7	8	9.3	8	8	9	9.3	9	9.7	8	8.3
SUJ	4	DRY	10	10	9	10	8	9	10	9.7	9	10	8	8
SUJ1	4	DRY	10	10	9.3	9.3	9.3	9.3	10	10	9	9.3	9	9
SUK	4	WET	9	9.3	8	8	9	8	9	9.3	9	9	9	9
SUK1	4	WET	9	9	10	9	10	9	9	9.3	9.3	9.3	9.3	9
SUL	5	DRY	10	10	10	9	10	9.3	10	10	9	10	10	9.3
SUL1	5	DRY	10	9.7	10	9	10	9.3	10	10	10	9	10	9.3
SUM	5	WET	9	9	9	9	9	9	9.3	8.3	9	9	9.3	9.3
SUM1	5	WET	9	10	9	10	10	9	9.3	10	9	10	9.3	9.3
SUN	6	DRY	7	7	6	6	8	6	7	8	6	6	7	6
SUN1	6	DRY	6	8	6	6	7	6	7	8	7	6	7	6
SUO	6	WET	8	8	7	7	6	7	8	8.3	7	7	6	7
SUO1	6	WET	8	7	6	7	7	7	8	7	6	6	7	6
SUP	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUP1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SUQ	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SUQ1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10

Table 16. Raw rust and scribe data from Kure Beach site (continued).

KURE BEACH 25 m LOT
A588 CONTROL (4 X 6 X 1/4)[3]

RUST RATINGS[3]

PANEL ID	PAINT CODE[2]	SURF PREP	MONTHS EXPOSURE 11	23	35	47
SZV	1	DRY	10	10	10	10
SZV1	1	DRY	10	10	10	10
SZW	1	WET	10	10	10	10
SZW1	1	WET	10	10	10	10
SZX	2	DRY	10	10	10	10
SZX1	2	DRY	10-	10	10-	10
SZY	2	WET	10	10	10	10
SZY1	2	WET	10	10	10	10
SZZ	3	DRY	10	10	10	10
SZZ1	3	DRY	10	10	10	10
TAA	3	WET	10	10	10	10
TAA1	3	WET	10	10	10	10
TAB	4	DRY	10	10	10	9+
TAB1	4	DRY	10	10	10	10-
TAC	4	WET	10	10	10	10
TAC1	4	WET	10	10	10	10
TAD	5	DRY	10	10	10	10
TAD1	5	DRY	10	10	10	10
TAE	5	WET	10	10	10	10
TAE1	5	WET	10	10	10	10
TAF	6	DRY	9	8	7	8
TAF1	6	DRY	8	8	7	8
TAG	6	WET	8+	8	7	7
TAG1	6	WET	8	7	6	6
TAH	7	DRY	10	10	10	10
TAH1	7	DRY	10	10	10	10
TAI	7	WET	10	10	10	10
TAI1	7	WET	10	10	10	10

[1] Reference table 1.
[2] Reference table 3.
[3] Scribe ratings are in units of 1/32 in (0.8 mm).

Table 16. Raw rust and scribe data from Kure Beach site (continued).

KURE BEACH 25 m LOT
A588 CONTROL (4 X 6 X 1/4)

PANEL ID	PAINT CODE	SCRIBE SURF PREP	MONTHS EXPOSURE 11	23	35	47
SZV	1	DRY	0	0	0	1
SZV1	1	DRY	0	0	0	1
SZW	1	WET	0	1	1	1
SZW1	1	WET	0	0	1	1
SZX	2	DRY	0	0	0	0
SZX1	2	DRY	0	0	0	0
SZY	2	WET	0	0	0	0
SZY1	2	WET	0	0	0	0
SZZ	3	DRY	0	0	4	6
SZZ1	3	DRY	0	0	2	5
TAA	3	WET	0	0	0	4
TAA1	3	WET	0	0	0	3
TAB	4	DRY	4	4	6	12
TAB1	4	DRY	4	4	8	12
TAC	4	WET	2	3	4	8
TAC1	4	WET	2	3	4	6
TAD	5	DRY	0	0	3	6
TAD1	5	DRY	0	0	4	20
TAE	5	WET	0	0	1	3
TAE1	5	WET	0	0	3	10
TAF	6	DRY	0	1	2	2
TAF1	6	DRY	0	1	2	3
TAG	6	WET	0	1	2	2
TAG1	6	WET	0	1	2	3
TAH	7	DRY	0	0	0	0
TAH1	7	DRY	0	0	0	0
TAI	7	WET	0	0	0	0
TAI1	7	WET	0	0	0	0

Table 17. Raw rust and scribe data from Louisiana site.

LOUISIANA BRIDGE EXPOSURE

LOUISIANA "T" SECTION

RUST RATINGS [4]

			9 MONTHS						21 MONTHS						41 MONTHS					
PANEL ID	PAINT CODE [1]	SURF PREP [2]	SURFACE OF "T" SECTION [3]					OVER ALL	SURFACE OF "T" SECTION					OVER ALL	SURFACE OF "T" SECTION					OVER ALL
			1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
SVD	1	DRY	10	10	10	10	10	10	9	9	9	9	9	9	8	9	8	8	9	8
SVD1	1	DRY	10	10	10	10	10	10	9	9	9	9	9	9	9	10	9	9	9	9
SVE	1	WET	10	10	10	9.7	10	10	9	9	9	9	9	9	8	9	9	9	9	9
SVE1	1	WET	10	10	10	10	10	10	9	9	9	9	8	9	9	9	9	9	9	9
SVF	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SVF1	2	DRY	10	10	10	10	10	10	10	10	10	10	9	10	10	10	10	9	10	10
SVG	2	WET	10	10	10	10	10	10	10	10	9	10	10	10	9	10	10	10	10	10
SVG1	2	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	10
SVH	3	DRY	9	10	9.7	10	10	9.3	8	8	8	9	9	9	8	8	8	10	8	8
SVH1	3	DRY	9	10	10	9.7	9	9	8	8	10	9	9	9	8	8	9	9	8	8
SVI	3	WET	9	10	9.7	10	10	9.3	8	8	9	9	9	9	8	9	8	10	7	8
SVI1	3	WET	9	10	10	10	8	9	7	9	9	9	8	9	8	10	9	9	7	8
SVJ	4	DRY	10	10	10	9.7	10	10	Panel Missing											
SVJ1	4	DRY	10	10	10	9.7	10	10	Panel Missing											
SVK	4	WET	9.7	10	10	9.7	9	9.3	8	8	9	9	9	9	8	8	9	8	8	8
SVK1	4	WET	10	10	9	9	9	9	9	9	9	9	9	9	9	9	8	8	8	8
SVL	5	DRY	9.7	10	10	10	9	9.3	9	9	9	8	9	9	8	9	9	9	9	9
SVL1	5	DRY	10	10	10	10	10	10	9	9	10	9	9	9	9	9	10	9	8	9
SVM	5	WET	10	10	10	10	9	9.3	9	9	9	10	8	9	9	10	9	9	9	9
SVM1	5	WET	9.7	10	10	9.7	9.3	9.3	9	9	9	9	9	9	9	9	9	8	6	9
SVN	6	DRY	7	7	9	9	8	7	5	5	8	7	7	6	5	4	7	7	7	6
SVN1	6	DRY	8	8	9	8	8	8	6	6	8	6	6	6	7	6	7	6	6	6
SVO	6	WET	7	8	9.3	8	8	7	5	6	8	6	6	6	5	6	8	6	6	6
SVO1	6	WET	7	7.7	9	8	6	7	5	6	8	7	5	6	5	7	7	7	5	6

[1] Reference table 1.
[2] Reference table 3.
[3] Reference figure 3.
[4] Rust ratings per ASTM D 610,scribe ratings are in units of 1/32 in (0.8 mm).

Table 17. Raw rust and scribe data from Louisiana site (continued).

LOUISIANA BRIDGE EXPOSURE

ONTARIO ANGLE (3 X 3 X 12 X 5/16)

RUST RATINGS

			9 MONTHS						21 MONTHS						41 MONTHS					
PANEL	PAINT	SURF	SURFACE OF ANGLE					OVER	SURFACE OF ANGLE					OVER	SURFACE OF ANGLE					OVER
ID	CODE	PREP	1	2	3	4	5	ALL	1	2	3	4	5	ALL	1	2	3	4	5	ALL
SWB	1	DRY	10	10	10	10	10	10	9	10	9	9	9	9	8	7	8	8	5	8
SWB1	1	DRY	10	10	10	10	10	10	9	9	9	9	9	9	8	8	8	9	8	8
SWC	1	WET	10	10	10	9.7	8	9	7	8	9	8	7	8	7	9	7	8	7	8
SWC1	1	WET	10	10	10	9.7	8	9	9	9	8	9	7	9	8	8	7	8	6	8
SWD	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10	9	10	9	10	10	9
SWD1	2	DRY	10	10	10	10	10	10	10	10	9	10	9	10	9	10	10	10	10	10
SWE	2	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SWE1	2	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	9	9	10	10	9
SWF	3	DRY	10	10	9.7	10	10	10	9	9	9	9	9	9	9	9	9	9	10	9
SWF1	3	DRY	10	9.7	9	10	10	9.3	9	9	9	9	9	9	9	8	8	9	9	8
SWG	3	WET	9.7	9.7	10	9.7	10	9.7	9	8	9	9	10	9	9	8	9	9	10	9
SWG1	3	WET	9	10	10	8	9	9	8	9	9	8	8	8	8	8	9	8	8	8
SWH	4	DRY	9	10	10	9	9	9	8	9	9	9	9	9	8	9	9	8	9	8
SWH1	4	DRY	9	10	10	9.7	9	9	8	9	9	9	9	9	8	9	9	9	8	9
SWI	4	WET	9	9.7	9	8.7	8	8	8	9	8	8	8	8	8	9	8	8	8	8
SWI1	4	WET	9	9	9.7	10	7	8	8	9	8	9	8	8	8	9	8	9	7	8
SWJ	5	DRY	9	10	10	9.7	8	9	8	9	9	9	7	8	8	9	9	9	7	9
SWJ1	5	DRY	9	10	9.7	10	10	9.3	8	9	10	9	8	9	8	9	9	9	9	9
SWK	5	WET	10	10	9	10	10	9.3	9	9	9	9	10	9	9	9	8	9	10	9
SWK1	5	WET	9	9.7	10	9.7	9	9	8	9	9	8	8	8	8	9	9	8	8	8
SWL	6	DRY	9.7	9	9	8	9	9	8	8	9	6	9	8	7	8	9	7	9	8
SWL1	6	DRY	8	8	8	9	6	7	6	7	6	7	5	6	7	8	7	7	8	7
SWM	6	WET	8	9.7	9.7	7	7	7	5	7	9	5	4	6	6	8	8	6	7	7
SWM1	6	WET	7	9.7	9.7	7	7	7	6	8	9	5	7	7	5	7	8	6	4	6

Table 17. Raw rust and scribe data from Louisiana site (continued).

LOUISIANA BRIDGE EXPOSURE
ONTARIO ANGLE (3 X 3 X 12 X 5/16)

SCRIBE RATINGS

PANEL ID	PAINT CODE	SURF PREP	MONTHS EXPOSURE 9	21	41
SWB	1	DRY	3	1	1
SWB1	1	DRY	4	1	3
SWC	1	WET	1	1	1
SWC1	1	WET	1	2	1
SWD	2	DRY	0	0	0
SWD1	2	DRY	0	0	0
SWE	2	WET	0	0	0
SWE1	2	WET	0	0	0
SWF	3	DRY	0	1	2
SWF1	3	DRY	0	1	2
SWG	3	WET	0	1	2
SWG1	3	WET	0	1	2
SWH	4	DRY	3	1	5
SWH1	4	DRY	2	2	2
SWI	4	WET	2	2	3
SWI1	4	WET	1	1	1
SWJ	5	DRY	0	1	1
SWJ1	5	DRY	0	1	1
SWK	5	WET	0	2	2
SWK1	5	WET	0	2	2
SWL	6	DRY	1	1	0
SWL1	6	DRY	1	1	0
SWM	6	WET	2	1	0
SWM1	6	WET	3	1	1

LOUISIANA BRIDGE EXPOSURE
A-588 CONTROL (4 X 6 X 1/4)

PANEL ID	PAINT CODE	SURF PREP	MONTHS EXPOSURE					
			9	21	41	9	21	41
			RUST			SCRIBE		
TBD	1	DRY	10	9	9	0	2	2
TBD1	1	DRY	10	8	9	0	1	1
TBE	1	WET	10	9	9	0	0	1
TBE1	1	WET	10	8	9	0	1	1
TBF	2	DRY	10	9	10	0	0	0
TBF1	2	DRY	10	9	9	0	0	0
TBG	2	WET	10	10	10	0	0	0
TBG1	2	WET	10	10	10	0	0	0
TBH	3	DRY	10	9	8	0	0	2
TBH1	3	DRY	10	9	9	0	0	1
TBI	3	WET	10	9	9	0	0	0
TBI1	3	WET	10	9	9	0	0	1
TBJ	4	DRY	10	9	8	0	0	3
TBJ1	4	DRY	10	9	8	0	0	3
TBK	4	WET	10	9	8	0	0	3
TBK1	4	WET	10	9	8	0	0	2
TBL	5	DRY	10	9	9	0	0	1
TBL1	5	DRY	10	9	9	0	0	0
TBM	5	WET	9.7	8	8	0	0	0
TBM1	5	WET	10	9	9	0	0	0
TBN	6	DRY	10	8	7	1	0	1
TBN1	6	DRY	9	8	6	1	1	0
TBO	6	WET	9	8	6	1	0	0
TBO1	6	WET	9	7	6	1	0	0

Table 18. Raw rust and scribe data from Michigan site.

MICHIGAN BRIDGE EXPOSURE

MD Bottom T - SALTED

RUST RATINGS [4]

			6 MONTHS						19 MONTHS						41 MONTHS					
PANEL ID	PAINT CODE [1]	SURF PREP [2]	SURFACE OF "T" SECTION [3]					OVER ALL	SURFACE OF "T" SECTION					OVER ALL	SURFACE OF "T" SECTION					OVER ALL
			1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
SSN	1	DRY	10	10	10	10	10	10	10	10	10	9	10	9.3	10	9.3	10	7	10	8
SSN1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10	9.3	10	10	9	10	9
SSO	1	WET	10	9.7	10	10	10	10	10	9.3	10	10	10	10	10	8.3	10	9.3	10	9
SSO1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	9.7	10	9	10	9
SSP	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	10	9.3
SSP1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10	9.7	10	10	10	10	10
SSQ	2	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SSQ1	2	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SSR	3	DRY	10	10	9.7	10	10	10	10	10	10	10	10	10	9	9.7	10	9	10	9
SSR1	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10	8.3	9.3	10	9.3	10	9
SSS	3	WET	9.7	10	9.7	10	10	10	10	10	9.3	10	10	10	8.3	9	9.7	9.3	9	9
SSS1	3	WET	9.3	10	9	10	9.3	9	10	10	9	10	10	10	9	8.3	8.3	9	10	8.3
SST	4	DRY	10	10	10	10	10	10	10	9	10	9	10	9	9.7	8.3	9.7	9	10	9
SST1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	9	9	9	10	9
SSU	4	WET	10	10	9.7	10	10	10	10	10	9.3	10	10	10	10	9.3	9.7	9	10	9
SSU1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10	9.3	9.3	10	9	10	9
SSV	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SSV1	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10	9.7	9.3	10	9.3	10	9.3
SSW	5	WET	10	10	10	9.7	10	10	10	10	10	10	10	10	10	9.3	10	10	10	9.7
SSW1	5	WET	10	10	10	10	10	10	10	10	10	10	10	10	9.7	9	10	9	10	9
SSX	6	DRY	10	10	10	10	10	10	9	10	10	10	10	9.3	8	9.7	9.7	9.7	10	9
SSX1	6	DRY	10	9	9	10	9	9	9	8	9	10	9	8	8	8	9	9	9	8
SSY	6	WET	10	9	8	9.7	9	9	10	8	8	8	9	8	10	8	8	8.3	9.3	8
SSY1	6	WET	9	8	9.7	9.3	10	9	8	7	10	8	10	7	7	6	10	8	9	7

[1] Reference table 1.
[2] Reference table 3.
[3] Reference figure 3.
[4] Rust ratings per ASTM D 610, scribe ratings are in units of 1/32 in (0.8 mm).

Table 18. Raw rust and scribe data from Michigan site (continued).

