Guidelines for Repair and Maintenance of Bridge Coatings: Overcoating

PUBLICATION NO. FHWA-RD-97-092

AUGUST 1997

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

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FOREWORD

This report describes a study of overcoating methods and materials for maintenance of steel highway bridges. The results of this study indicate that while overcoating with some of the commercially available coatings tested may provide a corrosion control benefit in some cases, the risk associated with potential early failure of overcoating applications should be strongly considered prior to selecting these materials and methods for steel bridge coating system maintenance.

This report is expected to be of interest to highway bridge engineers, maintenance engineers, and materials engineers and chemists.

Charles J. Nemmers
Director, Office of Engineering
Research & Development

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-97-092		

4. Title and Subtitle	5. Report Date
GUIDELINES FOR REPAIR AND MAINTENANCE OF BRIDGE COATINGS: OVERCOATING	August 1997
	6. Performing Organization Code
7. Author(s) Christopher Farschon, Robert Kogler, and J. Peter Ault	8. Performing Organization Report No.
9. Performing Organization Name and Address Ocean City Research Corporation Tennessee Avenue & Beach Thorofare Ocean City, NJ 08226	10. Work Unit No. (TRAIS) 3E4A0282
	11. Contract or Grant No. DTFH61-92-C-00091
12. Sponsoring Agency Name and Address Office of Engineering Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296	13. Type of Report and Period Covered Final Report & Guidelines Oct 1992 - March 1997
	14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contractoring Officer's Technical Representative: Robert A. Kogler, HNR-20

16. Abstract

The subject program investigated the applicability of various materials and methods for repair and overcoating of existing steel bridge paint systems. The program included information review, material selection, laboratory screening testing, and extended field exposure testing phases.

Sixteen commerically available industrial maintenance coating systems were applied in paralled test patches to four separate structures. These structures are located in Chicago, Illinois; New York, New York; Manchac, Louisiana; and Hookset, New Hampshire. Typical surface preparation procedures used on overcoatings jobs were used to clean test patch areas. This included low pressure water washing and mechanical removal of loose paint and rust using power tools.

Results indicate varying performance between the coatings tested. Failure of coatings occurred via two distinct mechanisms. A few coatings failed after one or two winter weather cycles by disbondment of the bond between the overcoat and existing coating or disbondment of the marginally adhered existing coating from the steel (millscale) substrate. Several coatings should significant pinpoint or edge rusting through the applied overcoat film in areas applied directly over rusted or contaminated steel. The chance of coating system disbondment or early rust though should be considered carefully prior to investing in overcoating maintenance for bridge paint systems.

17. Key Words	18. Distribution Statement
Overcoating, lead-paint, steel bridge maintenance	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	95	

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BACKGROUND

The construction of the U.S. interstate highway system from the 1950's through the 1970's created a large number of steel structures which are now reaching an age where significant maintenance is required. The majority of these structures were fabricated from carbon steel and painted with lead-containing alkyd coatings applied directly over intact mill-scale with little if any surface preparation. The deteriorating condition of these bridges coupled with increasing costs for coatings work has created problems for bridge owners in determining which maintenance strategies are the most cost-effective.

Maintenance painting of bridges has been the focus of much attention in recent years. Bridge owners have specified maintenance options such as full coating removal and repainting, spot power tool cleaning and full painting, and postponing of maintenance painting while improved technologies are developed. These different strategies have been adopted in an effort to identify the most reliable and cost-effective means of protecting highway bridges. Two factors have contributed to the experimentation with different maintenance painting practices; these are: 1) the increasing age and deterioration of a large percentage of highway bridges, and 2) the increasing cost of performing surface preparation and painting on bridges coated with lead-containing paint.

Regulations governing the protection of the environment and workers during lead-containing paint removal have significantly increased painting costs. There are basically two categories of regulations that pertain to bridge painting: those pertaining to worker protection and certification, and, those dealing with the release of lead outside the work area. The Occupational Safety and Health Administration (OSHA) regulates worker protection and certification. In 1993, OSHA adopted the Interim Final Rule for lead-in-Construction (29 CFR 1926.62). This regulation details the requirements for protection of workers removing or disturbing lead-containing paint during construction (and maintenance) activities.

Environmental protection regulations are less clear for bridge maintenance painting operations. The Resource Conservation and Recovery Act (RCRA) dictates measures for testing, control, and disposal of lead-containing debris, but controversy exists over how the dust emissions from blasting operations are addressed under the Clean Air Act. However, with increasing knowledge of the potential hazards to the environment and the public caused by abrasive blasting emissions, the use of containment systems with forced-air ventillation and dust collection systems has become commonplace.

The cost impact of these regulations to the bridge painting industry is significant. In the past decade, costs of typical abrasive blasting and repainting operations have increased 5 to 10 fold.[1] Containment structures used during abrasive blasting contribute a significant cost

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[1]L.M. Smith and G.R. Tinklenburg, *Lead-Containing Paint Removal, Containment, and Disposal*, Report No. FHWA-RD-94-100, February 1995.

increase. Workers assigned to coatings work on lead-paint jobs must be trained, monitored and take extra health precautions (i.e., use washing and decontamination facilities not previously required). These items also are an additional cost. In addition, treatment and disposal of large volumes of abrasive and paint waste is now costly due to the hazardous characteristic of lead.

Due to these cost increases, bridge owners have increasingly turned to alternative maintenance methods. The use of spot cleaning and overcoating has minimized the up-front costs of maintenance painting when compared directly with abrasive blasting. This factor is attractive to bridge owners with limited annual maintenance budgets and increasing bridge painting burdens.

It is accepted that spot cleaning and overcoating will provide significant savings in initial cost when compared directly with full removal and replacement of the existing paint system; however, it is critical to consider the performance trade offs associated with this up-front cost savings.[2] The following report documents the findings of a Federal Highway Administration study investigating the relative performance of various commercially available "overcoating" systems. Attached guidelines attempt to provide a reference for bridge owners making bridge maintenance painting decisions. These guidelines address the critical issues of cost, performance, and risk associated with bridge maintenance painting in the current environment.

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[2]T.F. Bernecki, G.M. Nichols, D. Prince, G. Shubinsky, and A. Zdunek, *Issues Impacting Bridge Painting: An Overview*, Report No. FHWA-RD-94-098, Federal Highway Administration, Washington, DC, August 1995.

OBJECTIVES

The subject research has two primary objectives.

- Identify non-hazardous, "environmentally acceptable" coating materials that may be used for corrosion protection of exposed steel and/or mill scale during repair/maintenance of aged bridge coating systems. These materials must be compatible with existing bridge coating system topcoats in addition to meeting proposed VOC regulations.

- Develop criteria for the specifying engineer for maintenance painting decisions. These criteria should include assessment of existing bridge coating conditions, prediction of the added lifetime of the coating system after overcoating, and comparative costing techniques for various maintenance options. Based on these criteria, the engineer should be able to make an economically and technically sound decision whether to replace or repair a deteriorated bridge coating system.

CONCLUSIONS

- The coating systems tested during the field exposure phase of this program were applied over various surfaces. These surfaces included existing paint, clean mill scale, light corrosion (SSPC surface condition C), and packed rust (condition D). Two failure modes were observed for the overcoating systems field tested:

  1. **Failure due to coating incompatibility:** Two of the 16 paint coating systems disbonded within the first 6 months.

  2. **Failure from corrosion:** Various degrees of rust-through were observed on all overcoating materials in areas of bare contaminated (previously rusted) steel and along the edges of steel beams.

  Of these two failure modes, failure of the overcoating system by rust through over bare-steel areas was the more common failure mode observed during this program.

- The success of overcoating applications depended upon several factors. Among these were the condition of the existing paint (adhesion, cohesion, thickness) and the condition of the exposed steel, the corrosivity of macro and micro-environments of the particular bridge, and the surface preparation/coating system chosen for the application. The performance of overcoating systems varied depending on the initial condition of the structure and the exposure environment on the structure.

- Overcoating must be approached with the knowledge of <u>increased risk</u> compared to other maintenance painting strategies. In this program, early failure was associated with paint failure over unclean surfaces, and incompatibility of the overcoat with the existing paint. Incompatibility initiated chemical or mechanical failure of the composite paint system that lead to delamination of the system and pinhole rusting occurred where overcoating paint was applied over existing adherent rust.

- The measured adhesion of the existing coating systems on the bridges was not found to correlate well with disbondment of the overcoating systems. Some field systems disbonded, but these same systems disbonded at multiple exposure locations, indicating this as a coating specific phenomena. The majority of the coating systems showed zero disbondment of the maintenance system from the existing coating or of the composite system from the bridge.

- In general, the coating systems that performed well at one bridge location performed well in all four exposure locations. Likewise, those that failed during the relatively short exposure times tended to fail at more than one location. This would indicate that there may be overall "high risk" and "low risk" coating material choices for overcoating applications.

- The difference in performance of similar test patches in different exposure locations on each of the bridges has shown that performance variability across a single structure should be expected. Bridges which experience variability in micro-environments should be considered for maintenance painting approaches such as "zone painting."

RECOMMENDATIONS

- Prior to overcoating a structure, a test patch program should be conducted. For bridges with varying micro-environments, a test patch should be applied in each specific environment (zone). ASTM D5064 "Standard Practice for Conducting a Patch Test to Assess Coating Compatibility," can be used as a guide in designing the test patches. The nominal time and money invested in test patch application and evaluation can produce meaningful results in short periods of time (less than 1 year). Patches should be evaluated after at least one winter cycle, particularly in colder climates. A test patch application can help to reduce the risk associated with overcoating.

- Various factors can be considered indicative of "high risk" for overcoating operations. The following factors, alone or in combination, should be carefully considered prior to investing in an overcoating application:

  - pack rust or heavy pitting corrosion
  - very poor adhesion of the existing coating
  - extremely high thickness of the existing coating

- Manage the expectations of bridge owners with regard to the durability of overcoating applications. Since overcoating represents a compromise in surface preparation in order to save initial cost, performance data of applied coatings over less-than-ideal (i.e., rusty or contaminated) surfaces should be used for service life prediction. This data has historically indicated reduced performance compared to data for the same coating materials applied over a blast cleaned surface.