MICHIGAN BRIDGE EXPOSURE
MD Bottom T - UNSALTED
RUST RATINGS

			6 MONTHS						19 MONTHS						41 MONTHS					
PANEL ID	PAINT CODE	SURF PREP	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL
SUR	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SUR1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	9.7	10	10	10	10
SUS	1	WET	10	10	10	10	9.3	10	10	10	10	10	9	9.3	10	10	9.7	10	9.7	9.7
SUS1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SUT	2	DRY	10	10	10	10	9.3	10	10	10	10	10	10	10	10	10	10	10	10	10
SUT1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	9.7	10	10	10	10
SUU	2	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SUU1	2	WET	10	10	9.7	10	9.7	10	10	10	9.7	10	10	10	10	10	10	10	10	10
SUV	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10	9.7	10	10	10	10	9.7
SUV1	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SUW	3	WET	10	10	9.3	10	10	10	10	10	10	10	10	10	10	9.7	9.7	10	10	9.7
SUW1	3	WET	10	10	9.7	10	10	10	10	10	10	10	10	10	9	10	9.3	10	10	9.3
SUX	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	10	9.3
SUX1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9.7	10	10
SUY	4	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	9.3	10	10	10	9.7
SUY1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SUZ	5	DRY	10	10	9.7	10	9.7	10	10	10	9.3	10	10	10	9.7	9.3	9.3	10	10	9.3
SUZ1	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10	8.3	9.3	10	10	10	9
SVA	5	WET	10	10	10	10	9	9.7	10	10	10	10	9.3	10	10	10	10	10	10	10
SVA1	5	WET	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	10	10	9.3
SVB	6	DRY	10	10	9.3	9.3	9	9	10	8	9	8	9	8	9.7	8	9.3	8	9.7	8
SVB1	6	DRY	10	10	10	10	10	10	10	9	10	8	9.3	9	9	8.3	10	8	9.3	8
SVC	6	WET	10	9	9	9	9.3	9	9.3	8	9	8	10	8	9.3	8	10	8	10	8
SVC1	6	WET	10	9	9.3	10	9.3	9	8	8	9	10	9	8	8	8	9	9	9.3	8

Table 18. Raw rust and scribe data from Michigan site (continued).

MICHIGAN BRIDGE EXPOSURE

A588 CONTROL (4 X 6 X 1/4)

PANEL ID	PAINT CODE	SURF PREP	MONTHS EXPOSURE					
			6	19	41	6	19	41
			RUST			SCRIBE		
TBP	1	DRY	10	10	10	0	0	2
TBP1	1	DRY	10	9.7	10	0	0	2
TBQ	1	WET	10	9.3	10	0	0	1
TBQ1	1	WET	10	10	10	0	0	0
TBR	2	DRY	10	10	9.3	0	0	1
TBR1	2	DRY	10	10	10	0	0	0
TBS	2	WET	10	10	10	0	0	1
TBS1	2	WET	10	10	10	0	0	0
TBT	3	DRY	10	10	10	0	0	0
TBT1	3	DRY	10	10	10	0	0	0
TBU	3	WET	10	10	10	0	0	0
TBU1	3	WET	10	10	10	0	0	0
TBV	4	DRY	10	10	9	0	0	6
TBV1	4	DRY	10	10	10	0	0	4
TBW	4	WET	10	10	10	0	0	0
TBW1	4	WET	10	10	10	0	0	4
TBX	5	DRY	10	10	10	0	0	0
TBX1	5	DRY	10	10	10	0	0	0
TBY	5	WET	10	10	10	0	0	0
TBY1	5	WET	10	10	10	0	0	0
TBZ	6	DRY	10	9	8.3	0	1	1
TBZ1	6	DRY	10	9	8.3	0	1	1
TCA	6	WET	10	9	8	0	1	1
TCA1	6	WET	10	9	8.3	0	0	1

Table 19. Raw rust and scribe data from Neville Island site.

NEVILLE ISLAND EXPOSURE
MD Top T - SALTED

RUST RATINGS [4]

PANEL ID	PAINT CODE [1]	SURF PREP [2]	10 MONTHS						21 MONTHS					
			SURFACE OF "T" SECTION [3]					OVER ALL	SURFACE OF "T" SECTION					OVER ALL
			1	2	3	4	5		1	2	3	4	5	
SQJ	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQJ1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQK	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQK1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQL	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQL1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQM	2	WET	10	10	9.7	10	10	10	10	10	10	10	10	10
SQM1	2	WET	9.7	9.7	10	10	10	10	10	10	10	10	10	10
SQN	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQN1	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQO	3	WET	10	9	8	10	10	9	10	10	8	10	10	9
SQO1	3	WET	10	8	8	10	9.3	8	10	8	7	10	10	8
SQP	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQP1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQQ	4	WET	10	10	10	9.7	10	10	10	10	10	10	10	10
SQQ1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQR	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQR1	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQS	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQS1	5	WET	10	10	10	9.7	10	10	10	10	10	9.7	10	10
SQT	6	DRY	8.3	8.3	8.3	8.3	8	8	8.3	9	10	8.3	9	9
SQT1	6	DRY	8	9.3	8.3	9	9	8	8.3	10	10	9	10	9
SQU	6	WET	8	8.3	9	8.3	8	8	8	9	10	8	8	8
SQU1	6	WET	8.3	9.3	9	8	10	8	9	9.7	7	7	10	8
SQV	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQV1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQW	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQW1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQX	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQX1	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQY	8	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQY1	8	WET	10	10	10	10	10	10	10	10	10	10	10	10

[1] Reference table 1.
[2] Reference table 3.
[3] Reference figure 3.
[4] Rust ratings per ASTM D 610, scribe ratings are in units of 1/32 in (0.8 mm).

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE

MD Top T - SALTED

RUST RATINGS

PANEL ID	PAINT CODE	SURF PREP	36 MONTHS SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL	44 MONTHS SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL
SQJ	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQJ1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQK	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQK1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQL	2	DRY	10	10	10	10	10	10	10	10	10	10	9.7	10
SQL1	2	DRY	10	10	10	10	10	10	10	10	10	10	9.7	10
SQM	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQM1	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQN	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQN1	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQO	3	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQO1	3	WET	10	9	9	10	10	9	10	9	8	10	10	9
SQP	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQP1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQQ	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQQ1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQR	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQR1	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQS	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQS1	5	WET	10	10	10	9.3	10	10	10	10	10	10	10	10
SQT	6	DRY	10	10	10	9	9.3	9	9.7	10	10	9	10	9.3
SQT1	6	DRY	10	10	10	9	10	9.3	9.7	9.7	10	9.3	10	9.3
SQU	6	WET	9	10	10	8	10	8	9	9.7	10	8	9	8.3
SQU1	6	WET	9	10	10	7	10	8	9.7	10	10	8	10	8.3
SQV	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQV1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQW	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQW1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQX	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQX1	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SQY	8	WET	10	10	10	10	10	10	10	10	10	10	10	10
SQY1	8	WET	10	10	10	10	10	10	10	10	10	10	10	10

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE

MD Top T - UNSALTED

RUST RATINGS

			10 MONTHS						21 MONTHS					
PANEL ID	PAINT CODE	SURF PREP	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL
SSZ	1	DRY	10	10	10	9.7	10	10	10	10	10	10	10	10
SSZ1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STA	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
STA1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
STB	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STB1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STC	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
STC1	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
STD	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STD1	3	DRY	10	10	10	10	10	10	10	10	10	9.7	10	10
STE	3	WET	10	10	10	10	9.3	10	10	10	10	10	10	10
STE1	3	WET	8.3	9	10	10	10	9	9	10	10	10	10	9.7
STF	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STF1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STG	4	WET	10	10	10	9.7	10	10	10	10	10	10	10	10
STG1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
STH	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STH1	5	DRY	10	10	10	9.7	10	9.7	10	10	10	9	10	9.7
STI	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
STI1	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
STJ	6	DRY	10	9	9.7	8	10	8	10	10	10	8	10	9
STJ1	6	DRY	9	9.3	9.3	10	10	9	10	10	10	9	10	9.3
STK	6	WET	9	8	10	10	9	8	9	8	10	10	10	8.3
STK1	6	WET	8.3	9	10	9	10	9	9	9	10	8	10	8.3
STL	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STL1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STM	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
STM1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
STN	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STN1	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STO	8	WET	10	10	10	10	10	10	10	10	10	10	10	10
STO1	8	WET	10	10	10	10	10	10	10	10	10	10	10	10

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE

MD Top T - UNSALTED

RUST RATINGS

			36 MONTHS						44 MONTHS					
PANEL	PAINT	SURF	SURFACE OF "T" SECTION					OVER	SURFACE OF "T" SECTION					OVER
ID	CODE	PREP	1	2	3	4	5	ALL	1	2	3	4	5	ALL
SSZ	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SSZ1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STA	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
STA1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
STB	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STB1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STC	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
STC1	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
STD	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STD1	3	DRY	10	10	10	10	10	10	10	10	10	9.7	10	10
STE	3	WET	10	10	10	10	10	10	10	10	10	10	10	10
STE1	3	WET	10	10	10	10	10	10	10	10	10	10	10	10
STF	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STF1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STG	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
STG1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
STH	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STH1	5	DRY	10	10	10	9	10	9	10	10	10	9.3	10	10
STI	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
STI1	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
STJ	6	DRY	10	10	10	8	10	8	9.7	10	10	8	10	8.3
STJ1	6	DRY	10	10	10	8.3	10	9	10	10	10	9	10	9.3
STK	6	WET	10	10	10	9	10	9.3	10	9.3	10	9.3	10	9.3
STK1	6	WET	10	10	10	8	10	8	10	9.7	10	8	10	8.3
STL	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STL1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STM	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
STM1	7	WET	10	10	10	10	10	10	10	10	10	10	10	10
STN	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STN1	8	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STO	8	WET	10	10	10	10	10	10	10	10	10	10	10	10
STO1	8	WET	10	10	10	10	10	10	10	10	10	10	10	10

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE
ONTARIO ANGLE (3 X 3 X 12 X 5/16)

RUST RATINGS

			10 MONTHS						21 MONTHS					
PANEL ID	PAINT CODE	SURF PREP	SURFACE OF ANGLE 1	2	3	4	5	OVER ALL	SURFACE OF ANGLE 1	2	3	4	5	OVER ALL
SVP	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVP1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVQ	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVQ1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVR	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVR1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVS	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVS1	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVT	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVT1	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVU	3	WET	10	8	9	10	10	8	10	8.3	10	10	10	9
SVU1	3	WET	10	9.3	8	10	10	9	10	10	10	10	10	10
SVV	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVV1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVW	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVW1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVX	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVX1	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVY	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVY1	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVZ	6	DRY	10	8	9.3	10	10	9	10	9	10	9	10	9
SVZ1	6	DRY	9.3	8	10	10	10	9	10	9	10	10	10	9.3
SWA	6	WET	9.3	9	8.3	8	9	8	10	10	10	8.3	10	9
SWA1	6	WET	8	10	9.7	8	6	8	10	10	10	8	6	8

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE

ONTARIO ANGLE (3 X 3 X 12 X 5/16)

RUST RATINGS

			36 MONTHS						44 MONTHS					
PANEL ID	PAINT CODE	SURF PREP	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL	SURFACE OF "T" SECTION 1	2	3	4	5	OVER ALL
SVP	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVP1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVQ	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVQ1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVR	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVR1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVS	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVS1	2	WET	10	10	10	10	9.3	10	10	10	10	9	9	9.3
SVT	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVT1	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVU	3	WET	10	9	10	10	10	9	10	9	10	10	10	9.3
SVU1	3	WET	10	10	9.3	10	10	10	10	10	10	10	10	10
SVV	4	DRY	10	10	10	9.3	10	9.3	10	10	10	10	10	10
SVV1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVW	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVW1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVX	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVX1	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVY	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVY1	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVZ	6	DRY						NO PANEL						
SVZ1	6	DRY						NO PANEL						
SWA	6	WET						NO PANEL						
SWA1	6	WET						NO PANEL						

Table 19. Raw rust and scribe data from Neville Island Site (continued).

NEVILLE ISLAND EXPOSURE

ONTARIO ANGLE (3 X 3 X 12 X 5/16)

RUST RATINGS

			36 MONTHS						44 MONTHS					
PANEL	PAINT	SURF	SURFACE OF "T" SECTION					OVER	SURFACE OF "T" SECTION					OVER
ID	CODE	PREP	1	2	3	4	5	ALL	1	2	3	4	5	ALL
SVP	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVP1	1	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVQ	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVQ1	1	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVR	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVR1	2	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVS	2	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVS1	2	WET	10	10	10	10	9.3	10	10	10	10	9	9	9.3
SVT	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVT1	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVU	3	WET	10	9	10	10	10	9	10	9	10	10	10	9.3
SVU1	3	WET	10	10	9.3	10	10	10	10	10	10	10	10	10
SVV	4	DRY	10	10	10	9.3	10	9.3	10	10	10	10	10	10
SVV1	4	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVW	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVW1	4	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVX	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVX1	5	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SVY	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVY1	5	WET	10	10	10	10	10	10	10	10	10	10	10	10
SVZ	6	DRY						NO PANEL						
SVZ1	6	DRY						NO PANEL						
SWA	6	WET						NO PANEL						
SWA1	6	WET						NO PANEL						

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE
ONTARIO COVER PLATE (4 X 6 X 1/4)

PANEL ID	PAINT CODE	SURF PREP	MONTHS EXPOSURE							
			10	21	36	44	10	21	36	44
			RUST				SCRIBE			
SXJ	1	DRY	10	10	10	10	0	0	2	0
SXJ1	1	DRY	10	10	10	10	0	0	1	0
SXK	1	WET	10	10	10	10	0	0	0	0
SXK1	1	WET	10	10	10	10	0	0	0	0
SXL	2	DRY	10	10	10	10	0	0	0	0
SXL1	2	DRY	10	10	10	10	0	0	0	0
SXM	2	WET	10	10	10	10	0	0	0	0
SXM1	2	WET	10	10	10	10	0	0	0	0
SXN	3	DRY	10	10	10	10	0	0	0	0
SXN1	3	DRY	10	10	10	10	0	0	0	0
SXO	3	WET	10	10	10	10	0	0	0	0
SXO1	3	WET	10	10	10	10	0	0	0	0
SXP	4	DRY	10	10	10	10	0	0	2	2
SXP1	4	DRY	10	10	10	10	0	0	2	3
SXQ	4	WET	10	10	10	10	0	0	1	1
SXQ1	4	WET	10	10	10	10	0	0	1	2
SXR	5	DRY	10	10	10	10	0	0	1	1
SXR1	5	DRY	10	10	10	10	0	0	1	0
SXS	5	WET	10	10	10	10	0	0	1	1
SXS1	5	WET	10	10	10	10	0	0	1	1
SXT	6	DRY	10	10	10	10	0	0	1	1
SXT1	6	DRY	10	10	10	10	0	0	1	1
SXU	6	WET	10	10	10	10	0	0	1	1
SXU1	6	WET	10	10	10	10	0	0	1	1
SXV	7	DRY	10	10	10	10	0	0	0	0
SXV1	7	DRY	10	10	10	10	0	0	0	0
SXW	7	WET	10	10	10	10	0	0	0	0
SXW1	7	WET	10	10	10	10	0	0	0	0

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE
NJ BRIDGE (4 X 6 X 1/4)

PANEL	PAINT	SURF	MONTHS EXPOSURE							
ID	CODE	PREP	10	21	36	44	10	21	36	44
			RUST				SCRIBE			
SYR	1	DRY	10	10	10	10	0	0	1	1
SYR1	1	DRY	10	10	10	10	0	0	1	1
SYS	1	WET	10	10	10	10	0	0	0	1
SYS1	1	WET	10	10	10	10	0	0	0	1
SYT	2	DRY	10	10	10	10	0	0	0	1
SYT1	2	DRY	10	10	10	10	0	0	0	1
SYU	2	WET	10	10	10	10	0	0	0	0
SYU1	2	WET	10	10	10	10	0	0	0	1
SYV	3	DRY	10	10	10	10	0	0	0	0
SYV1	3	DRY	10	10	10	10	0	0	0	0
SYW	3	WET	10	10	10	10	0	0	0	0
SYW1	3	WET	10	10	10	10	0	0	0	0
SYX	4	DRY	10	10	10	10	0	0	2	2
SYX1	4	DRY	10	10	10	10	0	0	3	4
SYY	4	WET	10	10	10	10	0	0	2	1
SYY1	4	WET	10	10	10	10	0	0	1	1
SYZ	5	DRY	10	10	10	10	0	0	1	1
SUZ1	5	DRY	10	10	10	10	0	0	2	1
SZA	5	WET	10	10	10	10	0	0	1	1
SZA1	5	WET	10	10	10	10	0	0	1	1
SZB	6	DRY	10	10	10	10	0	0	1	1
SZB1	6	DRY	10	10	10	10	0	0	1	1
SZC	6	WET	10	10	10	10	0	0	1	1
SZC1	6	WET	10	10	10	10	0	0	0	1
SZD	7	DRY	10	10	10	10	0	0	0	0
SZD1	7	DRY	10	10	10	10	0	0	0	0
SZE	7	WET	10	10	10	10	0	0	0	0
SZE1	7	WET	10	10	10	10	0	0	0	0

Table 19. Raw rust and scribe data from Neville Island site (continued).