- More research is needed to determine quantitative criteria for existing coating adhesion. The results presented herein suggest that the current adhesion test methods do not clearly correlate to predictable coating disbondment caused by insufficient existing coating adhesion.

- Continue the test panel and test patch exposures that originated with this program. Inspect the patches yearly to validate long-term durability factors associated with overcoating. This will help to confirm the limiting factors of the overcoating systems tested during this research and will aid in the understanding of these factors and how they relate to maintenance painting processes.

INFORMATION REVIEW

The initial information review for this program was conducted in 1992. This review included gathering information from published and in-process work on lead-based paint overcoating and works discussing painting over minimally prepared surfaces. The review also included a series of information gathering conversations with State maintenance painting authorities.

LITERATURE

The literature review consisted of obtaining relevant references for both published and in-process works. Studies were identified from the Georgia, New Jersey, and Pennsylvania Departments of Transportation. Previous contractor projects and the FHWA Sponsored PACE study were also studied to include information of coatings performance over hand- and power-tool cleaned surfaces.

Five studies related to overcoating of bridges were reviewed in detail.

Georgia Department of Transportation Study

The Georgia DOT performed a study which addressed surface tolerant coating performance.[1] This study tested the performance of various coating systems over hand-tool cleaned, brush-blasted, and commercial blasted surfaces. The standard Georgia DOT alkyd was used as a control system. Samples were exposed to salt fog testing, industrial atmospheric exposure, and marine atmosphere exposure. A three-coat moisture-cured urethane with an aluminum pigment in the primer performed best overall in this study. The alkyd control was the second best performing coating system of the 14 that were tested.

In 1992 the Georgia DOT was using maintenance painting on an "experimental" basis. They were using a commercially available waterborne system incorporating a direct to metal (DTM) primer. They were not using any moisture-cured urethane systems due to isocyanate and VOC considerations. However, moisture-cured urethanes are available with 340 g/l (2.8 lb/gallon) or less VOC.

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[1]P.L. King, *Evaluation of Coatings Tolerant of Minimal Surface Preparation*, Georgia Department of Transportation, FHWA Report No. FHWA-GA--92-8806, May 1992.

New Jersey Department of Transportation - Mathis Bridge Study

The New Jersey DOT has an ongoing evaluation of various bridge coatings on the Thomas Mathis Bridge which carries State Route 37 over Barnegat Bay in central New Jersey.[2] This project involved application of a different coating system to each span of the bridge. Each span was entirely painted with the test coating system (i.e., bearings, stringers, and diaphragms). The cost of application for each span was closely monitored by the NJDOT personnel and is presented in the reference.

The results of this test program after 1 year of exposure indicated mixed performance of overcoating systems. Those systems applied over an SP-2 (hand-tool cleaned) surface included alkyds, epoxies, and urethanes. The epoxy mastic systems covered a wide range of performance. Several different manufacturers' versions of this popular maintenance painting system were applied over SP-2 surfaces. Some of these systems had already failed at the 1 year inspection, while others were among the best performers over "surface tolerant" conditions. Other systems performing well over SP-2 surfaces were a calcium borosilicate pigmented alkyd system and an oil-alkyd system.

As a separate activity sponsored by the Federal Highway Administration, a followup visual inspection of the Mathis Bridge was conducted in the summer of 1995. The inspectors assigned ASTM D610 rust ratings to each span. Using the cost data and identification information from the NJDOT, reference the coating system performance was compared to the estimated system cost per square foot.

Figure 1 presents the inspection data on the Y-axis (ASTM D610 - 10 best, 0 worst) versus the cost of the coating system ($/ft^2) on the X-axis (escalated to 1995 dollars by adding estimated containment costs and an annual inflation factor). Each of the various surface preparations are indicated with the different markers. The SP-5 systems were perfect in 1995, but these are metallized coatings and represented a significant initial cost.

The risk associated with overcoating is inherent to the type of surface that is being painted. The minimal surface preparation leaves an inconsistent surface for overcoat application. The results of this can be seen by noticing the range of performance of systems applied over SP-2. The poorest performer had a rating of 2 while the best had a rating near 8. This wide variation in performance was not demonstrated by coatings applied over clean and consistent surfaces such as SP-5 or SP-10.

Pennsylvania Department of Transportation Experience

Experience with upgrading existing lead-alkyd bridge paint using an aluminum pigmented moisture-cured urethane system is described in a paper by Angeloff. Conversation with a Pennsylvania DOT representative confirmed the good performance of moisture-cure ure-

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[2]A. Chmiel, V. Mottloa, and J. Kauffman, *Structural Coating Evaluation in New Jersey*, Research News, Journal of Protective Coatings and Linings, January 1989, pp. 23-26.

thanes. This system has reportedly performed well as an overcoating paint for over 10 years on bridges in the Pittsburgh area.

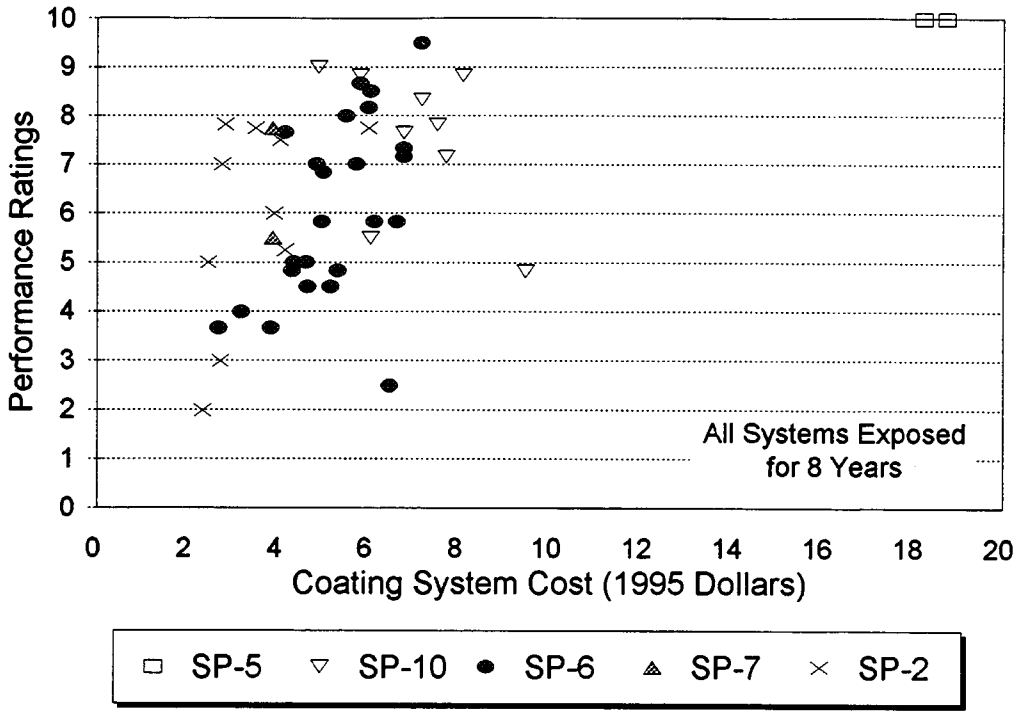

Figure 1. NJDOT study coating system performance versus cost.

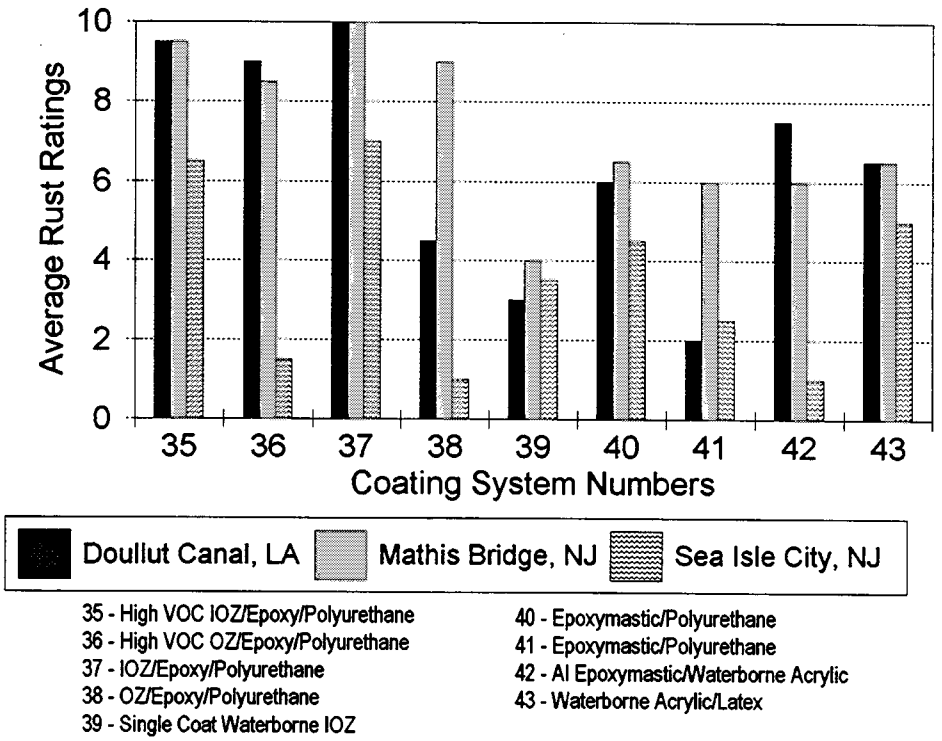

Figure 2. Rust ratings for coating systems applied over SP-3 for 5 years.

FHWA Bridge Coating Research

An 8 year research effort aimed at identification of "environmentally acceptable" coatings for steel bridges has recently been concluded by the contractor[3]. The work involved both laboratory testing of bridge coating systems and exposure of coated panels on bridges in Louisiana and New Jersey. Data was taken on the performance of several coating systems applied over SP-3 power-tool cleaned surfaces and exposed on two bridges and at a marine exposure site for 5 years. The performance of two inorganic zinc primer systems was better than the performance of epoxy mastic and water based acrylic systems tested in parallel.

Figure 2 shows the average ASTM D610 ratings for nine different coating systems exposed in three different locations. All of these coatings were applied to panels prepared to SP-3 and exposed for 5 years. Notice the best performing systems (35 and 37) have inorganic zinc primers.