NEVILLE ISLAND EXPOSURE

A588 CONTROL (4 X 6 X 1/4)

PANEL ID	PAINT CODE	SURF PREP	MONTHS EXPOSURE							
			10	21	36	44	10	21	36	44
			RUST				SCRIBE			
SZF	1	DRY	10	10	10	10	0	0	1	1
SZF1	1	DRY	10	10	10	10	0	0	1	1
SZG	1	WET	10	10	10	10	0	0	0	1
SZG1	1	WET	10	10	10	10	0	0	0	1
SZH	2	DRY	10	10	10	10	0	0	0	0
SZH1	2	DRY	10	10	10	10	0	0	0	1
SZI	2	WET	10	10	10	10	0	0	0	0
SZI1	2	WET	10	10	10	10	0	0	0	0
SZJ	3	DRY	10	10	10	10	0	0	0	0
SZJ1	3	DRY	10	10	10	10	0	0	0	0
SZK	3	WET	10	10	10	10	0	0	0	0
SZK1	3	WET	10	10	10	10	0	0	0	0
SZL	4	DRY	10	10	10	10	0	0	6	8
SZL1	4	DRY	10	10	10	10	0	0	6	8
SZM	4	WET	10	10	10	10	0	0	1	3
SZM1	4	WET	10	10	10	10	0	0	1	2
SZN	5	DRY	10	10	10	10	0	0	0	1
SZN1	5	DRY	10	10	10	10	0	0	0	1
SZO	5	WET	10	10	10	10	0	0	1	1
SZO1	5	WET	10	10	10	10	0	0	1	1
SZP	6	DRY	10	10	10	10	0	0	0	1
SZP1	6	DRY	10	10	10	10	0	0	0	1
SZQ	6	WET	10	10	10	10	0	0	0	1
SZQ1	6	WET	10	10	10	10	0	0	0	1
SZR	7	DRY	10	10	10	10	0	0	0	0
SZR1	7	DRY	10	10	10	10	0	0	0	0
SZS	7	WET	10	10	10	10	0	0	0	0
SZS1	7	WET	10	10	10	10	0	0	0	0
SZT	8	DRY	10	10	10	10	0	0	0	0
SZT1	8	DRY	10	10	10	10	0	0	0	0
SZU	8	NO PANEL								
SZU1	8	WET	10	10	10	10	0	0	0	0

Table 20. Raw rust and scribe data from Pennsylvania site.

SAXONBURG PA BRIDGE EXPOSURE

MD Top T - SALTED

RUST RATINGS [4]

PANEL ID	PAINT CODE [1]	SURF PREP [2]	9 MONTHS SURFACE OF "T" SECTION [3] 1	2	3	4	5	9 MONTHS OVER ALL	21 MONTHS SURFACE OF "T" SECTION 1	2	3	4	5	21 MONTHS OVER ALL
SQZ	1	DRY	9	9.7	9	10	9.7	9	9	9.3	8	8	9	8
SQZ1	1	DRY	9	10	9	10	9	9	9	9	8	9	8	8
SRA	1	WET	10	10	9	10	9.3	9	9	9	8.3	10	9	9
SRA1	1	WET	9	9.3	9	9.7	9	9	9	8.3	8	8	8	8
SRB	2	DRY	10	10	9.3	10	9.7	9.3	9	9	8.3	10	9	9
SRB1	2	DRY	9.3	9.7	9	10	9	9.3	9	8	8	10	8.3	8
SRC	2	WET	9.3	9.7	9	10	9.3	9.3	9	9	8	10	9	9
SRC1	2	WET	9.3	10	10	10	9.3	9.7	9	9.3	9.3	10	9	9
SRD	3	DRY	9.7	9.3	9.3	10	9.3	9.3	9	9	8	10	8	8.3
SRD1	3	DRY	9	9.3	9	10	10	9.3	8.3	9	8.3	10	8	8.3
SRE	3	WET	10	9.7	9.7	10	9.3	9.3	9	9	9	10	8.3	9
SRE1	3	WET	9	9.3	9.3	10	9.3	9	9	9.3	8.3	10	8	8.3
SRF	4	DRY	9.3	9.3	9	10	9.3	9.3	9	9	8	10	8	8.3
SRF1	4	DRY	10	9.7	9.3	9.7	9	9.3	9	9	8	9.3	8	8.3
SRG	4	WET	10	9	9	10	9.3	9	9	8.3	8.3	10	8	8.3
SRG1	4	WET	10	9.7	9.3	9.3	9.7	9.3	10	10	8.3	10	8.3	9
SRH	5	DRY	9.7	9	9.3	10	9.7	9.3	9	9	8.3	9.3	9	9
SRH1	5	DRY	10	9.3	9.3	10	10	9.3	9	9	9	10	9	9
SRI	5	WET	9.7	9.7	9	10	9.3	9.3	9	9	8	10	8	8.3
SRI1	5	WET	9	9.3	9	10	9	9	8.3	9	8	10	8.3	8.3
SRJ	6	DRY	9	9.3	8.7	9	9	9	9	8.3	8	8	8.3	8
SRJ1	6	DRY	8.3	9	9	10	9	9	8	8.3	8	8.3	8	8
SRK	6	WET	9	8.3	9	9	9	9	8	8	8	8	8	8
SRK1	6	WET	9	8	9	8	9	8	8.3	7	7	7	8	7
SRL	7	DRY	10	10	10	10	10	10	10	9.7	9	10	10	9.3
SRL1	7	DRY	10	10	10	10	10	10	10	10	10	10	10	10
SRM	7	WET	10	10	10	10	10	10	10	10	10	10	9	9.3
SRM1	7	WET	10	10	10	10	10	10	9	10	10	10	10	9.3
SRN	1	P.TOOL	9.7	9.3	9.3	10	9.3	9.3	10	10	9	9	9	9
SRN1	1	P.TOOL	9.3	9.7	9	10	9.3	9.3	9	10	9	9	9	9
SRO	2	P.TOOL	8.3	9.3	9	10	8	8	7	7	7	10	9	7
SRO1	2	P.TOOL	9	9	9	10	9	9	7	8	8	10	7	8
SRP	3	P.TOOL	9	9.3	9.7	10	9	9	8	10	10	10	9	8.3
SRP1	3	P.TOOL	9	9	9.7	10	9	9	9	9	9	10	9	9.3
SRQ	4	P.TOOL	8.3	9.7	9.7	9	9	9	8	9	7	9	8	8
SRQ1	4	P.TOOL	9	9.7	9.3	10	9	9	9	9	8.3	10	8	8.3
SRR	5	P.TOOL	9	9.7	9.7	10	10	9.3	9	10	10	9	9	9
SRR1	5	P.TOOL	9.3	10	10	10	10	9.7	9	9	9	9	9	9
SRS	6	P.TOOL	9	8	9.3	9	10	8	8	8	9	8	9	8
SRS1	6	P.TOOL	8.3	8	9	9	9	8	8	8	8	8.3	8	8

[1] Reference table 1.

[2] Reference table 3.

[3] Reference figure 3.

[4] Rust ratings per ASTM D 610, scribe ratings are in units of 1/32 in (0.8 mm).

Table 20. Raw rust and scribe data from Pennsylvania site (continued).

SAXONBURG PA BRIDGE EXPOSURE

MD Top T - SALTED

RUST RATINGS

			36 MONTHS						44 MONTHS					
PANEL	PAINT	SURF	SURFACE OF "T" SECTION					OVER	SURFACE OF "T" SECTION					OVER
ID	CODE	PREP	1	2	3	4	5	ALL	1	2	3	4	5	ALL
SQZ	1	DRY	9	9	8	8	8	8	10	10	9	8	9	9
SQZ1	1	DRY	9	9	8	8	8	8	10	10	8.3	8	9	8.3
SRA	1	WET	9	9	8	9	9	8.3	9	9	9	9	9.3	9
SRA1	1	WET	9	9	8	8	8	8	9	9.3	8	8	9.3	8
SRB	2	DRY	9	9	9	9	8	9	9.3	9	9	9.3	9.3	9
SRB1	2	DRY	9	8	8	9	8	8	9.3	9	9	9.3	9	9
SRC	2	WET	9	9	8	10	8	8.3	9	9	8	10	8	8.3
SRC1	2	WET	9	9	8	9.7	9	8.3	9	9.3	8	9.7	9	9
SRD	3	DRY	9	9	9	10	8	9	9.7	9	9	9.7	9	9
SRD1	3	DRY	9	10	8	10	9	9	9	9.7	9	10	9	9
SRE	3	WET	9	9	8	9	8	8.3	9.7	9	9	9.3	9.3	9
SRE1	3	WET	9	9	8	9	8	8.3	9	9.3	9	10	9	9
SRF	4	DRY	9	9	8	10	8	8.3	9	9.3	8.3	10	9	9
SRF1	4	DRY	9	9	8	9.7	8	8.3	9	9.3	9	9.7	9	9
SRG	4	WET	9	9	8	10	9	9	9	9	9	10	9.3	9
SRG1	4	WET	9	9	9	9	8	9	9	10	9	9.3	9	9
SRH	5	DRY	10	9	9	9.7	9	9	9.3	9.7	9.7	9.7	10	9.7
SRH1	5	DRY	9	9	9	10	9	9	10	9.7	9.7	10	10	9.7
SRI	5	WET	9	9	9	10	8	9	9	9.7	9.7	10	9.7	9.7
SRI1	5	WET	9	9	9	10	9	9	9	9.7	9.7	10	10	9.3
SRJ	6	DRY	9	8	8	7	8	7	9	8	8	7	8	8
SRJ1	6	DRY	8	8	6	8	2	6	8.3	8	7	8.3	2	6
SRK	6	WET	9	8	7	7	7	7	9	8.3	8	8	8	8
SRK1	6	WET	9	6	7	6	4	6	8.3	6	7	6	6	6
SRL	7	DRY	10	9	10	10	9	9.3	10	10	9.3	10	9.3	9.7
SRL1	7	DRY	10	10	10	10	9	9.3	10	10	10	10	10	10
SRM	7	WET	10	10	10	10	9	9.7	10	10	10	10	10	10
SRM1	7	WET	9.3	10	9.3	10	9.3	9.3	9.7	9.7	10	10	10	9.7
SRN	1	P.TOOL	9	9	9	8.7	10	9	9	10	9.3	8.3	9	9
SRN1	1	P.TOOL	9	9.3	9	8	9	8.3	9.3	9.7	9	8.3	9	9
SRO	2	P.TOOL	2	4	2	10	7	4	2	4	4	9.7	6	5
SRO1	2	P.TOOL	2	7	4	10	4	6	2	7	4	9	4	5
SRP	3	P.TOOL	9	9	10	10	9	9	8	9	10	10	9.3	8.3
SRP1	3	P.TOOL	10	8.3	10	10	10	9	9	9	9.7	10	10	9
SRQ	4	P.TOOL	8	9	8	8	9	8	8	9.3	8	8	9	8
SRQ1	4	P.TOOL	8	9	9	10	7	8	9	9.3	8.3	10	7	8
SRR	5	P.TOOL	9	9	10	9	10	9	9	9	10	9	10	9
SRR1	5	P.TOOL	9	9	10	9	10	9	9	9	10	9.7	10	9
SRS	6	P.TOOL	8	8	8	7	9	8	7	8	8	7.7	9	8
SRS1	6	P.TOOL	7	8	9	8	7	7	7	8	8	8	8	8

Table 20. Raw rust and scribe data from Pennsylvania site (continued).

SAXONBURG PA BRIDGE EXPOSURE
MD Top T - UNSALTED
RUST RATINGS

PANEL ID	PAINT CODE	SURF PREP	9 MONTHS						21 MONTHS					
			SURFACE OF "T" SECTION					OVER ALL	SURFACE OF "T" SECTION					OVER ALL
			1	2	3	4	5		1	2	3	4	5	
STP	1	DRY	10	9.7	10	9.7	10	10	9	9	8.3	9	8.3	8.3
STP1	1	DRY	9.3	10	9.7	9.7	9.3	9.3	9	10	9	9	9	9
STQ	1	WET	9.7	10	9.7	10	9.7	10	9	10	9	9.3	9	9.3
STQ1	1	WET	9.3	10	9.7	10	10	9.3	9	9	9	9	9	9
STR	2	DRY	10	9.7	10	10	9.7	10	9.3	9.3	9.3	10	9.3	9.3
STR1	2	DRY	9.7	10	10	10	10	10	10	9.3	9	10	9.3	9.3
STS	2	WET	9.7	10	10	10	9.7	10	9	9.3	9	10	9.3	9.3
STS1	2	WET	9.7	10	10	10	10	10	10	9	10	10	9.3	9.3
STT	3	DRY	10	10	10	10	10	10	10	10	9	10	9	9.3
STT1	3	DRY	9.7	10	9.7	10	9.7	10	9	10	9.3	9.3	9	9.3
STU	3	WET	10	10	10	10	9.7	10	9	9	9	10	9	9
STU1	3	WET	10	10	10	10	10	10	9	8.3	9	10	8	8.3
STV	4	DRY	9.7	9.7	9.7	10	9.7	10	10	10	9.3	10	9.3	9.7
STV1	4	DRY	9.7	10	10	9.7	10	10	9	9	10	10	10	9.3
STW	4	WET	10	9.7	10	9.7	10	10	10	10	9	9	10	9.3
STW1	4	WET	9.7	10	10	9.3	9.7	9.3	9	9.3	9	9	10	9
STX	5	DRY	10	10	9.7	10	10	10	10	10	9	10	9	9.3
STX1	5	DRY	9.7	10	10	10	10	10	10	10	10	9.3	10	9.7
STY	5	WET	9.7	10	10	10	10	10	10	10	10	9.3	10	9.7
STY1	5	WET	9.7	10	10	10	10	10	9.3	9.3	9.3	9	9	9.3
STZ	6	DRY	8.3	8.3	9	9.3	9.3	8.3	8	8	8	8	8	8
STZ1	6	DRY	8.3	8.3	9	10	10	8.3	8	8	8	9	8	8
SUA	6	WET	9	8.3	9.3	10	9	9	8	8	8	10	8	8.3
SUA1	6	WET	8.7	8	9.3	8	9.3	8	9	7	8	7	9	7
SUB	7	DRY	10	10	10	10	10	10	9	10	10	10	10	9.3
SUB1	7	DRY	10	10	10	10	10	10	10	9	10	10	10	9.3
SUC	7	WET	10	10	10	10	10	10	10	9.3	9.3	10	9	9.3
SUC1	7	WET	10	10	10	10	10	10	10	10	10	10	9	9.3

Table 20. Raw rust and scribe data from Pennsylvania site (continued).

SAXONBURG PA BRIDGE EXPOSURE

MD Top T - UNSALTED

RUST RATINGS

			36 MONTHS						44 MONTHS					
			SURFACE OF "T" SECTION					OVER	SURFACE OF "T" SECTION					OVER
PANEL ID	PAINT CODE	SURF PREP	1	2	3	4	5	ALL	1	2	3	4	5	ALL
STP	1	DRY	9	9	9	9	9	9	9.7	10	9.3	9.3	9	9.3
STP1	1	DRY	9	10	9	8	9	9	9.3	10	9.3	9	9.7	9.3
STQ	1	WET	9	10	9	9	10	9	9.3	10	9.3	9.3	10	9.3
STQ1	1	WET	9	9	10	8	9	8.3	9.7	9.3	9.3	9	9.7	9.3
STR	2	DRY	9	9	10	9	9	9	9.7	10	9.7	9.7	10	9.7
STR1	2	DRY	10	9.7	10	10	10	10	9.7	9.7	9.7	10	10	9.7
STS	2	WET	9	10	10	9.3	10	9.3	9.7	10	9.7	9.7	10	9.7
STS1	2	WET	9.3	9.3	10	10	10	9.3	9.7	9.7	10	10	9.7	9.7
STT	3	DRY	10	10	10	10	10	10	10	10	10	10	10	10
STT1	3	DRY	9	10	9.3	9.3	10	9.3	9.7	10	9.7	9.7	10	9.7
STU	3	WET	10	9	9	9.7	9	9	9.7	9	9	9.3	9.7	9
STU1	3	WET	9	9	9	10	9	9	9	9	9.3	10	9	9
STV	4	DRY	10	10	9	10	10	9.3	10	9.3	9.3	9.7	9.3	9.3
STV1	4	DRY	9	10	10	10	9	9.3	9.3	9.7	9.7	9.7	9.7	9.7
STW	4	WET	10	9	9	9	10	9	9.7	10	9.7	9.3	10	9.7
STW1	4	WET	9	10	10	9	9	9	9.3	9.7	9.7	9	9.7	9.3
STX	5	DRY	10	10	9	10	9	9.3	9.7	9.7	9.7	10	9.7	9.7
STX1	5	DRY	9.3	10	10	9.3	10	9.3	9.7	10	10	9.7	10	9.7
STY	5	WET	10	10	10	9	9	9.3	9.7	10	9.7	9.7	10	9.7
STY1	5	WET	9	9	9.3	10	9	9	9.7	9.7	10	9.7	10	9.7
STZ	6	DRY	8	8	8	9	8	8	8	9	8	9	8	8
STZ1	6	DRY	8	8	8	9	4	7	9	9	8	9	6	8
SUA	6	WET	9	8	9	9	8	8	9	8.3	7	9.7	8	8
SUA1	6	WET	9	7	7	6	8	6	9	7	7	7	8	7
SUB	7	DRY	10	10	9	10	10	9.3	10	10	9.3	10	9.7	9.7
SUB1	7	DRY	10	9	9	10	9	9	10	10	10	10	10	10
SUC	7	WET	10	10	9	10	10	9.3	10	9.7	9.7	10	9.7	9.7
SUC1	7	WET	10	10	10	10	10	10	10	10	9.7	10	10	9.7

Table 20. Raw rust and scribe data from Pennsylvania site (continued).

SAXONBURG PA BRIDGE EXPOSURE
ONTARIO COVER PLATE (4 X 6 X 1/4)

PANEL ID	PAINT CODE	SURF PREP	MONTHS EXPOSURE							
			RUST				SCRIBE			
			7	21	36	44	7	21	36	44
SXX	1	DRY	10	10	10	10	0	0	1	1
SXX1	1	DRY	10	10	10	10	0	1	1	1
SXY	1	WET	9.7	10	9.3	10	0	0	1	1
SXY1	1	WET	10	10	9.3	9.7	0	1	0	1
SXZ	2	DRY	10	10	10	10	0	1	0	0
SXZ1	2	DRY	10	10	10	10	0	0	0	0
SYA	2	WET	10	10	10	10	0	1	1	1
SYA1	2	WET	9.7	10	10	10	0	0	1	1
SYB	3	DRY	10	10	10	10	0	0	0	0
SYB1	3	DRY	10	10	10	10	0	0	0	0
SYC	3	WET	10	10	10	10	0	0	0	0
SYC1	3	WET	10	10	10	10	0	0	0	1
SYD	4	DRY	10	10	10	10	2	2	2	3
SYD1	4	DRY	10	10	10	10	3	2	2	1
SYE	4	WET	9.7	10	10	10	1	1	1	1
SYE1	4	WET	9.7	10	10	10	1	1	1	1
SYF	5	DRY	10	10	10	10	0	0	0	0
SYF1	5	DRY	10	10	10	10	0	1	1	1
SYG	5	WET	10	10	10	10	0	0	1	1
SYG1	5	WET	10	10	10	10	0	1	1	1
SYH	6	DRY	10	9.3	9	9	0	1	1	1
SYH1	6	DRY	7	8	6	6	1	1	2	1
SYI	6	WET	10	10	10	9.7	0	1	1	1
SYI1	6	WET	8	8	8	8	1	1	1	1
SYJ	7	DRY	10	10	10	10	0	0	0	0
SYJ1	7	DRY	10	10	10	10	0	0	0	0
SYK	7	WET	10	10	10	10	0	0	0	0
SYK1	7	WET	10	10	10	10	0	0	0	0
SYL	1	P.TOOL	10	9	9.3	9.3	1	1	1	1
SYL1	1	P.TOOL	10	10	10	10	1	1	1	1
SYM	2	P.TOOL	10	10	10	10	1	1	1	0
SYM1	2	P.TOOL	10	10	10	10	0	1	0	1
SYN	3	P.TOOL	10	10	10	10	0	6	10	8
SYN1	3	P.TOOL	10	10	10	10	0	6	6	4
SYO	4	P.TOOL	9.7	9	9	9	1	4	8	8
SYO1	4	P.TOOL	9.3	9	9	8	4	6	10	8
SYP	5	P.TOOL	10	10	10	10	0	6	8	8
SYP1	5	P.TOOL	10	10	10	10	1	2	3	1
SYQ	6	P.TOOL	8.3	8	7	7	2	2	2	2
SYQ1	6	P.TOOL	8	8	7	7	2	2	2	3

Table 20. Raw rust and scribe data from Pennsylvania site (continued).

SAXONBURG PA BRIDGE EXPOSURE
A588 CONTROL (4 X 6 X 1/4)

PANEL ID	PAINT CODE	SURF PREP	MONTHS EXPOSURE							
			7	21	36	44	7	21	36	44
			RUST				SCRIBE			
TAJ	1	DRY	10	10	10	9.7	4	4	4	6
TAJ1	1	DRY	10	10	10	9.7	2	1	2	1
TAK	1	WET	9.7	10	9.3	9.7	4	10	4	24
TAK1	1	WET	10	6	10	10	3	6	4	16
TAL	2	DRY	10	10	10	10	0	0	0	0
TAL1	2	DRY	10	10	10	10	0	0	0	0
TAM	2	WET	10	10	9.7	9.3	0	1	1	1
TAM1	2	WET	9.7	10	10	10	0	1	0	0
TAN	3	DRY	10	10	10	10	0	0	0	0
TAN1	3	DRY	10	10	9.7	10	0	0	0	0
TAO	3	WET	10	10	10	10	0	0	0	0
TAO1	3	WET	10	10	10	10	0	0	0	0
TAP	4	DRY	10	10	10	9.7	3	4	4	4
TAP1	4	DRY	9.3	10	10	10	4	2	3	3
TAQ	4	WET	9.7	10	10	10	1	1	0	1
TAQ1	4	WET	10	10	10	10	1	1	1	1
TAR	5	DRY	10	10	10	10	0	1	1	1
TAR1	5	DRY	10	10	10	10	0	1	0	1
TAS	5	WET	10	10	10	10	0	1	0	1
TAS1	5	WET	10	10	10	10	0	0	0	1
TAT	6	DRY	9.7	9.3	10	9.7	0	0	0	0
TAT1	6	DRY	9.3	10	10	10	0	1	0	1
TAU	6	WET	9.7	9	9	9	1	2	1	1
TAU1	6	WET	9	9	8	8	0	1	1	1
TAV	7	DRY	10	10	10	10	0	0	0	0
TAV1	7	DRY	10	10	10	10	0	0	0	0
TAW	7	WET	10	10	10	10	0	0	0	0
TAW1	7	WET	10	10	10	10	0	0	0	1
TAX	1	P.TOOL	9.3	9	9	9.3	6	10	12	12
TAX1	1	P.TOOL	10	10	10	10	8	16	20	20
TAY	2	P.TOOL	10	10	10	10	1	0	0	0
TAY1	2	P.TOOL	10	10	10	10	0	0	0	0
TAZ	3	P.TOOL	10	9.3	10	9.7	0	2	4	6
TAZ1	3	P.TOOL	10	10	10	10	0	3	12	16
TBA	4	P.TOOL	10	10	0	0	1	32	32	32
TBA1	4	P.TOOL	10	10	0	0	20	32	32	32
TBB	5	P.TOOL	9.7	10	9.3	9.7	1	1	4	8
TBB1	5	P.TOOL	10	10	10	10	0	1	4	6
TBC	6	P.TOOL	10	10	9	9	6	6	6	6
TBC1	6	P.TOOL	9	9	8	8	1	1	1	2

One ANOVA was run on each data set summarized in table 7. The ANOVA's were always run after partitioning each data set into the maximum number of elements. Taking the data set previously shown in table 8 and used in scribe ANOVA 3 as an example, the factors involved are:

- 6 coating systems.
- 3 surface preparations.
- 2 types of specimen.
- 1 site.
- Total number of specimens = 72.

Thus scribe ANOVA 3 is a three-way ANOVA, where the data is partitioned into 6 x 3 x 2 = 36 subsets of size 2 samples each.

ANOVA is based on an examination of the contribution to the total standard deviation in a sample by groupings of data based on influential variables. Variance is the square of the standard deviation for a set of data. ANOVA output is the sum of squares for the deviations from the mean value of the rating for each grouping variable, SS_i. The total sum of squares is the sum of squares for each grouping factor added to the error term (which is itelf the sum of squares within all groups). Equation 1 gives the form for ANOVA determination.

Equation 1. $SS_T = SS_a + SS_b + SS_c + \ldots SS_w$

ANOVA analysis is a powerful technique through which you can:

- Estimate the importance of experimental factors, e.g., coating system or surface preparation.

- Determine whether the difference between two means, e.g., between the mean rust ratings of two coating systems, is statistically significant.

The output shown in table 10 for scribe ANOVA 3 contains mean scribe ratings for each coating system examined for each surface preparation and for each specimen type examined.

Table 10 also contains a summary of the sum-of-squares of the deviations from the standard deviation for all samples in the data set associated with each of the three partitioning factors, their respective interactions, and the residue of the data set called the error term. Each of these sums-of-squares is then divided by the number of degrees of freedom for the factor or interaction between factors, which results in a mean square value for all sums-of-squares, along with a mean square error (MSE) term. The MSE is also the variance associated within groups, (subsets). Mean squares associated with each factor represent the variance between groups. The number of degrees of freedom is one less than the total number of levels associated with the factor or factor interaction term. In the case of coating systems analysis, six coatings were examined. Thus, the number of degrees of freedom (df), is five. The df values for interaction terms are the product of the df values for each factor in the interaction term. The df value for the error term is equal to one less than the difference between the total number of samples in the data set and the sum of the df values for all factors and their interactions. An F-test term, which is a ratio of the mean square to the variance (square of the standard deviation),

Table 21. Full dry film thickness measurements.

Dry Film Thickness Data, System 1

EXPOSURE SITE	PANEL TYPE	SURF PREP	PRIMER	MID-COA	TOP-COAT	EXPOSURE SITE	PANEL TYPE	SURF PREP	PRIMER	MID-COA	TOP-COAT
NEV	MDTS	D	1.03	7.8	9.8	LA	ONT ANG	D	0.59		
NEV	MDTS	D	1.31	8.7	10.9	LA	ONT ANG	W	0.55	6.4	8.2
NEV	MDTS	W	1.33	8.7	11.1	LA	ONT ANG	W	0.7	5.4	7.5
NEV	MDTS	W	1	7.2	9.1	EXTRA	ONT COV	D	1.25	6.2	8
PABR	MDTS	D	1.02	8.1	10.7	EXTRA	ONT COV	D	1.42	8.9	12.3
PABR	MDTS	D	1.65	9.1	10.7	EXTRA	ONT COV	W	1.17	9.1	11
PABR	MDTS	W	1.14	8.1	10.1	EXTRA	ONT COV	W	1.12	7.9	10.6
PABR	MDTS	W	1.13	7.8	10.4	EXTRA	ONT COV	P	2.16	8.1	11.3
PABR	MDTS	P	3.12	9.6	12.9	EXTRA	ONT COV	P	2.31	9.6	13.9
PABR	MDTS	P	3.09	8.3	11.2	NEV	ONT COV	D	1.48	10	13.8
KURE	MBTS	D	1.12	8.1	10.1	NEV	ONT COV	D	1.26	9.8	12.7
KURE	MBTS	D	1.23	8	12.2	NEV	ONT COV	W	0.97	8.6	11.1
KURE	MBTS	W	1.29	8.3	11.2	NEV	ONT COV	W	1.12	8.8	10.7
KURE	MBTS	W	1.33	7.8	11.1	PABR	ONT COV	D	1.42	8.5	10.1
KURE	MBTS	P	6.3	9.5	15	PABR	ONT COV	D	1.48	9.2	11.8
KURE	MBTS	P	3.6	8.2	15.1	PABR	ONT COV	W	1.16	8.1	9.7
M	MBTS	D	1.39	6.3	8.8	PABR	ONT COV	W	1.35	8.8	10.7
M	MBTS	D	1.27	8.1	10.7	PABR	ONT COV	P	2.15	9.2	12.7
M	MBTS	W	1.23	8.3	10.8	PABR	ONT COV	P	2.35	8.6	13.2
M	MBTS	W	1.65	8.6	11.9	NEV	NJCOV	D	1.21	8.5	12.5
NEV	MDTU	D	1.09	7.9	11	NEV	NJCOV	D	1.27	8.2	10.6
NEV	MDTU	D	1.11	7.9	11	NEV	NJCOV	W	1.13	8	10.9
NEV	MDTU	W	1.51	8.6	11	NEV	NJCOV	W	0.98	9	10.7
NEV	MDTU	W	1.24	7.5	10.5	NEV	A588	D	1.14	7.4	9.7
PA	MDTU	D	1.26	8	10.7	NEV	A588	D	0.85	7.8	10.1
PA	MDTU	D	1.06	7.7	9.8	NEV	A588	W	1.22	8.4	10.1
PA	MDTU	W	1.14	7.6	11	NEV	A588	W	1.16	7	9.1
PA	MDTU	W	1.33	7.7	10.4	KURE	A588	D	0.89	7.9	11.6
KURE	MBTU	D	0.92	7.7	9.5	KURE	A588	D	1.18	8.8	11.6
KURE	MBTU	D	1.12	7.6	10.8	KURE	A588	W	1.18	8.6	11.3
KURE	MBTU	W	1.69	8.6	12.5	KURE	A588	W	0.98	8	10.7
KURE	MBTU	W	1.39	8.1	9.9	PABR	A588	D	1.08	8.4	10.9
M	MBTU	D	0.95	7.7	10.7	PABR	A588	D	0.97	7.7	9.4
M	MBTU	D	0.89	7.6	9.9	PABR	A588	W	1.14	8.5	10.9
M	MBTU	W	1.01	7.2	11	PABR	A588	W	1.2	8.3	11.5
M	MBTU	W	1.26	8.3	10.6	PABR	A588	P	0.89	8.6	11.1
LA	LAT	D	1.1	8.1	10.3	PABR	A588	P	0.98	7.9	10.8
LA	LAT	D	1.43	8.2	10.5	LA	A588	D	1.02	7.2	10.9
LA	LAT	W	0.94	8.1	10.1	LA	A588	D	1.15	9.2	11.7
LA	LAT	W	1.47	7.4	11.9	LA	A588	W	0.93	9	12
NEV	ONT ANG	D	0.85	7	8.5	LA	A588	W	1.07	8.5	10.9
NEV	ONT ANG	D	0.9	6.5	8.2	M	A588	D	0.89	8.9	11.3
NEV	ONT ANG	W	0.51	5.7	9	M	A588	D	1.18	7.7	10.9
NEV	ONT ANG	W	0.58	6.4	7.8	M	A588	W	0.87	9.6	13
LA	ONT ANG	D	1.01	6.1	8	M	A588	W	1	8.2	10.5
Mean			1.422	7.9	10.6				1.1904	8.3	11
Std. Dev'n			0.94703	0.8	1.46				0.3898	0.9	1.37

Table 21. Full dry film thickness measurements (continued).