This result is interesting because inorganic zinc-based coating systems are not presently marketed as maintenance coatings. Various company representatives for vendors of inorganic zinc products reported good performance of their products over power tool cleaned surfaces; however, none of them would recommend this application. The increased expense associated with inorganic zinc coatings is enhanced with an additional investment in quality surface preparation. The performance of inorganic zinc in "surface tolerant" applications is also said to be inconsistent. It appears that, in general, the suppliers of inorganic zinc primers are presently conservative in their marketing, opting to stay with the most successful application of their product. Inorganic zinc coatings are also not compatible with existing organic-resin based systems–they should only be applied to cleaned metal surfaces. This would present obvious problems in overcoating applications.

The results in figure 2 show that the epoxy mastic systems perform similarly to the waterborne acrylic system in terms of rusting, and better the than single coat waterborne inorganic zinc coating over an SP-3 surface. The epoxy mastic systems are often marketed as surface tolerant coatings and are frequently recommended for application over SP-3 surfaces; however, the 5 year data presented in figure 2 shows marginal performance of these systems over SP-3 surfaces.

FHWA PACE Study

The10 year PACE (Performance of Alternative Coatings in the Environment) study examined the performance of various generic types of coatings applied over hand-tool cleaned surfaces.[4] The calcium-sulfonate modified alkyd type coatings performed the best as a generic

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[3]J.P. Ault, C.L. Farschon, and R.A. Kogler, *Environmentally Acceptable Materials for the Corrosion Protection of Steel Bridges,* FHWA-RD-96-058, Federal Highway Administration, Washington, DC, January 1997.

[4]B.R. Appleman, J.A. Bruno, and R.E. Weaver, *Performance of Alternative Coatings in the Environment (PACE)*, Report Nos. FHWA-RD-89-127, FHWA-RD-89-235, and FHWA-RD-89-236, Federal Highway Administration, Washington, DC, September 1990.

group followed by the oil-alkyd coatings. The results of the study did not recommend any other types of maintenance coatings tested over hand tool-cleaned steel, including the epoxy mastic maintenance coatings. Readers should be aware that this study did not test moisture-cured urethanes or zinc-rich coatings in the first round.

An interesting result of the later rounds of this testing indicated that inorganic zinc coatings could provide good performance over less than ideal surfaces. This result is consistent with that from previously referenced FHWA work on environmentally acceptable coatings.

Other Research

Previous researchers have discussed the cost and feasibility of overcoating as a maintenance strategy,[5] and have presented coating performance data for materials applied over less-than-ideal surfaces, but no long term studies exist for coatings applied over existing weathered coatings. Many case histories exist for overcoating projects, but controlled parallel comparisons of overcoating materials are scarce. Recently published results from a FHWA sponsored study conducted by the Basic Industrial Research Laboratory (BIRL) Northwestern University, included both field applications and accelerated laboratory testing of overcoating materials.[6] These results indicated that correlations may be drawn between field exposure testing and laboratory accelerated testing of overcoating materials. However, the variability of surfaces that are typically overcoated makes accelerated testing practical for comparative analysis only. Stand-alone accelerated testing is not a practical measure of an overcoating material's potential durability. The BIRL paper did not include any specific conclusions related to the performance among the various coatings tested, but results did seem to correlate with overcoating thickness and number of coats applied. Multicoat systems applied by brush performed better than single coat systems applied by brush. This conclusion is consistent with the findings of the present research reported herein.

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[5]B.R. Appleman, *Overcoating vs. Removing Lead Paint: A Comparative Analysis*, JPCL, November 1993, pp. 60-68.

[6]R.H. Krueger, G. Nichols, and T. Bernecki, *Field Analysis of Surface-Tolerant Coatings*, Proceedings from, the SSPC 95 Seminars, Dallas, Texas, November 9-16, 1995, SSPC 95-09, pp. 260-271.

STATE AGENCIES

A brief review was conducted to identify the maintenance painting practices of several State departments of transportation. The survey was conducted informally via telephone conversations with state DOT representatives. The information obtained included:

- Details of bridge inspection practices, such as qualifications for inspectors and specific coatings data obtained during bridge inspections
- The decision criteria used to determine State-implemented maintenance painting strategies
- The overall maintenance strategy of the State (repair and overcoat or removal of all lead-based paints)

This information was used to gauge the diversity of the maintenance painting strategies being implemented by the state DOT's. Many States that were either practicing or considering implementation of overcoating were particularly interested in the study. Since the contractor was tasked to evaluate overcoating products, some State agencies were interested in including State qualified products in this testing. This would provide the State with a benchmark to judge the performance of the product currently being specified versus those commercially available.

Bridge Paint Inspection

All States surveyed inspected all bridges under their responsibility for structural integrity at least once every 2 years. This requirement arises from a Federal safety mandate and often does not include a detailed assessment of coating condition. Some States cited inspections of certain bridges on an annual basis. Bridge paint inspections for the States interviewed are generally performed by project or resident engineers, who are not typically trained coating inspectors. Several of the States pointed to this system as a problem, causing inconsistent and possibly less thorough attention to coating degradation.

All States surveyed indicated that the routine bridge inspections included only visual assessment of coating degradation. The various States had their own qualitative rating systems. These systems all assigned a number - all on somewhat of a unique scale (i.e., 1 to 5, 1 to 7, etc.) indicating the overall condition of the bridge, or in some cases, the condition of the various areas of the bridge (i.e., zone inspections).

More detailed inspections may be conducted on "larger" bridge structures (e.g., if the inspection is competitively bid), or if the routine inspection indicates a very poor paint condition. An example of this is in Louisiana; if initial inspections indicate a critical condition, a coatings inspection team will be dispatched to perform a follow-on inspection including a detailed visual and physical analysis of the existing coating. The physical analysis consists of cross-hatch adhesion testing to assess the existing coating adhesion in various bridge areas.

Virginia, North Carolina, and Kentucky all indicated they used similar methods of collecting data on bridges. As in many of the other States contacted, coating inspections are performed in conjunction with the federally mandated biennial bridge inspections. In this regard, the inspections are generally not performed by trained coatings inspectors, and the resultant data is a qualitative description of the visual condition of the coatings.

In view of these issues, these states are trying to improve the information produced by the regular bridge coating inspections. Kentucky has recently provided formal, classroom type training to all personnel involved in bridge paint inspection to increase awareness of the failure modes, inspection techniques, and other critical issues surrounding bridge coatings. Virginia conducts field adhesion testing in accordance with ASTM D3359 method B for all bridges which appear in need of maintenance painting due to visual rusting. The current rule of thumb used by Virginia (as of 1992) specifies that an adhesion rating of "0B" constitutes a considerable risk of failure in a maintenance overcoating scenario. This is regardless of the particular coating materials involved. Virginia and Kentucky are presently attempting to assess the advantages and disadvantages of various overcoating materials. The adhesion criteria used in Virginia is in general agreement with an SSPC "State of the Practice" type document for overcoating that is currently under development.

One general result of the interviews with the various State representatives is that there is a need for valid criteria with which the "overcoatability" of an existing paint system may be evaluated. A general complaint of the State representatives is the lack of a suitable system for obtaining data with which rational maintenance decisions may be implemented. Virtually all of the States contacted are increasing the percentage of maintenance painting on their bridges. This trend has been motivated by the increasing costs associated with maintenance of lead-painted structures, coupled with decreasing maintenance painting budgets in many States. The increasing cost burdens of bridge paint removal and reapplication have motivated the industrial painting community to investigate alternatives to full removal by abrasive blasting.

Present Extent of Maintenance Painting

The maintenance approach of the States interviewed varies from total blasting and recoating of bridges as a policy to aggressive efforts to maintain all existing, intact bridge paint. There is a strong desire expressed by all State representatives contacted to find a practical means of maintenance painting to avoid the tremendous costs associated with containment and hazardous waste disposal when blast and recoat options are invoked.

Because of these costs, several States are presently stepping up maintenance painting operations in an effort to upgrade and preserve as much intact, adherent coating as possible. This type of effort is exemplified by New York, which is presently executing a comprehensive bridge paint maintenance plan. Under this plan, New York intends to maintain, restore, and upgrade the existing coating systems on approximately 600 bridges per year for the next 12 years. Since New York presently maintains over 7000 bridges, this 12 year cycle is designed to perform maintenance on every bridge in the State over the period. The key to this program is a dedicated

fund for bridge maintenance painting. State representatives indicated that this fund was approximately $33 million in 1992.

California has also undertaken an aggressive maintenance painting philosophy. California coatings personnel believe that if a coating system is intact it is irresponsible to remove it. Therefore, only the degraded areas of a coated structure are in need of maintained. California has employed maintenance painting on structures showing less than 30-percent degradation, but due to the rising costs and risks associated with blasting and disposing of lead paint, this number was increasing above 40%. While this is, at best, a semi-quantitative estimate, it is clearly reflective of the strenuous economics and public relations constraints presently at work in bridge painting. From information obtained in this survey, it is certainly feasible that some States may soon consider attempting to salvage a coating system that is more than half degraded. This practice is contrary to traditional bridge painting philosophies in which a coating system showing perhaps 15- to 20-percent degradation would be considered "totally failed."

Pennsylvania has also recently adopted a criteria of 25-percent degradation before blast and recoat options are considered. The Pennsylvania DOT specifies a "Spot & Zone Painting" approach for any bridge showing less than 25-percent coating degradation. In this approach, a bridge coating is power tool-cleaned and spot primed in the prepared areas with an aluminum-mastic coating, or a zinc-rich moisture-cured urethane coating. Either one or two urethane topcoats are then applied over the entire bridge.

The California approach embodies not only cost reduction, but also technical goals in the maintenance painting decisions. Approximately 50 years of maintenance painting experience on toll-bridge structures such as the San Francisco-Oakland Bay Bridge has led to the conclusion that the life of a coating system may vary greatly across the various areas of a single structure. By assuming an aggressive maintenance strategy on the selected areas which chronically fail, the bulk of the surface may go unmaintained for long periods of time.