Dry Film Thickness Data, System 2

EXPOSURE SITE	PANEL TYPE	SURF PREP	PRIMER	MID-COA	TOP-COAT	EXPOSURE SITE	PANEL TYPE	SURF PREP	PRIMER	MID-COA	TOP-COAT
NEV	MDTS	D	3.69	6.7	10	LA	ONT ANG	D	4.44	7.2	10.2
NEV	MDTS	D	4.28	6.8	10	LA	ONT ANG	W	4.2	6.6	7.2
NEV	MDTS	W	6.8	9.1	10	LA	ONT ANG	W	3.61	6.5	7.4
NEV	MDTS	W	5.2	8.2	11.3	EXTRA	ONT COV	D	4.77		11.2
PABR	MDTS	D	3.05	6.8	8.7	EXTRA	ONT COV	D	5.3		15.1
PABR	MDTS	D	2.84	7.7	11.1	EXTRA	ONT COV	W	6.2		17.8
PABR	MDTS	W	5.4	8.8	11.2	EXTRA	ONT COV	W	4.51		10
PABR	MDTS	W	5.1	8.8	11.2	EXTRA	ONT COV	P	5.6		20.9
PABR	MDTS	P	4.72	7.9	11.2	EXTRA	ONT COV	P	4.91		15.2
PABR	MDTS	P	4.19	9	10.9	NEV	ONT COV	D	6.5		16.8
KURE	MBTS	D	3.97	9.2	11.6	NEV	ONT COV	D	4.7		9.3
KURE	MBTS	D	3.91	7.3	11.6	NEV	ONT COV	W	4.25		11.7
KURE	MBTS	W	6.4	9.3	11.8	NEV	ONT COV	W	4.85		14.3
KURE	MBTS	W	5.4	8.1	9.1	PABR	ONT COV	D	4.73		10.6
KURE	MBTS	P	4.93	9.2	11.4	PABR	ONT COV	D	4.15		16.1
KURE	MBTS	P	5.5	7.9	9.8	PABR	ONT COV	W	4.77		11.1
MI	MBTS	D	3.13	6.9	9.8	PABR	ONT COV	W	5.2		15.7
MI	MBTS	D	5	8.5	11	PABR	ONT COV	P	5.3		15.7
MI	MBTS	W	6.6	8.9	12.1	PABR	ONT COV	P	5.6		18
MI	MBTS	W	8.9	11	12.6	NEV	NJCOV	D	4.58		10.9
NEV	MDTU	D	5.5	7.9	10.5	NEV	NJCOV	D	4.53		10.3
NEV	MDTU	D	4.57	7.4	10.3	NEV	NJCOV	W	6.5		17.2
NEV	MDTU	W	5.8	8.7	11.2	NEV	NJCOV	W	4.79		9.6
NEV	MDTU	W	4.92	8.6	10.3	NEV	A588	D	5.1		14.2
PA	MDTU	D	4.02	8	9.8	NEV	A588	D	4		10
PA	MDTU	D	4.74	7.8	11.8	NEV	A588	W	4.82		16
PA	MDTU	W	6.9	9	13.6	NEV	A588	W	4.81		12.1
PA	MDTU	W	6.8	9.2	12	KURE	A588	D	3.64		9.8
KURE	MBTU	D	4.81	9.1	11.1	KURE	A588	D	4.65		10.7
KURE	MBTU	D	4.7	7.9	10.9	KURE	A588	W	4.64		12.2
KURE	MBTU	W	5.6	7.7	10.9	KURE	A588	W	4.63		10.6
KURE	MBTU	W	6.1	8.5	10	PABR	A588	D	4.69		13.7
MI	MBTU	D	4.14	7.2	10.2	PABR	A588	D	5		15.8
MI	MBTU	D	4.58	8.1	10.8	PABR	A588	W	4.12		9.5
MI	MBTU	W	5.7	8.9	10.1	PABR	A588	W	5.2		16.8
MI	MBTU	W	6.8	9.3	11.5	PABR	A588	P	4.12		15.7
LA	LAT	D	4.2	8	9.7	PABR	A588	P	4.69		16.3
LA	LAT	D	4.08	7.4	10.2	LA	A588	D	4.17		14.2
LA	LAT	W	5.7	9.1	9.9	LA	A588	D	4.46		11.4
LA	LAT	W	6.6	9.2	9.8	LA	A588	W	4.26		10.6
NEV	ONT ANG	D	4.13	6.5	9	LA	A588	W	4.53		10.8
NEV	ONT ANG	D	3.71	6.4	9	MI	A588	D	4.85		11.1
NEV	ONT ANG	W	4.27	5.7	8.1	MI	A588	D	4.48		16
NEV	ONT ANG	W	3.97	7.2	8.4	MI	A588	W	5.1		15.1
LA	ONT ANG	D	3.81	5.8	8.2	MI	A588	W	5.1		14.2
Mean			5.00356	8.1	10.5				4.7789	6.8	13.1
Std. Dev'n			1.22517	1.1	1.17				0.6214	0.4	3.16

Table 21. Full dry film thickness measurements (continued).

Dry Film Thickness Data, System 3

EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-	EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-
NEV	MDTS	D	7	15	18.5	LA	ONT ANG	D	7	15	16.2
NEV	MDTS	D	7.6	14	18.2	LA	ONT ANG	W	8.5	13	17.7
NEV	MDTS	W	9.3	15	17.2	LA	ONT ANG	W	7.3	14	18.1
NEV	MDTS	W	8.9	16	16.5	EXTRA	ONT COV	D	8.3	15	17.5
PABR	MDTS	D	7.3	14	16.7	EXTRA	ONT COV	D	7.3	15	18.3
PABR	MDTS	D	10.4	17	20.9	EXTRA	ONT COV	W	7.7	13	15.5
PABR	MDTS	W	6.9	15	17	EXTRA	ONT COV	W	8.6	14	16.8
PABR	MDTS	W	8.1	17	19.1	EXTRA	ONT COV	P	5.5	11	14.3
PABR	MDTS	P	9.6	20	22	EXTRA	ONT COV	P	8	12	14.6
PABR	MDTS	P	10.9	18	22.2	NEV	ONT COV	D	7.2	14	18.6
KURE	MBTS	D	7.7	14	17.5	NEV	ONT COV	D	8.1	15	17.7
KURE	MBTS	D	10	16	17.1	NEV	ONT COV	W	8.3	14	15.9
KURE	MBTS	W	6	14	16.6	NEV	ONT COV	W	10	16	18
KURE	MBTS	W	7.9	14	16.6	PABR	ONT COV	D	7.3	13	16
KURE	MBTS	P	9.8	20	21.5	PABR	ONT COV	D	8	12	16.4
KURE	MBTS	P	9.9	18	20.8	PABR	ONT COV	W	8.4	15	16.2
M	MBTS	D	10.7	16	18.8	PABR	ONT COV	W	8.8	13	15.9
M	MBTS	D	7.4	13	16.4	PABR	ONT COV	P	6.4	15	18.C
M	MBTS	W	9.3	17	19.6	PABR	ONT COV	P	6.4	12	14.2
M	MBTS	W	8.7	17	18.8	NEV	NJCOV	D	8.8	17	18.8
NEV	MDTU	D	9.5	17	20.4	NEV	NJCOV	D	7.9	14	18.3
NEV	MDTU	D	8.6	17	19	NEV	NJCOV	W	9.9	15	17.6
NEV	MDTU	W	7.5	14	16.9	NEV	NJCOV	W	8	12	14.9
NEV	MDTU	W	8.1	14	17.3	NEV	A588	D	7.9	15	17.7
PA	MDTU	D	7.3	15	16.4	NEV	A588	D	9	17	19.2
PA	MDTU	D	8.6	14	18.2	NEV	A588	W	7.8	14	15.7
PA	MDTU	W	9.3	18	19.4	NEV	A588	W	7	13	16.2
PA	MDTU	W	9.8	16	20.9	KURE	A588	D	8.7	15	18.6
KURE	MBTU	D	7.1	13	16.1	KURE	A588	D	7.8	14	17.7
KURE	MBTU	D	7.1	16	17.2	KURE	A588	W	7.5	13	15
KURE	MBTU	W	8.8	18	19.2	KURE	A588	W	7.3	13	15.3
KURE	MBTU	W	7.3	15	17.5	PABR	A588	D	16.8	25	28
M	MBTU	D	8.7	16	17.7	PABR	A588	D	8.7	15	17.9
M	MBTU	D	7.7	14	17.6	PABR	A588	W	10.1	16	17.3
M	MBTU	W	8.4	14	17.4	PABR	A588	W	9.1	17	20
M	MBTU	W	7.5	16	17.5	PABR	A588	P	4.97	11	14.5
LA	LAT	D	8.2	15	16	PABR	A588	P	5.1	12	14.8
LA	LAT	D	9.3	13	15.1	LA	A588	D	3.28	8.9	12.4
LA	LAT	W	7.3	14	16.8	LA	A588	D	6	137	15.3
LA	LAT	W	5.9	12	14	LA	A588	W	7.3	13	15.1
NEV	ONT ANG	D	7.5	13	15.8	LA	A588	W	7.9	12	15.8
NEV	ONT ANG	D	7.1	14	17.8	M	A588	D	8.8	14	16.8
NEV	ONT ANG	W	7.6	12	17.7	M	A588	D	8.7	15	17.9
NEV	ONT ANG	W	7.4	12	15.4	M	A588	W	8.7	14	16.6
LA	ONT ANG	D	6.8	14	16.7	M	A588	W	9	13	16.1

Mean			8.26222	15	17.9				7.9811	17	16.9
Std. Dev'n			1.22313	2	1.86				1.8966	18	2.33

Table 21. Full dry film thickness measurements (continued).

Dry Film Thickness Data, System 4

EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-	EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-
NEV	MDTS	D	3.81	6.6	9.8	LA	ONT ANG	D	3.33	8	10.3
NEV	MDTS	D	4.42	6.4	9.4	LA	ONT ANG	W	3.28	7.2	9.6
NEV	MDTS	W	3.68	9	10.1	LA	ONT ANG	W	3.35	7.8	9.6
NEV	MDTS	W	3.82	7.9	10.1	EXTRA	ONT COV	D	6.2	10	13.5
PABR	MDTS	D	4.09	7.9	9.4	EXTRA	ONT COV	D	5.3	9.3	13.3
PABR	MDTS	D	4.23	8	8.8	EXTRA	ONT COV	W	6.2	9.4	14.1
PABR	MDTS	W	3.78	7.7	10	EXTRA	ONT COV	W	7	11	14.4
PABR	MDTS	W	3.55	6.8	8.8	EXTRA	ONT COV	P	7.5	12	14.2
PABR	MDTS	P	6.1	8.1	10.9	EXTRA	ONT COV	P	8.1	12	15.6
PABR	MDTS	P	5.9	11	13.3	NEV	ONT COV	D	5.1	10	11.4
KURE	MBTS	D	3.74	6.8	9.4	NEV	ONT COV	D	5.9	9.6	12.5
KURE	MBTS	D	5.1	8	8.8	NEV	ONT COV	W	7.8	12	14
KURE	MBTS	W	4.36	8.3	11.9	NEV	ONT COV	W	6.2	10	12.7
KURE	MBTS	W	5	8.1	9.3	PABR	ONT COV	D	7.6	11	14.3
KURE	MBTS	P	6.5	11	12.1	PABR	ONT COV	D	6.1	9.2	13.7
KURE	MBTS	P	6.4	11	14.5	PABR	ONT COV	W	6.9	12	14.4
M	MBTS	D	4.72	8.5	9.8	PABR	ONT COV	W	7	13	14.1
M	MBTS	D	4.13	8.4	9.7	PABR	ONT COV	P	8.2	12	15
M	MBTS	W	3.93	7.5	10.4	PABR	ONT COV	P	8.3	12	16.3
M	MBTS	W	3.83	7.6	8.5	NEV	NJCOV	D	6.1	12	14.5
NEV	MDTU	D	3.58	6.6	8.9	NEV	NJCOV	D	6.2	11	14.2
NEV	MDTU	D	4.35	7.8	10.1	NEV	NJCOV	W	7	13	16.1
NEV	MDTU	W	3.44	8.7	10	NEV	NJCOV	W	8.4	13	16.6
NEV	MDTU	W	3.8	7.2	10.1	NEV	A588	D	9	11	15.1
PA	MDTU	D	4.8	7.4	10.5	NEV	A588	D	8	12	16.4
PA	MDTU	D	3.5	6.9	8.8	NEV	A588	W	6.9	12	14.9
PA	MDTU	W	3.48	6.2	9.6	NEV	A588	W	7.9	12	15.5
PA	MDTU	W	3.67	6.9	10.1	KURE	A588	D	4.48	8.8	10.6
KURE	MBTU	D	4.14	7.2	9.7	KURE	A588	D	4.49	7.5	11
KURE	MBTU	D	3.62	6.3	9.4	KURE	A588	W	6.4	11	15
KURE	MBTU	W	3.59	7.3	10.2	KURE	A588	W	7.1	12	15
KURE	MBTU	W	3.77	7.9	9.7	PABR	A588	D	7.2	11	14.3
M	MBTU	D	3.85	7	9	PABR	A588	D	6.9	11	15
M	MBTU	D	3.66	6.8	10.6	PABR	A588	W	9.4	14	19.2
M	MBTU	W	3.65	7.3	9.6	PABR	A588	W	6.7	13	15
M	MBTU	W	4.58	7.6	10.8	PABR	A588	P	5.2	9.1	12.5
LA	LAT	D	3.97	8.7	9.6	PABR	A588	P	5.1	13	14.6
LA	LAT	D	3.67	7.6	9.8	LA	A588	D	5.4	8.8	10.9
LA	LAT	W	3.76	7.5	9.2	LA	A588	D	4.87	8.6	11.2
LA	LAT	W	3.84	7.2	10.2	LA	A588	W	7.4	12	15.7
NEV	ONT ANG	D	3.84	7.9	9.7	LA	A588	W	6.8	12	15
NEV	ONT ANG	D	3.39	7.8	11.9	M	A588	D	6.4	11	13.5
NEV	ONT ANG	W	3.4	6.9	14.2	M	A588	D	6.9	11	16
NEV	ONT ANG	W	3.27	7.7	10	M	A588	W	7.5	12	16
LA	ONT ANG	D	3.63	6.6	10.1	M	A588	W	8.1	13	14.1
Mean			4.11867	7.7	10.2				6.56	11	14
Std. Dev'n			0.79138	1.1	1.31				1.4467	1.7	2.01

Table 21. Full dry film thickness measurements (continued).

Dry Film Thickness Data, System 5

EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-	EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-
NEV	MDTS	D	5.4	9.4	11.5	LA	ONT ANG	D	10.5	12	14.2
NEV	MDTS	D	6.2	9	12.3	LA	ONT ANG	W	8.4	11	14.8
NEV	MDTS	W	6.3	9.4	12.4	LA	ONT ANG	W	7.3	8.7	13.6
NEV	MDTS	W	6.7	9.3	12.7	EXTRA	ONT COV	D	6.1	10	13.7
PABR	MDTS	D	5.9	9	11.9	EXTRA	ONT COV	D	5.9	10	14.4
PABR	MDTS	D	5.9	8.3	10.8	EXTRA	ONT COV	W	14.1	18	21.8
PABR	MDTS	W	7.4	9.4	15.4	EXTRA	ONT COV	W	6.4	9.2	12.2
PABR	MDTS	W	7.9	11	13.8	EXTRA	ONT COV	P	7	12	16
PABR	MDTS	P	9.6	15	17.1	EXTRA	ONT COV	P	7.3	10	14.8
PABR	MDTS	P	9.6	13	16.2	NEV	ONT COV	D	13.2	15	21.6
KURE	MBTS	D	5.9	11	14.6	NEV	ONT COV	D	5.7	11	12.9
KURE	MBTS	D	7.6	9.2	12.2	NEV	ONT COV	W	6.8	10	12
KURE	MBTS	W	9	9.9	14.1	NEV	ONT COV	W	6.7	8.6	13.5
KURE	MBTS	W	9.3	11	13.8	PABR	ONT COV	D	7.9	11	15.1
KURE	MBTS	P	13.1	15	18.6	PABR	ONT COV	D	8.5	11	15.7
KURE	MBTS	P	13.9	17	19.6	PABR	ONT COV	W	5.5	9.4	12
M	MBTS	D	5.9	9	11.5	PABR	ONT COV	W	7.1	11	13.8
M	MBTS	D	6.5	11	12.6	PABR	ONT COV	P	8.1	11	15.2
M	MBTS	W	7	11	15.3	PABR	ONT COV	P	7.6	11	15
M	MBTS	W	9.8	12	15.4	NEV	NJCOV	D	7.2	10	15.7
NEV	MDTU	D	6.2	8.9	11.6	NEV	NJCOV	D	8.5	13	16.4
NEV	MDTU	D	6.1	8.3	11.2	NEV	NJCOV	W	6.6	12	15.3
NEV	MDTU	W	6.8	10	13.1	NEV	NJCOV	W	6.2	9.4	13.6
NEV	MDTU	W	7.5	11	13.6	NEV	A588	D	5.9	10	13.3
PA	MDTU	D	8	11	14.2	NEV	A588	D	8.5	11	14.2
PA	MDTU	D	7	8.1	10.9	NEV	A588	W	5.7	8.6	14.5
PA	MDTU	W	7.2	9.7	12.6	NEV	A588	W	5.7	9.4	13.2
PA	MDTU	W	8.2	11	14	KURE	A588	D	6.5	11	14.6
KURE	MBTU	D	5.3	10	11.2	KURE	A588	D	9.4	12	15.9
KURE	MBTU	D	6.5	10	12.8	KURE	A588	W	6.7	9.4	14.4
KURE	MBTU	W	6.4	10	11.5	KURE	A588	W	6.2	9.5	13.1
KURE	MBTU	W	8.5	11	13.6	PABR	A588	D	6.5	9.7	12.3
M	MBTU	D	6	7.4	11.1	PABR	A588	D	7.9	12	16.2
M	MBTU	D	7.4	9.1	11.8	PABR	A588	W	7.6	12	16.3
M	MBTU	W	10.3	11	14.7	PABR	A588	W	7.4	11	15
M	MBTU	W	8.2	11	14.7	PABR	A588	P	5.5	8.2	14
LA	LAT	D	6.8	8.4	10.9	PABR	A588	P	5.7	8.5	11.6
LA	LAT	D	6.7	8	10.7	LA	A588	D	8	12	17
LA	LAT	W	8.5	11	15.6	LA	A588	D	7.9	11	14.8
LA	LAT	W	7.9	11	15.5	LA	A588	W	8.7	11	14.4
NEV	ONT ANG	D	7.2	11	14.8	LA	A588	W	5.9	10	13.7
NEV	ONT ANG	D	8.6	12	12.4	M	A588	D	6.3	12	16.2
NEV	ONT ANG	W	6.3	8.4	13.3	M	A588	D	6.4	11	14.4
NEV	ONT ANG	W	6.9	8.4	13.1	M	A588	W	6.8	9.2	13.6
LA	ONT ANG	D	8.3	9.6	11.2	M	A588	W	14	17	23.5
Mean			7.59333	10	13.4				7.5067	11	14.9
Std. Dev'n			1.79182	1.9	2.07				2.0269	2	2.39

Table 21. Full dry film thickness measurements (continued).