In contrast to the California approach is that of Connecticut. Connecticut removes existing paint and applies a total recoat if more than approximately 20 percent of the coating is deteriorated. In addition, if the adhesion of the existing coating is below 1.38 MPa (200 lbf/in^2) as measured using an ASTM D4541 pull-off adhesion tester, the coating is considered unsuitable for maintenance painting, and will be removed. In addition, if the coating thickness is greater than 508 μm (20 mils), the risk is considered too great for overcoat application.

Another interesting approach is that of Georgia. Georgia is aggressively removing deteriorated lead-containing paint systems from all State-owned steel bridges in order to eliminate the hazard in a short time frame and upgrade the durability of inservice coating systems.

TECHNICAL APPROACH

The testing portion of this research was carried out in two phases. Overcoating materials were identified that satisfied the VOC and hazardous material (constituent) requirements and were tested both in the laboratory and in the field. A laboratory evaluation was conducted for coating materials applied over pre-weathered substrates. A field test patch exposure phase was also conducted to evaluate overcoating material exposures on actual bridges.

This program was divided into several distinct tasks. The following items briefly identify each specific phase of this research program and provide references for the objectives and results of each program task.

- A two part literature review was conducted: State agencies were contacted concerning their maintenance painting practices and strategies for controlling bridge maintenance painting costs; and, applicable research programs and case studies were reviewed to provide a baseline for designing this research program. The information review section of this report documents these findings.

- A discussion of compatibility between various aged bridge topcoats and potential overcoating system primers was generated to help select overcoating systems for verification testing. This discussion is presented in appendix I.

- Six candidate overcoating systems were tested over panels previously painted with traditional bridge coating systems and weathered for several years. A cyclic accelerated laboratory test and accelerated marine atmosphere exposure were conducted.

- Field test patch exposures were conducted using a total of 16 overcoating systems. These coatings were applied in four geographical locations across the United States. In total, 113 patches were applied and evaluated over a 2-year period.

- Maintenance guidelines were written to assist engineers with bridge maintenance coating decisions. These guidelines include decision criteria aimed at identifying the most cost effective maintenance strategy for a particular bridge. The guidelines are presented in appendix II.

The technical considerations used to complete these tasks are discussed in the following subsections.

LABORATORY TESTING

The laboratory testing served as a precursor to the field testing phase of the program and provided a more controlled environment for the evaluation of the overcoating materials. Six overcoating systems were subjected to laboratory testing. These systems are detailed in table 1, but can briefly be described as; a two-coat aluminum alkyd, an epoxy sealer/epoxy mastic, a calcium sulfonate, a two-coat waterborne acrylic, a three-coat polyurethane, and an epoxy mastic/polyurethane. These coatings were chosen to generically represent the majority of the overcoating systems currently used in the bridge industry. Two tests were performed on each coating system; a cyclic accelerated test and accelerated marine atmosphere exposure. Laboratory testing was performed on aged panels coated with typical traditional bridge coating systems. These panels had been exposed to the marine environment for a period of 4 years and were in various States of deterioration prior to cleaning and overcoating. This testing was performed to obtain a gross determination of the compatibility of new overcoating materials with typical aged bridge coatings and to assess the general performance trends of these materials in an accelerated test environment.

Pre-exposed Panel Surface Preparation Procedure

Panels exposed to the natural marine environment under a previous FHWA sponsored program were retrieved from the Ocean City Research, Sea Isle City Marine Exposure Site after approximately 4 years of exposure. These panels were originally used as control coatings in a bridge paint study sponsored by FHWA.[1] The panels of interest were originally topcoated with basic lead silico-chromate alkyd, aliphatic polyurethane, and vinyl topcoats typical of those found on existing bridge structures. Samples of aged, non-lead alkyd coatings were not available for testing, so panels were prepared with two coats of a leafing aluminum alkyd paint and exposed for 1 month prior to being retrieved and overcoated.

Prior to overcoating, each of the test panels was returned to the laboratory for surface preparation. The steps in this process are described below:

- Pressure washing at nominally 3.45 MPa (500 lbf/in^2). This pressure was chosen in an attempt to leave as much of the marginally adherent coating intact as possible. This low pressure removed the majority of the dirt and surface contaminants without damaging the existing paint.

- Power tool cleaning to remove loose rust and coating using a rotating peening tool.

- Power tool cleaning using a rotating grinder on the bare areas to remove more adherent rust.

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[1] J.P. Ault, C.L. Farschon, and R.A. Kogler, *Environmentally Acceptable Materials for the Corrosion Protection of Steel Bridges,* FHWA-RD-96-058, Federal Highway Administration, Washington, DC, January 1997.

- Power tool cleaning using a rotating peening tool to impart roughness on the bare metal areas

The surface preparation procedure described above was able to approach the definition of SSPC SP-11 (power tool-cleaning to bare metal) over areas where the existing coating was removed. However, for some of the more deteriorated panels, the adherent rust imbedded in pits and crevices was virtually impossible to remove using practical mechanical means. The combination of the grinder and the peening tool provided a relatively clean and well abraded surface for painting. Figure 3 shows an example panel following the surface preparation described above.

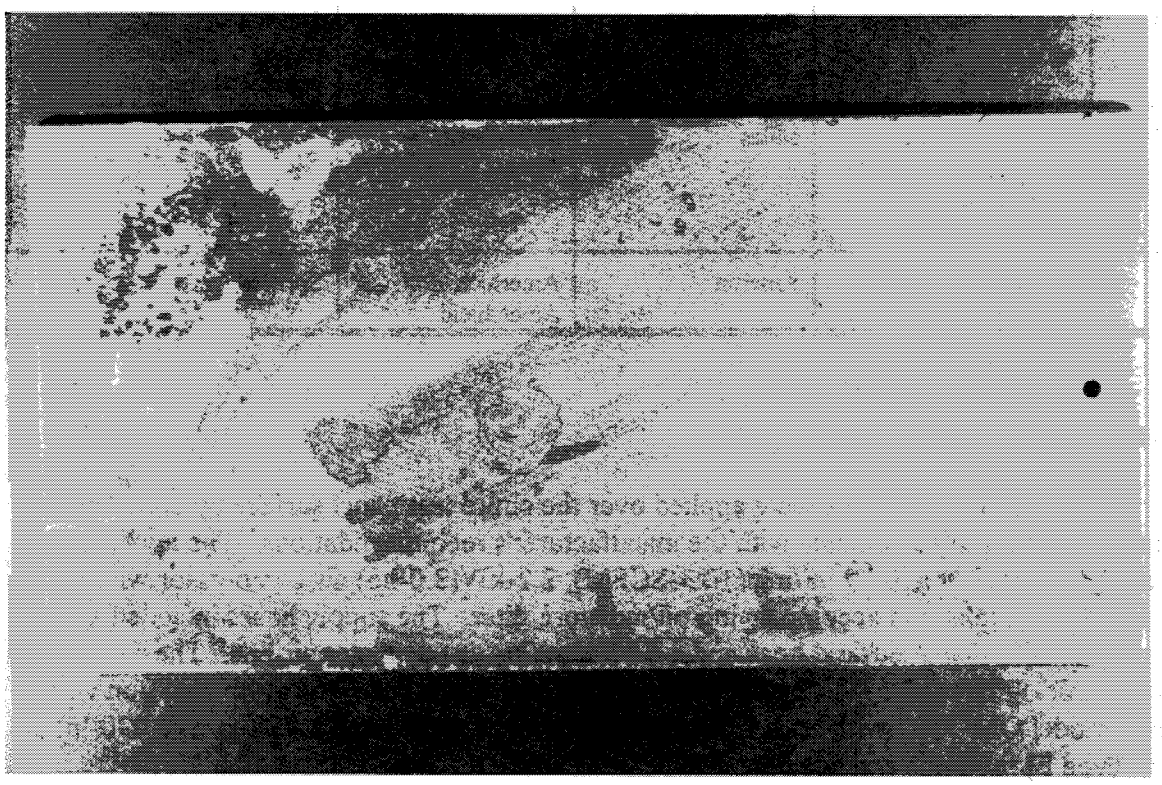


Figure 3. Representative panel following surface preparation.

Coatings

Table 1 describes the six overcoating systems exposed to accelerated testing.

Table 1. Overcoating systems selected for accelerated testing.

System ID	Generic Description	Manufacturer	Product(s)	Application comments
A	two-coat leafing aluminum pigmented alkyd	Carboline	Subox GridGuard 2600	Sprayed well
B	low viscosity epoxy sealer/ Al epoxy mastic	Devoe	PrePrime 167/ BarRust 239	PrePrime sprayed well. BarRust did not spray with conventional air spray equipment without thinning.
C	single coat calcium sulfonate modified alkyd	CPC Corp.	Chemotex 81	Sprayed well
D	two-coat waterborne acrylic	Rohm and Haas	Maincote HG-56	Sprayed well. Slight flash rusting of primer coat over bare metal areas.
E	Al moisture-cured polyurethane/ aliphatic polyurethane/ aliphatic polyurethane	Miles	#292-7/ #2220/ #291-47	Sprayed well
F	epoxy mastic/ aliphatic polyurethane	Ameron	Amerlock 400/ Amershield	Sprayed well

Application Procedures

The test coating systems were applied over the entire test panel surface by conventional air spray equipment in accordance with the manufacturer's recommendations. The application equipment consisted of a 0.29 m^3/min(10.3-SCFM), 2.2-kW(3.0-hp) air compressor with a 0.112-m^3 (4.0-ft^3) tank and accompanying oil/moisture filter. The supply hoses included a 9.525-mm (3/8-in) diameter fluid hose and a 6.35-mm (1/4-in) diameter air line. The fluid reservoir was an air-agitated, 7.57-L (2-gal), dual-regulated pressure pot. The atomizing gun was a Devilbiss model QM-5507 with both 1.09-mm (0.043-in) [Type E] and 1.778-mm (0.070-in) diameter [Type F] fluid tips and needles.

The ambient environmental conditions during application were monitored. The dry and wet bulb temperatures were monitored using a Check-it Electronics Co. Model 424 wet bulb/dry bulb thermocouple assembly with a digital thermometer. The surface temperature was determined using the same gauge with a surface temperature thermocouple attachment. The rel-

ative humidity and dew point were determined using a psychometric chart. Prior to application, it was ensured that the surface temperature was at least 3 degrees celcius (5 degrees fahrenheit) higher than the dew point to avoid coating over condensation on the panel surfaces.

Prior to spray application, all panel edges were stripe-coated with the candidate coating using a brush. On the test panel surfaces, the required film build was generally applied in several passes of the spray gun to ensure uniform coverage. Adequate application over the U-channel (if present) was accomplished by narrowing the gun fan angle and applying paint over the channel in short bursts.

The film build was monitored during application using a wet film thickness gauge. Dry film thickness (DFT) readings for each coating in each system were obtained using an electronic (type II) dry film thickness gauge calibrated with plastic shims. A template was used to facilitate acquisition of DFT measurements at consistent locations from panel to panel. Five DFT readings were taken on each side of each panel for each coating layer.

Following cure of the coatings, each panel was scribed with the scribe intersecting an area of prepared bare steel and an area of remaining adherent topcoat (beneath the maintenance coat). Scribes were cut down to the steel substrate in all cases and provided a test site for coating delamination from the bare steel and delamination from the existing topcoat.

Accelerated Cyclical Test Procedures

A cyclic accelerated test was used to gauge the performance of each overcoating system tested. The test cycle addressed several of the failure modes common to coating systems. The susceptibility to moisture and chloride contamination was simulated with an ASTM B117 "Standard Test Method for Salt Spray (Fog) Testing" cycle. Each coating system was exposed to ultraviolet radiation through natural marine exposure. Panels were cycled through a freezer to simulate freeze/thaw temperature cycling typical of a northern United States environment.

The order and duration of each component of the cyclic test are identified as follows:

1. 4 days of salt fog exposure in accordance with ASTM B117.

2. 4 days of exposure in a laboratory freezer (nominally -2°C (28°F)).

3. 6 hours of exposure at in a laboratory oven (nominally 66°C (150°F)).

4. 5¾ days of natural marine exposure.

The complete 14 day accelerated testing cycle was executed 7 times.

Accelerated Marine Atmosphere Exposure Procedures

Natural marine exposure with daily seawater spray was conducted at the contractor's marine exposure facility in Sea Isle City, NJ. This site is located approximately 30.5 m (100 ft) from mean high tide of the Atlantic Ocean and represents a severe marine site. Depending on specific exposure conditions, ASTM A36 steel corrodes at a rate of between 127 and 508 micrometers (5 and 20 mils) per year at this site.

This test incorporated natural exposure of the test panels facing South at a 45° angle in accordance with ASTM D 1014 "Standard Test Method for Conducting Exterior Exposure Tests of Paints on Steel," coupled with daily spray of natural seawater on the panels to accelerate degradation.

Rating Procedures

All panels were rated on three separate parameters; rusting, blistering, and delamination. The panels were rated on the front side only. The paragraphs below describe the specific methods used to obtain the data for all coating systems.

Rusting. The rust rating for each panel was determined by rating only the flat coated surfaces of each panel. Corrosion as a direct result of underfilm corrosion (from the intentional scribe) or damage to the edges of the panel did not contribute to the rating. ASTM D610, "Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces," was the method used to quantify the amount of rust visible on bold-coated surfaces. This system assigns a "10" to a perfect surface (no rust) and is scaled semi-logarithmical, so that a "1" represents roughly 50-percent rust and a "0" would be 100% rusted. Both the laboratory and field inspection results are presented using this rating system.

Blistering. The degree of blistering was determined for each panel. Blisters were evaluated using ASTM D714, "Standard Test Method for Evaluating Degree of Blistering of Paints." This rating system evaluates the blister size (0-10, 10 being no blistering) and density (f = few, m = medium, md = medium dense, d = dense). For simplicity in reporting results the composite blister rating scale used in the results section of this report rationalizes the ASTM blister ratings into a single 1 to 10 scale. Figure 4 shows the distribution of blister ratings and how they were converted to the 1 to 10 scale.

ASTM Blister Density Ratings

ASTM Blister Size Ratings	D	MD	M	F
10	10	10	10	10
9	4.8	8	8.75	9.22
8	2.5	6	7.5	8.44
7	1.6	4.6	6.25	7.67
6	1.1	3.7	5	6.89
5	0.9	3	4.4	6.11
4	0.75	2.5	3.8	5.33
3	0.55	2.1	3.2	4.56
2	0.35	1.65	2.6	3.78
1	0	1	2	3

Figure 4. Conversion table for relating blister size and density to composite rating.

Delamination. The coatings were evaluated on their ability to be separated from the existing weathered substrate. This procedure was accomplished by prying the edge of the intentional scribe between the layers of maintenance coating and aged existing coating. A qualitative observation of the delamination was then observed. Scribe cutback was also observed as the direct measurement (field measurements were in inches, reported measurements are in millimeters) of the maximum distance of visual undercutting (underfilm corrosion) from the center of the intentional scribe.

FIELD TESTING

The field testing phase of this program was accomplished by applying test patches of each overcoating material to inservice bridges. This was considered the most meaningful phase of the project as actual structures were painted. Bridge locations were selected to represent varying environments in the United States and various types of aged coating systems. The test patch locations on each bridge were selected to represent at least two areas of differing exposure on each structure (micro-environments). One area was typically exposed to sunlight and mildly corrosive conditions (such as a facia girder) and the second area was typically the most corrosive location on the bridge (typically under an expansion joint or the bottom flange on a girder).

Coating systems were selected for testing based on an industry survey. Over 80 industrial paint manufacturers were solicited for their best recommended system for an "overcoating" application as proposed for the bridge patches. Approximately one-half of the manufacturers responded in writing and the test matrix was selected from these responses. The matrix was develope to cover the majority of the recommendations as a generic manner; however, specific commercially available products were tested.

Bridge Locations

Four bridges were selected for test patch applications. These were located in Chicago, New York City, Southern Louisiana, and Eastern New Hampshire. Two girder sections from a demolished Louisiana bridge were also overcoated at the Louisiana bridge test site. The following subsections describe each bridge site. The results section of this report shows diagrams and photographs of each bridge site.

Illinois Bridge

The first test patch applications were completed in late September of 1993 on a viaduct section of Interstate 55 in Chicago, IL. This same small section of bridge was being used for other FHWA sponsored research work through the Basic Industry Research Laboratory (BIRL) at Northwestern University.[2] The bridge is located in a northern industrial/urban environment, so the coatings are exposed to freeze/thaw cycles, deicing salts, and industrial air pollutants. The test patch locations on this bridge are along a facia girder exposed to sunlight, yet sheltered from roadway runoff and along diaphragm members under a leaking expansion joint.

The existing coating system on the bridge consists of an alkyd topcoat over a basic lead silico chromate (BLSC) primer applied over millscale. The bridge was believed to have been originally painted in 1976. The overall condition of the bridge was poor due to advanced corrosion and steel section loss under the expansion joints. The bridge is scheduled for replacement in the near future. This short desired remaining life makes the bridge an ideal candidate for overcoating because the investment (in terms of expected coating lifetime) of full removal and coating replacement is not justified. The existing coating on the expansion joint diaphragms was severely deteriorated, and the bridge members were heavily corroded. The coating on the facia member was peeling in isolated locations, and light corrosion existed where the coating was missing.

New York Bridge

Test patch applications were completed in mid October of 1993 on the Verrazano-Narrows Bridge. This is a very large suspension bridge consisting of 2 roadway levels carrying 12 lanes of traffic across the entrance to New York Harbor. The bridge is located in a northern coastal/urban environment, so the coatings are exposed to freeze/thaw cycles, deicing salts, and a combination of marine/industrial air pollutants. The test patch locations on this bridge are along a large box-beam located above the east anchorage in Brooklyn. The locations are below the lower level roadway adjacent to a large expansion joint. One set of patches covers the inside and outside faces of the box-beam and the other set of patches covers the outside of the beam

[2]R.H. Krueger, G. Nichols, and T. Bernecki, *Field Analysis of Surface-Tolerant Coatings,* Proceedings from the SSPC 95 Seminars, Dallas, Texas, November 9-16, 1995, SSPC 95-09, pp. 260-271.

facing the expansion joint. None of the patches are exposed to direct sunlight for any significant length of time.

The existing coating system on the bridge consists of two to three coats of lead alkyd paint applied over a red-lead primer over millscale. The bridge was constructed throughout the mid 1960's and the area of the test patches was last painted in 1978. Since the bridge is very large, the condition of the structure varies greatly from point to point. The beam overcoated in this program was directly adjacent to a large expansion joint and the side facing the joint was in poor condition. The box-beam was fabricated using rivets and steel plates. The existing coating was degraded on all edges and some rivet heads facing the expansion joint. The interior sides of the box-beam were in good condition except for the horizontal plate facing down. This plate had extensive amounts of peeling paint accompanied by light corrosion (the exterior side of the beam facing down was in similar condition). The interior face of the beam facing up was completely caked with bird dropping and nests, but appeared to be in good condition after washing.

Louisiana Bridge

These test patch applications were completed in February of 1994. This bridge is located on route 51 in Manchac, LA on the west side of Lake Pontchartrain and is constructed of rolled girder spans. The test patches are located near the southern abutment of the bridge. The area painted varies in height above tidal brackish water from 3 to 5 ft. The bridge is located in a southern marine environment, so the coatings are exposed to high temperatures, high humidities, and frequent rain. Freezing temperatures are uncommon, so the bridge is not exposed to deicing salts. The test patch locations on this bridge are on a facia girder exposed to sunlight, yet sheltered from roadway runoff and along a parallel girder located further from the edge of the bridge.

The existing coating system on the bridge consists of an inorganic zinc primer applied over sandblasted steel with a vinyl topcoat. This coating system was approximately 20 years old at the time of the test applications. The condition of the coating system on the bridge varied depending upon the location of the bridge members. The fascia members were in better condition than members sheltered from sunlight beneath the bridge. The bottom of the lower flanges of the girders were in the worst condition and had light to medium (SSPC surface condition C) rusting over most of this area. The web sections of the girders were generally in good condition. No significant differences were seen along the length of each girder from the expansion joints to the midsection of the girders.