Dry Film Thickness Data, System 6

EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-	EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-
NEV	MDTS	D	3.85	5	6.6	LA	ONT ANG	D	3.95	5.3	7.9
NEV	MDTS	D	5.3	7.2	8	LA	ONT ANG	W	4.84	5.3	7.4
NEV	MDTS	W	4.72	5.5	7.4	LA	ONT ANG	W	3.68	4.6	6.8
NEV	MDTS	W	4.15	5.2	7.1	EXTRA	ONT COV	D	3.7	4.6	5.3
PABR	MDTS	D	3.36	4.9	6.4	EXTRA	ONT COV	D	3.88	5	5
PABR	MDTS	D	5.6	7.1	8	EXTRA	ONT COV	W	4.81	5.9	7.5
PABR	MDTS	W	4.77	5.5	6.7	EXTRA	ONT COV	W	4.42	5.9	6.5
PABR	MDTS	W	3.98	5	8.2	EXTRA	ONT COV	P	5.4	7	8.3
PABR	MDTS	P	5.9	6.3	9.4	EXTRA	ONT COV	P	5.9	8.1	8.7
PABR	MDTS	P	5.5	7	9.6	NEV	ONT COV	D	2.71	4	4.84
KURE	MBTS	D	4.82	6.7	8	NEV	ONT COV	D	3.81	5	5.7
KURE	MBTS	D	4.32	5.2	7.3	NEV	ONT COV	W	4.79	6.3	7.8
KURE	MBTS	W	5.2	7.4	8.4	NEV	ONT COV	W	5.2	6.9	8.1
KURE	MBTS	W	7.6	8.3	11.1	PABR	ONT COV	D	3.98	5.2	5.9
KURE	MBTS	P	5.7	7.9	9.6	PABR	ONT COV	D	3.41	4.3	4.84
KURE	MBTS	P	7.2	8.9	10.7	PABR	ONT COV	W	5	6.8	9.3
M	MBTS	D	5.9	7.4	8.4	PABR	ONT COV	W	4.55	6.3	7.9
M	MBTS	D	3.85	4.7	7.6	PABR	ONT COV	P	5.8	7.5	8.6
M	MBTS	W	4.44	5.8	6.9	PABR	ONT COV	P	5.4	6.8	8.3
M	MBTS	W	4.65	6.3	7.4	NEV	NJCOV	D	3.9	5.9	7.3
NEV	MDTU	D	3.24	4.2	5.7	NEV	NJCOV	D	4.02	4.8	5.9
NEV	MDTU	D	3.52	4.8	5.9	NEV	NJCOV	W	7.6	9.8	11
NEV	MDTU	W	4.47	5.2	6.4	NEV	NJCOV	W	5.5	6.1	7.8
NEV	MDTU	W	5.2	6	8.2	NEV	A588	D	4.1	4.9	6.1
PA	MDTU	D	4.3	5.2	6.5	NEV	A588	D	3.66	4.8	6.2
PA	MDTU	D	5	6.9	8.1	NEV	A588	W	4.2	5.7	7.1
PA	MDTU	W	4.71	5.2	6.6	NEV	A588	W	4.01	6	7.3
PA	MDTU	W	4.9	5.4	6.4	KURE	A588	D	3.57	5	6.2
KURE	MBTU	D	3.82	5	6.6	KURE	A588	D	3.61	4.8	6.1
KURE	MBTU	D	3.71	4.5	6	KURE	A588	W	4.1	6.5	7.2
KURE	MBTU	W	3.75	5.5	6.8	KURE	A588	W	3.55	5.1	6.1
KURE	MBTU	W	3.55	5	6.3	PABR	A588	D	4.21	5.9	6.7
M	MBTU	D	3.56	4.6	5.6	PABR	A588	D	3.72	4.8	5.5
M	MBTU	D	3.39	4.9	5.7	PABR	A588	W	4.34	5.5	7.3
M	MBTU	W	4.54	6.1	7.5	PABR	A588	W	4.3	6.1	7.9
M	MBTU	W	4.13	5	6.5	PABR	A588	P	3.13	4.9	6.2
LA	LAT	D	4.2	5.6	6.9	PABR	A588	P	2.49	4.1	6
LA	LAT	D	3.74	5.6	6.6	LA	A588	D	3.81	4.9	5.9
LA	LAT	W	4.19	4.9	6.4	LA	A588	D	3.05	4.7	5.3
LA	LAT	W	4.79	6.2	9.2	LA	A588	W	3.96	5	7
NEV	ONT ANG	D	4.1	5	6.4	LA	A588	W	4.12	5.6	6.6
NEV	ONT ANG	D	3.43	4.3	7.3	M	A588	D	4.05	5.4	6
NEV	ONT ANG	W	3.72	5.1	7.2	M	A588	D	4.2	6.2	6.2
NEV	ONT ANG	W	4.11	5.4	6.4	M	A588	W	3.27	5.5	6.2
LA	ONT ANG	D	3.88	5	6.7	M	A588	W	3.45	5	6.3
Mean			4.50578	5.7	7.35				4.2033	5.6	6.85
Std. Dev'n			0.95411	1.1	1.29				0.9196	1.1	1.26

Table 21. Full dry film thickness measurements (continued).

Dry Film Thickness Data, System 7

EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-	EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-
NEV	MDTS	D	15.1			EXTRA	ONT COV	W	15.3		
NEV	MDTS	D	14.4			EXTRA	ONT COV	W	12.4		
NEV	MDTS	W	15.8			NEV	ONT COV	D	15.9		
NEV	MDTS	W	15.9			NEV	ONT COV	D	15.1		
PABR	MDTS	D	11.8			NEV	ONT COV	W	15.5		
PABR	MDTS	D	9.6			NEV	ONT COV	W	15.6		
PABR	MDTS	W	16.3			PABR	ONT COV	D	17		
PABR	MDTS	W	17.4			PABR	ONT COV	D	17.4		
KURE	MBTS	D	14			PABR	ONT COV	W	16.4		
KURE	MBTS	D	13			PABR	ONT COV	W	12.5		
KURE	MBTS	W	19.8			NEV	NJCOV	D	15.5		
KURE	MBTS	W	16.8			NEV	NJCOV	D	14.2		
NEV	MDTU	D	14.2			NEV	NJCOV	W	16.1		
NEV	MDTU	D	13.1			NEV	NJCOV	W	15.3		
NEV	MDTU	W	12.1			NEV	A588	D	15.7		
NEV	MDTU	W	14.3			NEV	A588	D	21.2		
PABR	MDTU	D	13.6			NEV	A588	W	13.6		
PABR	MDTU	D	11			NEV	A588	W	10.4		
PABR	MDTU	W	15.4			KURE	A588	D	15.3		
PABR	MDTU	W	13.9			KURE	A588	D	15.6		
KURE	MBTU	D	10.9			KURE	A588	W	13.3		
	MBTU	D	14.8			KURE	A588	W	10.9		
	MBTU	W	13.3			PABR	A588	D	17.1		
	MBTU	W	14.5			PABR	A588	D	15.9		
EXTRA	ONT COV	D	19			PABR	A588	W	12.9		
EXTRA	ONT COV	D	16.5			PABR	A588	W	11.4		
Mean			14.4808						14.904		
Std. Dev'n			2.39717						2.3064		

Dry Film Thickness Data, System 8

EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-	EXPOSURE	PANEL	SURF	PRIMER	MID-	TOP-
NEV	MDTS	D	11.2		13.8						
NEV	MDTS	D	9.4		10.9						
NEV	MDTS	W	8		10.2						
NEV	MDTS	W	8.9		10.5						
NEV	MDTU	D	8.8		11.8						
NEV	MDTU	D	10.4		13.8						
NEV	MDTU	W	7.7		11.7						
NEV	MDTU	W	9.1		11.9						
EXTRA	ONT COV	D	8.1		11.1						
EXTRA	ONT COV	D	8.1		11.6						
EXTRA	ONT COV	W	10		12.4						
EXTRA	ONT COV	W	8.6		12						
NEV	A588	D	10.6		13.7						
NEV	A588	D	7.8		9.7						
NEV	A588	W	9.5		13.1						
NEV	A588	W	9.1		13.1						
			9.08125		12						
			1.05339		1.29						

for each factor is included in the ANOVA design. The larger the F-test statistic, the greater the likelihood that the effect of the factor upon total variance is significant. Following the F-test statistic, a listing of probability factors for each factor is given. A low "P" value (<0.05) indicates a statistically significant factor in the experimental design.

Only certain data in the ANOVA outputs were needed. These were culled from each ANOVA output and are shown in tables 22 through 29. In each case, the MSE from the ANOVA is shown, labelled as the variance term. Also shown are the mean values for the rust or scribe data associated with the particular group under consideration. These were taken from incidence tables such as those shown in table 10. All other data in tables 22 through 29 are computed from this base data set. For instance, the standard deviation shown is the square root of the variance value.

General conclusions derived from the ANOVA's were shown earlier in table 9. For each of the ANOVA's , an estimation of the percent of variance attributable to the primary and contributory causes of variance was given. The estimations of contribution to variance are based on the Hay's ω^2 Test.

Equation 2. Hay's Test: $\omega^2 = SS_r - df_r(ms_w)/SS_T + ms_w$

SS_r = Sum of Squares for Factor r
SS_T = Total Sum of Squares

The factor ms_w in equation 2 is identical with the mean square error.

Duncan or Tukey mean significant difference tests can be used to establish the relative ranking of factors within each ANOVA data set. For instance, the average rust rating for all specimens subjected to dry blasting is usually higher than that for wet blasted specimens, see table 23. A mean significant difference test reveals that the two surface preparation methods are not significantly different one from the other. The general equation for Tukey HSD (Honestly Significant Difference) analysis is given below.

Equation 3. Tukey HSD: $CR_T = (q_{k,dfw}) \sqrt{ms_w/n}$

In equation 3, the factor q is obtained from a table of Student's *t* statistic for the maximum number of treatment groups being compared (k), and the degrees of freedom within groups (df_w), n is the number of cases in each sample and ms_w is the MSE value, or error term. When several grouping variables or factors are used each group will have a unique term q, and a different number of cases, n. The form of the Duncan Significant Difference Test employed in this analysis is identical with the Tukey HSD equation when the difference between the mean value for only two groups is being ascertained. The factor, CR_T, is defined as the critical range for testing significant mean differences.

Except for the case in which only two groups are being examined, critical ranges from the Tukey equation will be larger. Thus this is a more severe test than the Duncan test. As a general rule, if the mean differences for any two groups are very significantly different with

Table 22. Rust ANOVA coatings data.

	ANOVA 1	ANOVA 2	ANOVA 3	ANOVA 4	ANOVA 5	ANOVA 6	ANOVA 7
NO SAMPLES (N)	48	120	20	36	32	12	18
MEAN RUST							
CTG SYSTEM [1]	1 9.76	1 9.47	1 9.76	1 9.74	1 9.77	1 9.10	1 9.53
CTG SYSTEM	2 9.74	2 9.52	2 9.88	2 9.68	2 9.83	2 8.07	2 9.21
CTG SYSTEM	3 9.67	3 9.34	3 9.75	3 9.66	3 9.83	3 8.89	3 9.76
CTG SYSTEM	4 9.59	4 9.21	4 9.49	4 9.55	4 9.84	4 8.16	4 8.37
CTG SYSTEM	5 9.79	5 9.54	5 9.75	5 9.77	5 9.94	5 8.90	5 9.86
CTG SYSTEM	6 8.19	6 7.58	6 8.18	6 8.05	6 8.81	6 6.83	6 8.10
CTG SYSTEM	7	7	7	7 9.97	7 9.96		7
OVERALL MEAN	9.46	9.67	9.47	9.49	9.71	8.32	9.14
VARIANCE [2]	0.07	1.05	0.07	0.07	0.10	0.47	0.20
STD DEV	0.27	1.02	0.27	0.26	0.32	0.69	0.45
TUKEY D1-2	0.16	0.39	0.25	0.18	0.23	0.83	0.43
r2(N)	2.85	2.88	2.95	2.87	2.88	3.08	2.97
R2(DUNCAN)	0.11	0.27	0.18	0.13	0.16	0.61	0.31
RANKING [3]	SIGNIFICANT Y/N ⇓	SIGNIFICANT Y/N ⇓	SIGNIFICANT Y/N ⇓	SIGNIFICANT Y/N ⇓	SIGNIFICANT Y/N ⇓	SIGNIFICANT Y/N ⇓	SIGNIFICANT Y/N ⇓
CTG SYSTEM	5 9.79	5 9.54	2 9.88	7 9.97	7 9.96	1 9.10	5 9.86
CTG SYSTEM	1 9.76 N	2 9.52 N	1 9.76 N	5 9.77 Y	5 9.94 N	5 8.90 N	3 9.76 N
CTG SYSTEM	2 9.74 N	1 9.47 N	3 9.75 N	1 9.74 N	4 9.84 N	3 8.89 N	1 9.53 N
CTG SYSTEM	3 9.67 N	3 9.34 N	5 9.75 N	2 9.68 N	2 9.83 N	4 8.16 Y	2 9.21 Y
CTG SYSTEM	4 9.59 N	4 9.21 N	4 9.49 Y	3 9.66 N	3 9.83 N	2 8.07 N	4 8.37 Y
CTG SYSTEM	6 8.19 Y	6 7.58 Y	6 8.18 Y	4 9.55 N	1 9.77 N	6 6.83 Y	6 8.10 N
CTG SYSTEM				6 8.05 Y	6 8.81 Y		
Percent variance explained by paint system	45%	9%	37%	46%	37%	31%	17%

[1] Refer to table 1 for coating systems.
[2] For explanations of statistical terms, refer to appendix 2.
[3] Stepwise rankings are significant at 95 percent level when mean differences exceed R2 (Duncan) value.

Table 23. Rust ANOVA site data.

SITES	ANOVA 1		ANOVA 2			ANOVA 3			ANOVA 4			ANOVA 5			ANOVA 6			ANOVA 7	
NUMBER (N)	72		240			24			84			112			36			108	
KURE 1	8.99		1	9.17		1	9.50		1	9.14		1			1	7.93		1	
LA 2			2			2	8.42		2			2			2			2	
MI 3	9.60		3	9.25		3	9.63		3			3			3			3	
NEV 4	9.89		4			4	10.00		4	9.87		4	9.91		4			4	
PABR 5	9.38		5	9.26		5	9.78		5	9.45		5	9.52		5	8.72		5	9.14
OVERALL ME	9.47			9.23			9.47			9.49			9.71			8.32			9.14
VARIANCE	0.07			1.05			0.07			0.07			0.10			0.47			0.20
STD DEV	0.27			1.02			0.27			0.26			0.32			0.69			0.45
TUKEY HSD	0.11			0.25			0.21			0.10			0.08			0.33			N/A
r2(N)	2.82			2.80			2.92			2.82			2.80			2.87			2.81
R2(DUNCAN)	0.09			0.19			0.16			0.08			0.08			0.33			0.12
RANKING																			
NEV 4	9.89		5	9.26		4	10.00		4	9.87		4	9.91		5	8.72		5	9.14
MI 3	9.60	0.30	3	9.25	0.01	5	9.78	0.22	5	9.45	0.42	5	9.52	0.38	1	7.93	0.79	1	
PABR 5	9.38	0.22	1	9.17	0.08	3	9.63	0.15	1	9.14	0.32	1			2			2	
KURE 1	8.99	0.39	2			1	9.50	0.13	2			2			3			3	
LA 2			4			2	8.42	1.08	3			3			4			4	
Variance due to site	14%			1%			32%			12%			10%			8%			n/a

[1] Refer to table 3 for sites.

[2] For explanations of statistical terms, refer to appendix 2.

[3] Stepwise rankings are significant at 95 percent level when mean differences exceed R2 (Duncan) value.

Table 24. Rust ANOVA surface preparation data.

SURFACE PREP.	ANOVA 1		ANOVA 2			ANOVA 3			ANOVA 4			ANOVA 5			ANOVA 6			ANOVA 7		
NUMBER (N)	144		360			60			126			112			24			36		
DRY 1 [1]	9.46		1	9.20		1	9.50		1	9.53		1	9.74		1	8.58		1	9.49	
WET 2	9.42		2	9.12		2	9.44		2	9.45		2	9.69		2	8.71		2	9.45	
POWER TOOL 3			3			3			3			3			3	7.68		3	8.48	
OVERALL MEAN	9.44			9.16			9.47			9.49			9.71			8.32			9.14	
VARIANCE [2]	0.07			1.05			0.07			0.07			0.10			0.47			0.20	
STD DEV	0.27			1.02			0.27			0.26			0.32			0.69			0.45	
TUKEY HSD	0.06			0.19			0.10			0.07			0.08			0.48			0.25	
r2(N)	2.77			2.80			2.83			2.77			2.80			2.92			2.87	
R2(DUNCAN)	0.06			0.15			0.10			0.06			0.08			0.41			0.21	
RANKING [3]																				
DRY	9.46		1	9.20		1	9.50		1	9.53		1	9.74		2	8.71		1	9.49	
WET	9.42	0.04	2	9.12	0.08	2	9.44	0.06	2	9.45	0.08	2	9.69	0.05	1	8.58	0.13	2	9.45	0.04
POWER TOOL			3			3			3			3			3	7.68	0.90	3	8.48	0.97
Variance due to surface prep.	0%			0%			0%			0%			0%			11%			8%	

[1] Refer to table 3 for sites.