Louisiana Beams

The Louisiana bridge location is also the exposure site for two additional test beams. The beams were overcoated with the same coatings at the same time as the Manchac Bridge test patch applications. These beams were transported to the Manchac Bridge location by the LA DOT from a separate site where a bridge was demolished. The beams are tucked slightly beneath the Manchac Bridge near the south abutment and rest on the ground next to the edge of

the lake. Unlike the bridge test patches the overcoated beams represent only one micro-environment.

The existing coating system on the test beams consists of a BLSC primer applied over mill-scale with a silver-colored alkyd topcoat. Most of the loose paint had been removed from the beams during demolition and transportation to the Manchac site. Both flanges were 75 to 100 percent corroded, but did not have heavy packed rust or pitting. The webs of the beams were mechanically damaged during demolition and were rusting at the damaged areas of the coating. All sides of the beams were painted with the experimental systems except for the bottom of the lower flange which was inaccessible.

New Hampshire Bridge

This bridge is located on NH State Route 3 near Allentown, New Hampshire. It is a two-level truss-span bridge carrying two lanes of traffic on each level. The test patch applications were completed in early October 1994. The bridge is located in a northern rural environment, so the coatings are exposed to high yearly temperature variations and deicing salts. The test patch locations on this bridge are on the south truss members along the lower level roadway and along a floorbeam located adjacent to an expansion joint at the east abutment of the lower level of the bridge.

The original coating system on the bridge consisted of a red-lead primer applied over mill scale with an aluminum-pigmented finish coat. The bridge has been maintenance painted 1 or 2 times leading up to the last maintenance effort in 1987. This latest maintenance painting of the bridge consisted of spot blasting and application of a two-coat, hot-applied vinyl system. The condition of the coating system on the bridge depended upon the location of the bridge members. Members exposed to runoff were corroding and in poor condition. Members exposed to the lower level roadway "splash zone" were corroding at locations of peeling paint. Members that were reasonably sheltered from runoff and roadway splashing had paint peeling to a mill scale substrate. The extent of this peeling was enough to cover approximately 15 to 25 percent of the bridge surface area.

Coating Systems

A total of 16 different overcoating systems were evaluated during the field test patch exposure phase of this project. Table 2 describes the coating systems evaluated and provides comments pertaining to coating application. Due to timing and availability constraints, not all of the sixteen coating systems were applied in all test locations. However, each test site contained a matching set of patches applied to the two local bridge micro-environments at that particular bridge location.

Table 2. Systems for field test patch exposure.

System Number	Generic Description	Manufacturer	Product	Application comments
1	three-coat 100% acrylic waterborne system	Con-Lux	Metal-Plex 24 (White) / Metal-Plex 60 (Grey) / Steel-Plex 9333 (Wing-grey)	Applied to all five locations
2	three-coat acrylic emulsion	Berkley Products	Red Oxide Primer / White Intermediate / Gloss White Finish	Applied to all five locations. Waterborne coatings formulated with non-toxic inhibitive pigment. Topcoat did not hide well.
3	three-coat moisture-cure polyurethane	Wasser High-Tech Coatings	Wasser MC-Zinc/ Wasser MC-Miomastic/ Wasser MC-Ferrox A	Applied to all five locations
4	multi-purpose epoxy/ aliphatic polyurethane gloss enamel	Devoe Coatings	BarRust 235/ Devthane 379	Applied to all five locations. Epoxy covers well by brushing.
5	penetrating sealer/ multi-purpose epoxy/ aliphatic polyurethane gloss enamel	Devoe Coatings	Pre-Prime 167/ BarRust 235/ Devthane 379	Applied to all five locations. (2nd and 3rd coats identical to system 4)
6	penetrating sealer/ aluminum epoxy mastic/ leafing Al alkyd	Carboline	Rustbond Penetrating Sealer/ Carbomastic 15 Low Odor/ Subox 2600	Applied to all five locations. Very viscous epoxy. Extended cure times were needed for the sealer.
7	calcium sulfonate alkyd	CPC Corp.	Chemotex 81	Applied to all five locations
8	long oil-alkyd/ long oil-alkyd/ silicone alkyd (low VOC > 2.8 lbs/gal)	Con-Lux	NC DOT Red Primer Specification/ NC DOT Red Primer Specification/ Steel-Master 9533 Cadet Gray	Applied to all five locations
9	epoxy polysiloxane	Ameron	Amercoat 3337	Applied to all five locations. Covered well but tended to pinhole in single coat brush application.

Table 2. Systems for field test patch exposure (continued).

System Number	Generic Description	Manufacturer	Product	Application comments
10	moisture-cure urethane/ acrylic polyurethane enamel	Tnemec	50-330 Poly-Ura-Prime/ Series 75 Endura-Shield	Applied in New York, New Hampshire and Illinois only
11	waterborne epoxy/ 100% acrylic emulsion	Sherwin Williams	Water Based Catalyzed Epoxy Primer/ DTM Acrylic Primer-Finish	Applied to all five locations
12	three-coat moisture-cure polyurethane	XymaX Coatings Inc.	MonoLock PP/ Mono Zinc Aluminum/ Bridge Finish	Applied in Louisiana and New Hampshire only
13	two coat oil-alkyd	Keeler & Long Inc.	Tri-Polar Ferrite Primer No. 6000/ Anodic Self-Priming Paint No. 4400	Applied in New York and New Hampshire only. Viscous alkyds that covered well by brushing.
14	three-coat oil-alkyd	Keeler & Long Inc.	Tri-Polar Ferrite Primer No. 6000/Tri-Polar White Primer No. 6040/Tri-Polar Gray Primer No. 6060	Applied in New York only
15	higher VOC, two-coat moisture-cure polyurethane	Superior Protective Coatings	No Rust #1	Applied in Louisiana only
16	two-coat waterborne acrylic emulsion	Sigma Coatings/ Rohm and Haas (resins)	LA DOT Waterborne Formulation.	Applied in Louisiana only

Test Patch Application

Each test patch was applied in accordance with ASTM D 5064 "Standard Practice for Conducting a Patch Test to Assess Coating Compatibility." The existing bridge coatings were evaluated for peeling, rusting, adhesion, and coating thickness. These factors were qualitatively used to gauge each bridge's ability to accept an overcoat. Each individual test patch was at least $0.99m^2$ ($10\ ft^2$) in size with most averaging $1.86m^2$ ($20\ ft^2$). The members selected for test patch locations were painted on all accessible sides to cover all critical areas of a beam (edges, bottom flange, corners, lap joints, rivets, etc.). All coatings were applied using manufacturer recommended application practices.

Surface Preparation

The test patch locations were prepared using two surface preparation levels. All locations received an initial pressure wash using 7 to 14 MPa (1000 to 2000 psi) potable water to remove contamination and loose coating material. The test patch area was then prepared to an SSPC SP-3 "Power Tool Cleaned" surface using power tools (needle gun for edges or corners or shaped areas and a rotary peening tool for flat areas) with vacuum shrouds. A HEPA vacuum was used to collect dust and debris generated during cleaning. Within the area prepared to SP-3, a 15 cm (6 in.) "stripe" was prepared to the best SSPC SP-11 "Power Tool Cleaned to Bare Metal" surface preparation possible in the field using the rotary peening tool. These two surface preparations were selected to best represent the surface preparation levels practically attainable on a production scale for overcoating work.

Paint Application

Prior to paint application, environmental conditions were monitored using a sling psychrometer and surface temperatures were recorded for test patch locations. The surface temperature was at least 3 °C (5 °F) higher than the dew point before any painting began for the day. All coatings were brush applied using 15 cm (6 inch) synthetic brushes for the waterborne coatings or natural bristle brushes for the solventborne coatings. Wet film thickness gauges were used to monitor the applied film build.

RESULTS AND DISCUSSION

Laboratory and field patch testing results are presented below. The laboratory studies were conducted to quickly identify coating materials applicable as field overcoating systems and screen these coating systems for material incompatibilities. Results include performance/durability data for six coating systems tested in two accelerated tests. Results of the field exposure testing are also included and will be emphasized throughout this section. The field phase of the research program was considered the most pertinent for identifying the variables which may or may not justify overcoating as a viable and cost-effective maintenance strategy.

LABORATORY TESTING

The following is a discussion of results from the accelerated laboratory testing and the accelerated marine atmosphere exposure testing performed as a precursor to the field exposure phase of this program. Six overcoating systems were evaluated in these two tests over four different aged coating systems. The full coating system matrix was outlined in the technical approach.

The laboratory testing results did not produce any failures due to incompatible coating chemistries (as discussed in the overcoating compatibility section). Most overcoating materials were easy to apply and covered the test panels well. The use of aged test panels from a previous FHWA sponsored research program provided a simulated "real world" surface for evaluation of the overcoating systems. The surface of these panels varied greatly and typically included areas of intact existing coating, areas of cleaned metal (result of power tool cleaning), areas with corrosion imbedded in pits, and the transition areas between these types of surfaces. Figure 3 of the technical approach showed a typical aged test panel prior to application of the candidate overcoating systems.

The adhesion of the existing coatings is commonly used as a measure of the ability of an aged coating system to support an overcoating system. To show the existing adhesion conditions of the panels used in this study, adhesion data was collected. Figure 5 shows adhesion data taken from the aged test panels before application of the overcoating system. The figure compares two common adhesion evaluation techniques published by ASTM. All coating systems show pull-off adhesion results greater than 1.38 MPa (200 psi) except for the aluminum pigmented alkyd.

The non-lead alkyd was considered to be an important substrate for evaluation of overcoating systems, but aged samples of this coating were not available. The data for the aluminum pigmented alkyd system is misleading due to the very short aging period for this system. The adhesion results indicate that the 6-week cure time for this substrate was not long enough for the coating to completely cure, and some un-oxidized resin may have remained near the substrate. The other three substrate coatings had either lead-alkyd, vinyl, or polyurethane

topcoats. These samples were all aged 3.5 years in the natural marine environment and achieved full cure and satisfactory adhesion as measured with standard ASTM adhesion tests.

The adhesion data presented in figure 5 provides some insight into the relationship between adhesion as measured using current ASTM test methods, and the potential for disbondment and peeling of the existing coating by the applied overcoat. This mode of failure has been seen in the field, in some cases after only short periods after overcoating application. Field measurement of adhesion has been proposed as a method for determining the "acceptability" of an existing paint system for overcoating; however, no standard value of adhesion has been sufficiently identified. The test panels used in this program had adhesion ranging from zero to 5,500 kPa (800 lbf/in^2), even over the limited surface area of the relatively small test panels. Following surface preparation, only the areas with adhesion on the order of 1,400 kPa (200 lbf/in^2 as indicated in figure 5) remained on the panels. Since no gross disbondment of the paint systems was seen during the testing, it is reasonable to conclude that the coating remaining on the panels after surface preparation had adequate adhesion to accept the various overcoating systems. It is also reasonable to assume that a less aggressive surface preparation may have left more existing coating with potentially lower adhesion on the panels, which may have produced different results with respect to disbondment of the remaining paint systems after overcoat application.

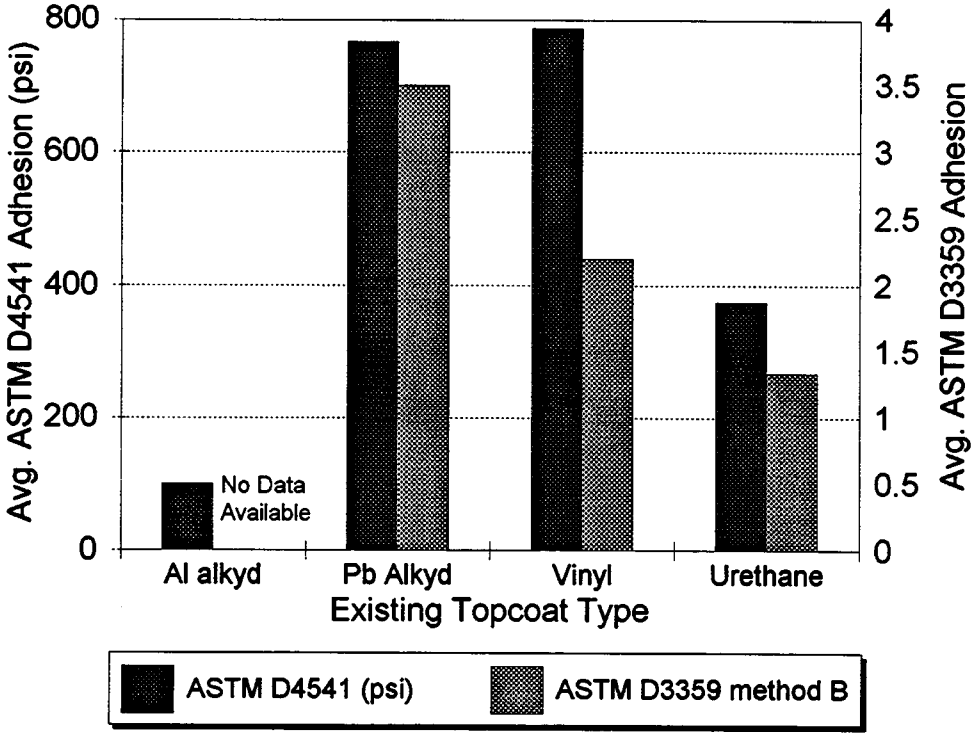


Figure 5. Initial adhesion results for the cyclic accelerated test panels.

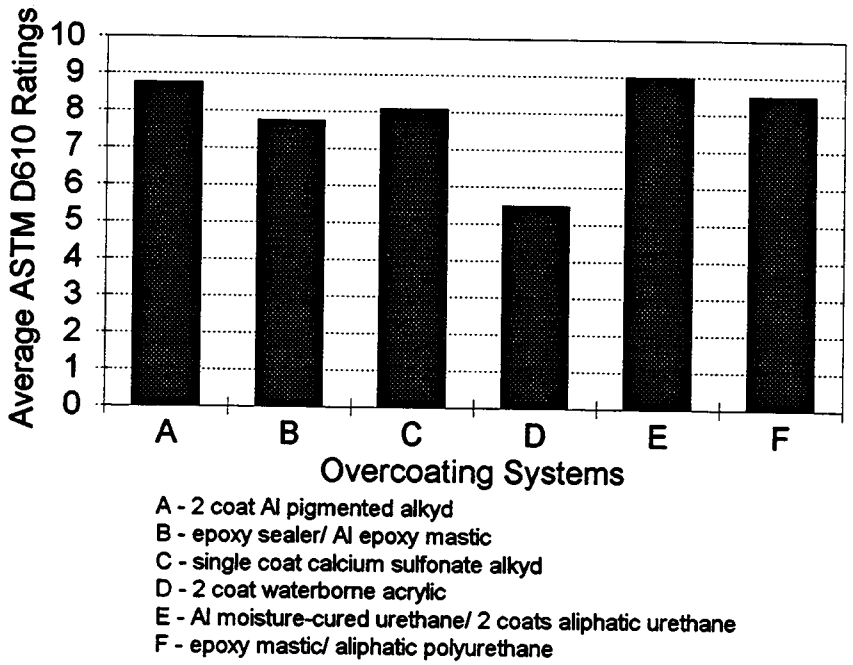


Figure 6. Average ASTM D610 rust ratings for the cyclic accelerated test panels.

Cyclic Accelerated Testing

Figure 6 shows the ASTM D610 visual rust ratings of the six overcoating systems following the final cycle of the accelerated testing. All of the different existing topcoat materials used as substrates for these panels were combined to produce the data presented in this figure. The figure shows that, on an overall basis, the two-coat waterborne acrylic system performed the poorest by showing the most through-film rust. The remaining five systems performed similarly with ASTM D610 ratings ranging from 8 to 8.5.

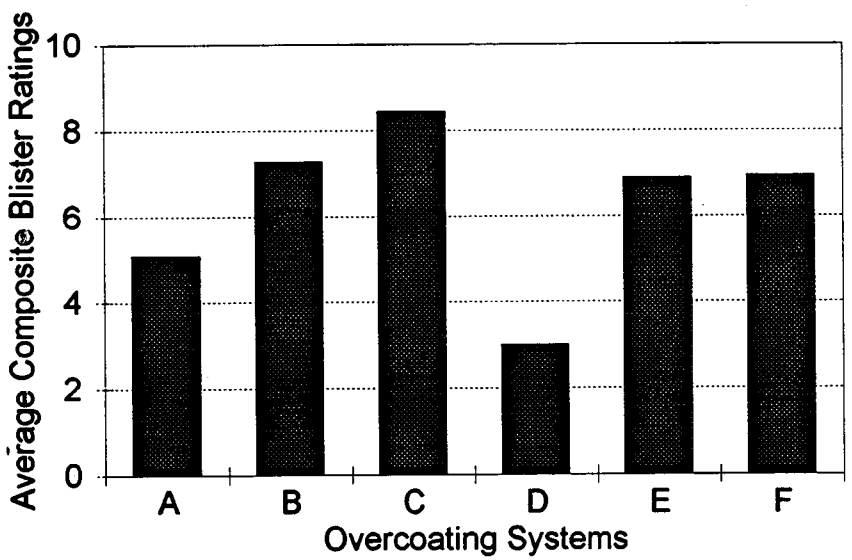
The ASTM D610 scale is designed to be sensitive to early rusting and the rating numbers will easily show small areas of rust. A comparison of the actual percentage of rusting represented by the ASTM D610 rust ratings may provide perspective of the ratings. The 8 to 8.5 range of results for coating systems A, B, C, E, and F converts to an actual rusted area of less than 0.15 percent. System D had a converted percent rust of roughly 1.7 percent. These numbers would not be considered "failure" on an actual structure, but corresponding amounts of rust would be clearly visible on the structure. However, accelerated testing is intended to project small scale results to field situations that may be applicable. These results may then indicate that a waterborne system similar to System D would show corrosion in the field sooner than the other systems tested.

Figure 7 shows the composite blister ratings derived from ASTM D714 for the cyclic accelerated test panels. The previously salt contaminated (due to previous marine exposure) surfaces and the aggressive exposure environment contributed to blistering of all overcoating systems tested. The most dense areas of blistering were around the intentional scribes of each coating system. The figure shows that the calcium sulfonate alkyd was the most resistant to blistering throughout the testing, the epoxy and polyurethane coatings were second most resistant, the traditional non-lead alkyd was third, and the waterborne acrylic system showed the most blistering.

Figure 8 shows an observation not displayed by the data from figures 6 and 7. This coating system was the only one of the 24 combinations of existing topcoat/overcoat system that experienced disbondment. The polyurethane system (moisture-cure/ aliphatic/ aliphatic) softened the aluminum pigmented alkyd coating and disbonded within (split the alkyd) the existing alkyd coating. The most likely explanation for this was the soft state of the partially cured alkyd coating (6 weeks old). The chemically cured polyurethane overcoat would have also prevented oxygen from reaching the alkyd coating and allowing it to fully complete its cure. The polyurethane system did not disbond or soften the fully cured lead-alkyd coatings.

Figures 9 and 10 show some of the panels following the cyclic accelerated testing. On most of the panels the "islands" of intact coating that were painted over can be seen. The edges of these areas (transition from painting over old paint to painting over metal/rust) typically showed the most rusting. Other areas on the panels that frequently rusted were around the intentional scribe, the U-channel, and the edges of the samples. These are areas that were previously corroded and required overcoating over marginally cleaned bare steel. The rust stains caused by wet test conditions were considered cosmetic only. The actual deteriorated area that created the stains was rated and shown in figure 6.

Figure 11 shows the results of adhesion testing following the cyclic accelerated test. With the exception of the calcium sulfonate alkyd, all of the overcoating systems adhered sufficiently to the existing topcoats to cause adhesion failure within the layers of the existing substrate coating. This means that the older coatings were the "weak link" in the composite coating system in terms of mechanical adhesion. The lesser physical properties of the calcium sulfonate alkyd system attributed to the poor mechanical adhesion results for that system. An important observation from figure 11 is the general correlation between the cross cut and pull off type adhesion tests. With the exception of system F, the relative results from system to system for these two adhesion test methods show that either method may be sufficient to compare the mechanical adhesion of different maintenance overcoating systems.