[2] For explanations of statistical terms, refer to appendix 2.

[3] Stepwise rankings are significant at 95 percent level when mean differences exceed R2 (Duncan) value.

Table 25. Rust ANOVA specimen data.

SPECIMENS [1]	ANOVA 1			ANOVA 2			ANOVA 3		ANOVA 4			ANOVA 5			ANOVA 6		ANOVA 7	
NUMBER (N)	96			48			120		84			56			72		36	
A588 1	9.73		1	9.89		1	9.47	1	9.80		1	9.91		1		1	9.18	
MTS 2	9.12		2	9.25		2		2	9.15		2	9.43		2	8.32	2	8.72	
MTU 3	9.52		3	9.60		3		3	9.52		3	9.65		3		3	9.52	
ONTCOV 4			4	9.84		4		4			4	9.86		4		4		
MEAN	9.46			9.65			9.47		9.49			9.71			8.32		9.14	
VARIANCE	0.07			1.05			0.07		0.07			0.10			0.47		0.20	
STD DEV	0.27			1.02			0.27		0.26			0.32			0.69		0.45	
TUKEY HSD	0.09			0.21			N/A		0.10			0.15			N/A		0.25	
r2(N)	2.81			2.80			2.80		2.82			2.84			2.82		2.87	
R2(DUNCAN)	0.08			0.41			0.07		0.08			0.12			0.23		0.21	
RANKED																		
A588 1	9.73	[4]	1	9.89		1	9.47	1	9.80		1	9.91		1		4	9.52	
MTU 3	9.52	0.21	4	9.84	0.05	2		3	9.52	0.28	4	9.86	0.04	2	8.32	1	9.18	0.34
MTS 2	9.12	0.40	3	9.60	0.24	3		2	9.15	0.37	3	9.65	0.21	3		2	8.72	0.46
ONTCOV 4			2	9.35	0.25	4		4			2	9.43	0.22	4		3		
Variance due	9%			4%			n/a		9%			9%			0%		4%	
to specimen	207			###			111.5		193			83			128.7		281	
	18			66			n/a		18			8			n/a		12	

[1] Refer to table 3 for description of specimens.

[2] For explanations of statistical terms, refer to appendix 2.

[3] Stepwise rankings are significant at 95 percent level when mean differences exceed R2 (Duncan) value.

[4] Compare this number with R2 (Duncan) above, if larger than R2 (Duncan) the mean difference is significant.

Table 26. Scribe ANOVA coating data.

COATINGS[1]	ANOVA 1		ANOVA 2			ANOVA 3		
NUMBER (N)	20			16			12	
COATING 1	0.80		COATING1	3.44		COATING1	7.08	
COATING 2	1.40		COATING2	0.25		COATING 2	0.33	
COATING 3	2.65		COATING 3	0.06		COATING 3	2.92	
COATING 4	3.95		COATING4	2.75		COATING 4	7.92	
COATING 5	0.85		COATING5	0.88		COATING 5	2.50	
COATING 6	0.50		COATING6	0.94		COATING 6	1.67	
COATING 7			COATING7	0.06		COATING 7		
OVERALL MEAN	1.69			1.20			3.74	
VARIANCE[2]	3.13			0.93			4.85	
STD. DEV.	1.77			0.96			2.20	
r2(N)	2.95			3.00			3.08	
R2(DUNCAN)	1.17			0.72			1.96	
TUKEY HSD	1.46			1.03			2.65	
RANKING[3]								
COATING 2	0.20		COATING 3	0.06		COATING 2	0.33	
COATING 3	1.10	0.90	COATING7	0.06	0.00	COATING 6	1.67	1.33
COATING 6	1.10	0.00	COATING2	0.25	0.19	COATING 5	2.50	0.83
COATING 5	2.40	1.30	COATING5	0.88	0.63	COATING 3	2.92	0.42
COATING 1	3.25	0.85	COATING6	0.94	0.06	COATING 1	7.08	4.17
COATING 4	4.65	1.40	COATING4	2.75	1.81	COATING 4	7.92	0.83
COATING 7			COATING1	3.44	0.69	COATING 7		
Variance due to coating system	15%			18%			17%	

[1] Refer to table 1 for coating systems.
[2] For explanations of statistical terms, refer to appendix 2.
[3] Stepwise rankings are significant at 95 percent level when mean differences exceed R2 (Duncan) value.

Table 27. Scribe ANOVA site data.

SITES [1]	ANOVA 1		ANOVA 2			ANOVA 3	
NUMBER (N)	24		56				72
KURE	4.52		KURE			KURE	
LA	0.92		LA			LA	
MI	1.04		MI			MI	
NEV	1.41		NEV	0.88		NEV	
PABR	2.67		PABR	1.52		PABR	3.74
OVERALL MEAN	2.11			1.20			3.74
VARIANCE [2]	3.13			0.93			4.85
STD. DEV.	1.77			0.96			2.20
TUKEY HSD	1.28			0.37			
r2(N)	2.92			2.83			2.82
R2(DUNCAN)	1.05			0.37			0.73
RANKING [3]							
LA	0.92		NEV	0.88		PABR	3.74
MI	1.04	0.12	PABR	1.52	0.64	KURE	
NEV	1.41	0.37	KURE			LA	
PABR	2.67	1.26	LA			MI	
KURE	4.52	1.85	MI			NEV	
	12%			1%			n/a

Table 28. Scribe ANOVA surface preparation data.

SURF. PREP. [1]	ANOVA 1		ANOVA 2			ANOVA 3		
NUMBER (N)	60			56			24	
DRY	2.37		DRY	1.02		DRY	1.08	
WET	1.92		WET	1.38		WET	2.42	
POWER TOOL			POWER TOOL			POWER TOOL	7.71	
OVERALL MEAN	2.15			1.20			3.74	
VARIANCE [2]	3.13			0.93			4.85	
STD. DEV.	1.77			0.96			2.20	
TUKEY HSD	0.58			0.37			1.54	
r2(N)	2.83			2.83			2.92	
R2(DUNCAN)	0.65			0.37			1.31	
RANKING [3]								
WET	1.92		DRY	1.02		DRY	1.08	
DRY	2.37	0.45	WET	1.38	0.36	WET	2.42	1.33
POWER TOOL			POWER TOOL			POWER TOOL	7.71	5.29
	0%			0%			18%	

[1] Refer to table 3 for sites.

[2] For explanations of statistical terms, refer to appendix 2.

[3] Stepwise rankings are significant at 95 percent level when mean differences exceed R2 (Duncan) value.

Table 29. Scribe ANOVA specimen data.

SPECIMENS[1]	ANOVA 1	ANOVA 2			ANOVA 3		
NUMBER (N)	120		56			36	
A-588	1.69	A588	1.77		A588	1.81	
ONTCOV		ONTCOV	0.63		ONTCOV	5.67	
OVERALL MEAN	1.69		1.20			3.74	
VARIANCE[2]	2.52		0.93			4.85	
STD. DEV.	1.59		0.96			2.20	
TUKEY HSD	N/A		0.37			1.05	
r2(N)	2.80		2.83			2.87	
R2(DUNCAN)	0.41		0.37			1.05	
RANKING[3]							
A-588	1.69	ONTCOV	0.63		A588	1.81	
ONTCOV		A588	1.77	1.14	ONTCOV	5.67	3.86
	n/a		4%			8%	

[1] Refer to table 3 for description of specimens.

[2] For explanations of statistical terms, refer to appendix 2.

[3] Stepwise rankings are significant at 95 percent level when mean differences exceed R2 (Duncan) value.

the Duncan test (a probability value of $p = 0.01$), they will only be significantly different ($p = 0.05$) under Tukey. The rankings shown in tables 22 through 29 are based upon the values for CR_T derived from the Duncan test.

APPENDIX 3
LABORATORY EVALUATION OF COATINGS

The only valid proven test for bridge coatings is outdoor exposure representative of the bridge conditions. In this project, such an evaluation was planned to be run for a 4-year period. Prior to field evaluations, however, it was useful to conduct laboratory evaluation tests to identify coatings suitable for the subsequent field evaluations. A major purpose of the laboratory testing was to screen coating systems to eliminate those which are less likely to provide long term durability properties and those which do not exhibit acceptable application properties.

The laboratory evaluations include three major phases: design, testing, and analysis.

A. DESIGN OF LABORATORY EVALUATIONS

The experimental design for this phase of the research project is summarized in table 30. A full discussion of the reasoning behind the system choices and selection of laboratory tests is in the interim report.

1. Selection of Coatings

Coating selection was based on input from State and Federal highway officials, manufacturers and consultants, the existing literature, and results of previous evaluations on related types of structures.

The criteria established were as follows:

- Successful case histories on bridges or similar structures.
- Ability to protect chloride-contaminated surfaces.
- Commercial availability of the product.
- Previous use on carbon steel structures.
- Ability to be applied with standard application equipment.
- Absence of lead, chromate, or other hazardous materials.

The coatings selected are listed in table 30.

2. Selected Surface Preparations and Substrates

a. Surface Preparations

Surface preparations were selected based on their suitability for field use and their capability to remove surface chlorides. The four preparations were:

- Dry abrasive blasting with medium sand (30 mesh).
- Wet abrasive blasting with medium sand.
- Power tool cleaning, using roto-peen flaps and non-woven abrasive discs (as described in SSPC-SP 11).

Table 30. Final plan for laboratory evaluation of coatings.[1]

Laboratory Test Methods

1. Salt Spray (ASTM B-117).
2. Immersion (deionized water), ambient temperature (to 70 ± 5 °F) (21 ± 3 °C).
3. UV Condensation (ASTM G-53)/Freeze-Thaw (ASTM D-2246).

Coating Systems

1. Oil/alkyd, Federal Spec. TT-P-615, lead silico-chromate, two-coat system.
2. Inorganic zinc-rich primer, two-package ethyl silicate, plus vinyl topcoat.

3 A, 3B. Epoxy polyamide zinc-rich system with high-build epoxy polyamide topcoat (two different systems).

4. High-solids epoxy polyamide mastic with epoxy polyamide topcoat.
5. Moisure-cured urethanes containing aluminum and zinc with high-build epoxy topcoat.
6. Zinc-rich urethane with urethane topcoat.
7. Petroleum wax-type coating (two-coat system).
8. Thermal spray zinc.

Surface Preparation

1. Dry blasting (medium abrasive) to near-white metal.
2. Air abrasive wet blasting (medium abrasive) to near-white metal.
3. Hand tool cleaning (wire brushing) to SSPC-SP 2.
4. Power tool cleaning (roto-peen) to remove most rust.

Types of Substrates (all weathering steel)

1. Laboratory specimen corroded in salt spray (low chloride).
2. Laboratory specimen corroded in salt spray (high chloride).
3. Field specimens from Michigan or Ontario (high chloride).
4. Field specimens from New Jersey (low chloride).
5. New millscale-bearing steel.

Testing Plan

Branch A - Blast Cleaned Surfaces
Six coatings (numbers 2, 3A, 3B, 4, 5, 6 above)

[1] See reference number 1 for complete details of the laboratory coating evaluation program.

Table 30. Final plan for laboratory evaluation of coatings (continued).

Three surfaces:

- Dry blast of high-chloride lab specimens.
- Air abrasive wet blast of high-chloride lab specimens.
- Dry blast of new mill scale steel.

Three lab tests: salt spray, UV-condensation/freeze-thaw, and immersion.
Two replicates per panel.
Total panels needed 6 x 3 x 3 x 2 = 108.

Branch B - Non-Blast Cleaned Surfaces
Four coatings (numbers 1, 4, 6, and 7)
Two initial surfaces (high-chloride and low-chloride laboratory specimens)
Two surface preparations (hand tool clean and power tool clean)
Two tests (salt spray and W condensation-freeze/thaw)
Three replicates per system
Total panels: 4 x 2 x 2 x 2 x 3 = 96

Branch C - Field Steel as Substrate
Three coatings (I, 3A, 4)
Four substrates (high-chloride field specimen, low-chloride field specimen, high-chloride lab specimen, new millscale specimen)
Three surface preparations (dry blast clean, wet blast clean and power tool clean)
One test (salt spray)
Three replicates
Total panels: 3 x 4 x 3 x 3 = 108

Branch D - Evaluation of Thermal Spray Zinc
Two coatings (3B and 8)
Two surfaces (dry blast and wet blast of high-chloride lab specimens)
Two tests (salt spray and UV Condensation/freeze-thaw)
Three replicates
Total panels: 2 x 2 x 2 x 3 = 18

Total test panels to be included - approximately 320.

- Hand tool cleaning (control technique).

b. Substrates

It was important that the steel substrate selected represented the bridge steel to be protected. As discussed in the interim report, we obtained and examined a variety of bridge specimens for use in this project. In addition, considerable effort was expended on laboratory techniques to simulate these types of steel. The steel substrates selected were:

- Mill scale bearing A 588 steel.
- High chloride field steel.
- Low chloride field steel.
- High chloride laboratory steel.
- Low chloride laboratory steel.

3. Selected Laboratory Tests

Although laboratory-accelerated tests are not suitable for predicting or correlating field performance, they may be suitable for identifying major deficiencies in coating systems. The approach was to select a battery of tests which provided a range of acceleration factors with conditions that might be experienced in the field. The exposure conditions in the program were: salt spray, water immersion, moisture condensation, ultraviolet radiation, and freeze-thaw conditions. To represent these conditions, the following three exposure tests were selected:

- Salt spray test (ASTM B 117).
- Immersion in deionized water.
- Composite Test: ultraviolet radiation/condensation/freeze-thaw conditions.

The actual cycle used was:

- Ultraviolet: 2 hours at 158 °F (70 °C)
- Condensation cycle: 2 hours at 104 °F (40 °C)
- Two times per week the specimens were removed to freezer at -4 °F (-20 °C), left there overnight, and then reintroduced to the UV-Con chamber.

4. Design of Laboratory Test Matrix

The parameters included:

- 9 coatings (primer/topcoat combination).
- 5 substrates.
- 4 surface preparation methods.
- 3 exposure tests.
- 3 replicates (necessary in order to provide adequate precision).

The full factorial resulted in 1,620 panels (9 x 5 x 4 x 3 x 3), which was beyond the scope of this test program. The scope was reduced by assigning the following branch tests:

- Branch A

This was a major test to evaluate coatings over blast cleaned steel. It included six coatings which were applied over high- and low-chloride substrates cleaned by wet and dry blasting. The steel (new stock from the mill) was sheared into test panels by a fabricator. Dry blast over mill scale was used as a control substrate-surface preparation. This branch included all three accelerated tests.

- Branch B

The objective was to evaluate coatings over non-blast cleaned steel. It included the four coatings designed for rusty steel. Substrates included high- and low-chloride specimens. Preparation was by hand tool cleaning and power tool cleaning. These systems were exposed to salt spray and the composite UV-condensation/freeze-thaw test.

- Branch C

This branch was designed to compare the performance of coatings over laboratory contaminated steel versus coatings over field-contaminated steel. Mill scale steel was used as a control substrate. Three surface preparation methods were used, with salt spray as the exposure test.

- Branch D

This branch evaluated thermal spray zinc coatings versus an organic zinc system. It was necessary to prepare the thermal spray at a separate facility. The zinc was applied by wire spray to a dry film thickness of 6 to 10 mils (150 to 250 microns). Branch D is a condensed version of branch A. A summary of the laboratory test plans is given in table 30.

B. LABORATORY EVALUATIONS

Panel preparation and paint application procedures were described in the interim report.

1. Evaluation Procedures

The rust was measured in accordance with modified ASTM D 610/SSPC-Vis 2, in which the amount of rust present is visually compared to a photographic standard. The ratings range from 10 (perfect) to 0 (totally rusted) in a roughly logarithmic scale related to the percentage of the surface containing rust. SSPC, along with other groups, has adopted the rating of 7 as representing failure. Thus an important parameter is the number of hours it takes to reach a 7 rating.

The blistering was evaluated in accordance with a modified version of ASTM D 714. In this case, both the size and frequency of blisters was estimated against a series of photographic standards. The smallest blisters were assigned a numerical rating of 8, and the largest, a rating of 0 or 2. Frequency ranges from VF (very few) to D (dense). The SSPC failure criterion for blistering is 8 and MD (blistering of size 8 and frequency of medium dense). Blister ratings considered failing include 8D, 8MD, 6D, 6 MD, 6M, 4D, 4MD, 4M, 4F, 2D, 2MD, 2M, 2F, 2VF.

The rating schedules were approximately:

- Salt spray: 24, 48, 72, 144, 216, 360, 408, 960, 1512 hours.
- Immersion: 48, 500, 1000, 1500, 2000, 2500 hours.
- UV-CON/FT: 48, 100, 200, 500, 1000 hours.

2. Comparison of Coatings

Coating system 1 (2-coat oil alkyd, lead, TT-P-615 standard) was significantly inferior to the high-technology coatings in the salt spray tests in branch B (hand and power tool cleaned). In the composite UV-con/freeze-thaw tests in branch B, the coatings all exhibited some blistering, none of the four was particularly effective. Overall in the composite test, system 6 (zinc-filled urethane) had the worst rating based on blistering failures. Coating 7 gave very poor rust resistance. Blistering was difficult to rate because of the damages which could not be readily distinguished from blisters. Overall, coating 7 (petroleum wax) was the poorest performing coating.

Among the high technology coatings (i.e., systems 2, 3A, 3B, 4, 5, and 6), the organic zinc-rich coatings (systems 3A and 3B) gave the best overall blister resistance, while system 6 had the worst blister resistance. System 6 was also inferior to system 4 over hand cleaned steel (branch B) in all tests. Coating system 5 (zinc aluminum moisture cured urethane) had overall excellent properties over blast cleaned steel in both immersion and salt spray. The thermal spray metallic zinc coating gave essentially perfect ratings in salt spray and UV-con/freeze-thaw.

3. Comparison of Substrates

As expected, the surface producing the fewest failures was blast cleaned intact mill scale that had not been exposed to a chloride environment. The low chloride specimens from both laboratory and field pre-exposures resulted in substantially fewer failures than the coatings applied to high chloride surfaces. There was little difference in the results observed with the high chloride specimens obtained from field sources (Michigan and Ontario bridges) and those obtained from a laboratory corrosion sequence. Thus, the laboratory-prepared specimens are considered appropriate substrates for evaluating coatings over chloride contaminated weathering steel.

4. Evaluation of Surface Preparations

Abrasive blast cleaning methods were clearly superior to power tool cleaning for bare metal. An even greater difference in performance based on failure times is noticed between power tool and hand tool cleaning. The data on failures for wet and dry blasting over chloride-contaminated surfaces are summarized in table 16. While these data show that the two methods were approximately equivalent for rust failures in salt spray, the wet blast gave fewer failures by blistering in salt spray and immersion. There were no failures evident on any of the panels exposed in the UV-con/freeze-thaw test.

C. DISCUSSION OF ACCELERATED TEST RESULTS

The following trends and conclusions were identified based upon the limited exposures, number of specimens, and the need to select a single formulation representing the generic coating types compared.

1. The oil alkyd, lead silico-chromate (Federal Specification TT-P-615) two-coat system control (system 1) performed poorly in all comparisons and exposures.

2. The thermal sprayed zinc (system B) performed excellently over blast cleaned surfaces.

3. Testing of system 5 (aluminum-zinc filled, moisture-cured polyurethane with a polyamide topcoat) was limited to abrasive blasted substrates, over which it performed excellently in salt spray and immersion testing.

4. System 6 was similar to system 5, except the metallic content in system 6 was limited to zinc. System 6 exhibited very poor blister resistance over blast cleaned substrates. This system did not perform well over hand cleaned substrates.

5. Both inorganic zinc (system 2) and zinc-rich epoxy (systems 3A and 3B) performed extremely well over abrasive blasted substrates in immersion. In salt spray, each of the systems exhibited some rust failures on high-chloride substrates. In addition, the vinyl topcoat blistered over the inorganic zinc-rich primer. The vinyl-inorganic zinc intercoat blistering has been noted by other investigators and is often dependent upon the chemical character of the vinyl constituents.

6. All systems tested (systems 1, 4, 6, and 7) with power and hand tool cleaning performed poorly when evaluated for blistering in the salt spray and UV-Con/freeze-thaw tests. System 4 (the epoxy mastic) was superior to the others tested, exhibiting only one failure over hand tool cleaning due to rusting in the salt spray. Blistering problems were also experienced with system 4 in salt spray and water immersion over abrasive blasted surfaces.

7. Abrasive blast cleaning methods were clearly superior to power and hand tool cleaning. An analysis of the time to failure of power and hand tool cleaned surfaces showed that power tool cleaning is significantly better than hand tool cleaning.

8. Coating performance was similar over the laboratory prepared pitted panels and the field corroded specimens. Thus, corroded specimens prepared by the previous documented laboratory procedure are appropriate substrates for evaluating coatings over chloride-contaminated weathering steel.

Table 31. Outline of test plan for contaminant levels in contaminated surfaces study.[1]

EXPOSURE TEST->		PROHESION				IMMERSION				ACCEL. ATM.				ATM. (NORMAL)			
PAINTS	STEEL	CONT	Cl-	SO4--	SLAG	CONT	Cl-	SO4--	SLAG	CONT	Cl-	SO4--	SLAG	CONT	Cl-	SO4--	SLAG
1	A36	T	T	D	D	D	D	D	D	D	D	D	D	D	D	X	X
	A588	D	D	D	D	X	X	X	X	D	D	D	D	X	X	X	X
2	A36	T	T	D	D	D	D	D	D	D	D	D	D	D	D	X	X
	A588	D	D	D	D	X	X	X	X	D	D	D	D	X	X	X	X
3	A36	T	T	D	D	D	D	D	D	D	D	D	D	D	D	X	X
	A588	D	D	D	D	X	X	X	X	D	D	D	D	X	X	X	X
4	A36	T	T	D	D	X	X	X	X	D	D	D	D	D	D	X	X
	A588	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	A36	T	T	D	D	D	D	D	D	D	D	D	D	D	D	X	X
	A588	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
# OF PANELS	A36	15	90	50	20	8	48	40	16	10	60	50	20	10	60	0	0
	A588	6	36	30	12	0	0	0	0	6	36	30	12	0	0	0	0
SUM		21	126	80	32	8	48	40	16	16	96	80	32	10	60	0	0

TOTALS		PROHESION	IMMERSION	ACCEL. ATMOSPH.	ATM. (NORMAL)
	A36	175	112	140	70
	A588	84	0	84	0
		259	112	224	70

GRAND TOTAL - 665 PANELS

CONT = PRISTINE CONTROL
Cl- = 6 CHLORIDE LEVELS (µg/sq cm)
1.6, 3.1, 7.6, 15.6, 28.9, 63.3
Cl-, Cl-1, Cl-2, Cl-3, Cl-4, Cl-5
SO4-- = 5 SULPHATE LEVELS (µg/sq cm)
3.7, 7.4, 14.7, 105.0, 53.4
SO4-, SO4-1, SO4-2, SO4-3, SO4-4
SLAG = 2 SLAGS (coal slag, Cu slag)

PAINTS

1. = IOZ / EPOXY / URETHANE -- 161 panels
2. = EPOXY ZN / EPOXY / URETHANE -- 161 panels
3. = EPOXY MASTIC (2 COATS) -- 161 panels
4. = ACRYLIC LATEX (3COATS) -- 77 panels
5. = WATER BASED ZN / ACRYLIC LATEX (2 COATS) -- 105 panels

D = DUPLICATE PANELS
T = TRIPLICATE PANELS
X = NOT TESTED

PANEL SIZE

4 x 6 x 1/4 in (10 x 15 x 0.8 cm) - PROHESION AND IMMERSION
4 x 12 x 1/4 in (10 x 30 x 0.8 cm) - ACCELERATED ATMOSPHERIC AND NORMAL ATMOSPHERIC

SCRIBES

2 in (5 cm) VERTICAL - PROHESION
4 in (10 cm) VERTICAL - ACCELERATED ATMOSPHERIC AND NORMAL ATMOSPHERIC
NO SCRIBE - IMMERSION

[1] See reference number 4 for complete details.

Table 32. Times to failure by blistering for cyclic salt spray test in contaminated steel project.[1]

Level Dopant[2]	System 2[3,4] A 36	System 2[3,4] A 588	System 3[4] A 36	System 3[4] A 588	System 4[4] A 36	System 5[4] A 36
Control	S[5]	S	S	S	5000+	S
Coal Slag	S	S	S	S	5000+	S
Cl, 1.56	S	S	S	S	S	S
Cl, 3.13	S	S	S	S	S	S
Cl, 15.55	S	S	5000+	S	2700	S
Cl, 28.89	5000+	S	5000+	S	1800	3350
Cl, 63.33	5000+	S	S	S	2000	1550
SO_4, 3.68	S	S	S	S	S	S
SO_4, 7.37	S	S	S	S	S	S
SO_4, 14.73	5000+	S	S	S	S	S
SO_4, 52.4	1000	2700	S	S	S	S
SO_4, 105	5000	1850	S	S	S	S

1 Times are average of 2 or 3 replicates of hours to failure using criterion of 7 blister rating (i.e., 8M, 6F, 4 VF or worse considered failure), see refernce number 4 for further details.
2 Levels are expressed in $\mu g/cm^2$, dopant by name or chemical symbol.
3 For system 2 (ethyl silicate zinc/epoxy/urethane) severe blistering occurred between the zinc primer and the topcoats and 2000 to 3000 hours.
4 System 2 = epoxy zinc/epoxy/urethane.
System 3 = two-coat epoxy mastic.
System 4 = three-coat waterborne acrylic.
System 5 = waterborne alkali silicate zinc/acrylic.
5 S indicates that all the panels survived (i.e. did not fail) for the entire 5375 hours.

Table 33. Times to failure by blistering for pressure immersion test in contaminated steel project.[1]

Level Dopant[2]	System 1[3] A 36	System 2[3] A 36	System 3[3] A 36	System 5[3] A 36
Control	S[4]	S	2040	168
Coal Slag	S	S	1370	96
Copper Slag	S	S	2040	24
Cl, 1.56	S	S	2040	24
Cl, 3.13	S	S	2040	24
Cl, 7.56	S	2040	2040	48
Cl, 15.55	S	1370	2040	48
Cl, 28.89	S	1010	2040	96
Cl, 63.33	S	192	1370	648
SO_4, 3.68	S	S	2040	24
SO_4, 7.37	S	S	2040	48
SO_4,14.73	S	2040	1370	48
SO_4, 52.4	S	192	1370	168
SO_4, 105	S	192	672	24

1 Times are average of 2 or 3 replicates of hours to failure, using criterion of 7 blister rating (8M, 6F, 4VF or worse considered failure), see reference number 4 for further details.

2 Levels are expressed in $\mu g/cm^2$, dopant by name or chemical symbol.

3 System 1: ethyl silicate zinc/epoxy/urethane.
System 2: epoxy zinc/epoxy/urethane.
System 3: two-coat epoxy mastic.
System 5 alkali silicate zinc/waterborne acrylic.

4 S indicates that all the panels survived (i.e., did not fail) for the entire 5375 hours.

APPENDIX 4
REVIEW OF RECENT RELEVANT PROJECTS

A. EFFECT OF SURFACE CONTAMINANTS ON COATING PERFORMANCE(4)

An evaluation was conducted for the FHWA of the performance of five different coating systems applied to surfaces contaminated with various loadings of either sulfate or chloride salts. The contaminated surfaces included weathering steel specimens. The general conclusions from this work are described in appendix 3.

From a battery of laboratory tests and 12- to 18-month exterior exposures, it was concluded that the most effective system for protection against high chloride levels ($\geq$ 50 $\mu g/cm^2$) was based on an inorganic zinc-rich primer. The full system also incorporated an epoxy intermediate and urethane topcoat. The organic zinc-rich system equal to that qualified by Michigan DOT did not perform equally well. It exhibited barrier properties, not sacrificial properties, at the scribe.

The final conclusions from this study still require ratification from field exposures. This can be expected by 1995. A brief outline of the results from this testing as they pertain to weathering steel is given below.

1. Results of Exposure Studies

A summary of the threshold limit test parameters is given in table 31. There were 5 coating systems (systems 1-3 were applied to A 588 steel), 4 exposure tests, 14 contaminants (including 6 chloride levels and 5 sulfate levels), and A 588 and A 36 steel substrates. The test design was not a full factorial since that would have resulted in a prohibitively large number of test specimens. System 5 in these tests is identical with system 6 in the outdoor exposures described later in this report.

Attempts were made to assign threshold levels for acceptable surface cleanliness based on the failures observed in these tests. The dominant mode of failure which permitted such assignment was blistering. The results for the cyclic salt spray and high temperature pressure immersion tests are given in tables 32 and 33, respectively.

The data shown includes details of the performance of coatings applied to A 36 panels for systems 4 and 5. Little difference was observed in the extent of failure of the test coatings placed on A 36 versus A 588 panels. Thus the data for systems 4 and 5 may be predictive of how these coatings would perform upon corroded weathering steel surfaces.

This immersion test did not include A 588 test panels. It did prove very informative in assessing the resistance of barrier coatings to blistering failure when applied to contaminated surfaces. This is likely to be independent of the steel used. Easy assignment of the extent of failure was possible for systems 1, 2, and 3, all of which employed epoxy coatings as part of the system.

In general the pressure immersion test was a successful means for assessing the sensitivity of a coating system to contamination. Chloride was twice as virulent a corrosive on a weight to weight basis than sulfate. The subset of abrasive blasted controls, included in the experimental design, showed little deviation from one another. Marginally greater degradation was observed for the organic zinc system 2 when applied to a copper slag blasted surface. The overall excellent behavior of inorganic zinc coatings may be attributable to the sacrificial zinc pigment. That this behavior is not mirrored in the organic zinc coatings suggests that system 2 is behaving as a three coat barrier system. The poor performance of the organic zinc system (system 2), over contaminated steel is especially worrying as it is a frequently specified coating system for bridge structures.

2. A 36 Versus A 588 Steel

For most of the Prohesion and accelerated atmospheric tests, A 588 (weathering steel) was tested under the same conditions as A 36, including control panels, alternate abrasives, varying levels of chloride and sulfate contamination, and various coatings. The results show that the two substrates gave almost identical results for coating performance. There was no evidence that these coatings gave superior performance over weathering steel than over carbon steel.

3. Comparison of Chloride and Sulfate Levels

The six chloride levels and five sulfate levels were selected to give a range from very low levels of these contaminants to very high levels. These levels are believed to be representative of those that can be encountered on field specimens. Because of differences in molecular weight and ionic dissociation effects, to provide an equivalent number of ions, twice as much sulfate is needed as chloride on a weight basis.

The results show that, for the most part, the effects of chloride and sulfate on accelerating the degradation of coatings was approximately equal. The one exception occurred for the two water borne acrylic systems in cyclic salt spray; other chloride contaminated surfaces exhibited increased degradation, whereas the sulfate contaminated surfaces did not.

B. FHWA LOW-VOC COATINGS RESEARCH

In a project supported by the FHWA, Ocean City Research has been evaluating a wide variety of coating products for use on new steel. As a component of this research effort, low VOC coatings have been exposed following application to weathering steel specimens. This work is in progress. Some preliminary details of the program were reported in 1991 at the SSPC National Conference in Long Beach, California. A final report from this work can be expected before the end of 1993.[7]

Though this project did not focus on remedial painting of existing structures it provides good data supporting a conclusion that a wide range of coating products give excellent performance on new weathering steel. The data will be of use for specifiers intending to mitigate corrosion for future installations of weathering steel bridges in highly corrosive environments.

C. NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 314(2)

A seminal treatise describing the causes, extent, and severity of corrosion found on unprotected weathering steel structures, this report also provides excellent guidelines for mitigation of these problems. The primary focus is to reduce the future incidence of unwanted corrosion through better design and detailing of new weathering steel bridges. Additional guidelines are given on surface preparation and system selection for remedial painting of affected existing structures.

D. MICHIGAN DEPARTMENT OF TRANSPORTATION LABORATORY TESTING

The Michigan DOT has an annual program of coating system submittal to a test program which screens samples based on two criteria. Successful candidates are added to a qualified products list (QPL). The two criteria used for screening candidate systems are:

- Successful passage through a battery of five accelerated tests based on a final overall rating. The tests incorporate combined cyclic and serial exposure in different cabinets along with freeze-thaw cracking.

- Evaluation of application and film forming characteristics using airless spray equipment.

The Michigan DOT has used this test program since 1982 to aid development of a specification based upon an organic (epoxy polyamide) zinc-rich primer. An intermediate coat of two component epoxy and a finish coat of aliphatic urethane typically comprise the qualified systems. This test program is strongly supported by Michigan DOT. The program has focussed on examination of a narrow class of coating systems. The validity of the test criteria when applied to a wider range of coating systems remains in question. The program has consistently evaluated systems with low VOC. The requirements for VOC have been recently reduced to a maximum of 3.5 lb/gal (420 g/l). All systems tested have been free of lead and chromate pigments.(5)

A strong component of this product qualification procedure is the evaluation of its application, handling, and film forming characteristics. These are tested using airless spray application methods, intended to duplicate those used in subsequent bridge coating work.(6)

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