A - 2 coat Al pigmented alkyd
B - epoxy sealer/ Al epoxy mastic
C - single coat calcium sulfonate alkyd
D - 2 coat waterborne acrylic
E - Al moisture-cured urethane/ 2 coats aliphatic urethane
F - epoxy mastic/ aliphatic polyurethane

Figure 7. Composite blister ratings for the cyclic accelerated test panels.

Figure 8. System E (Al-MCU/urethane/urethane) applied over 6 week old alkyd following the cyclic test. The soft alkyd disbonded within the coating.

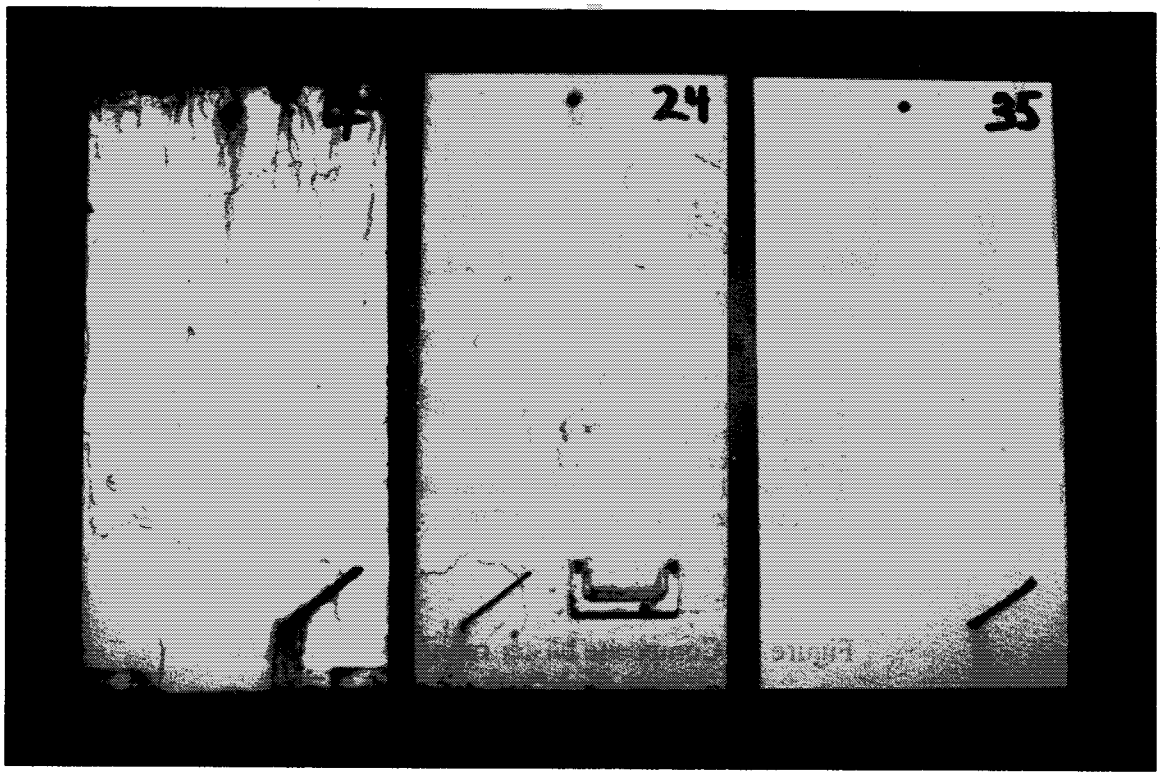


Figure 9. Systems A (2-coat Al-alkyd), C (Calcium sulfonate alkyd), and F (epoxy mastic/urethane) applied over an aged IOZ/Vinyl system following the cyclic accelerated testing.

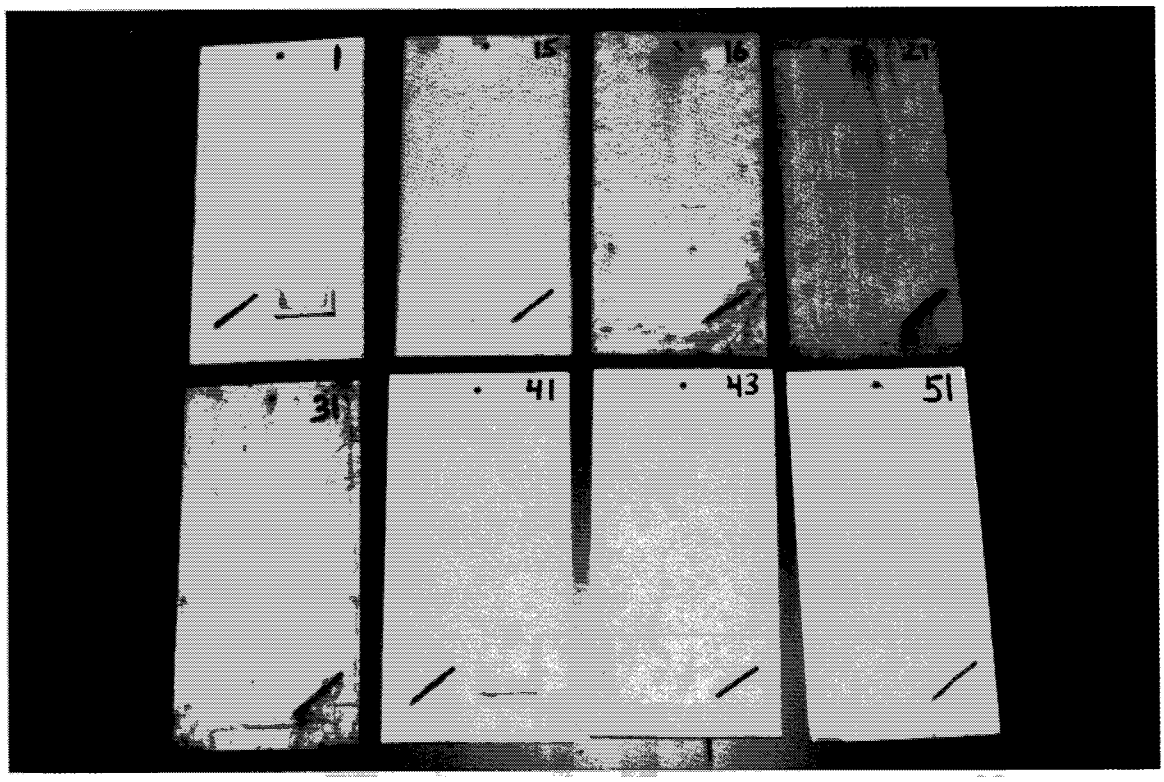


Figure 10. Six systems applied over an aged Basic Lead Silico Chromate coating system following the cyclic accelerated testing.

Key to panel numbers:

1.	System A (2-coat Al-alkyd) over Pb Alkyd over SP-10 (A-36)
15.	System B (Epoxy sealer/Al-epoxy mastic) over Pb Alkyd over SP-2 (A-588)
16.	System B (Epoxy sealer/Al-epoxy mastic) over Pb Alkyd over SP-2 (A-36)
21.	System C (Calcium sulfonate alkyd) over Pb Alkyd over SP-10 (A-588)
31.	System F (epoxy mastic/urethane) over Pb Alkyd over SP-2 (A-36)
41.	System D (2-coat waterborne acrylic) over Pb Alkyd over SP-10 (A-36)
43.	System D (2-coat waterborne acrylic) over Pb Alkyd over SP-2 (A-588)
51.	System E (Al-MCU/urethane/urethane) over Pb Alkyd over SP-10 (A-588)

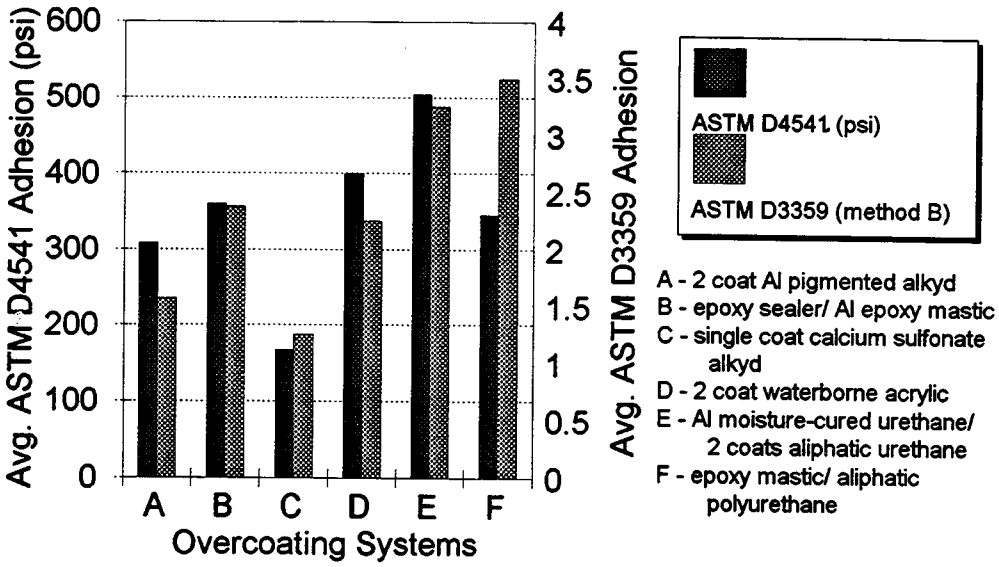


Figure 11. Adhesion testing results following the cyclic accelerated test.

Exposure Testing

A set of panels was also exposed in the natural marine environment for a 3.5-year period. This set was similar to the panels tested under accelerated test conditions. This atmospheric exposure was accelerated by spraying the panels daily with natural seawater. These panels were prepared with the same four initial coating system types and six overcoating systems as the cyclic test panels. The samples were inspected for visual rusting, blistering, and scribe cutback after six months and 3.5 years of exposure.

Figure 12 shows a photograph of the panels exposed at the marine exposure location. Figure 13 is a diagram identifying the steel condition, coating system, and overcoating system history of each panel. The panels are arranged according to the overcoating systems (columns) and the original type of topcoat (rows). The figures have panels missing in some places because every possible scenario could not be evaluated due to the limited number of panels available from the previous FHWA project. By observing the conditions of the panels in figure 12, and knowing the condition history of the surfaces painted through figure 13, one can see that several factors affect the performance of the coatings.

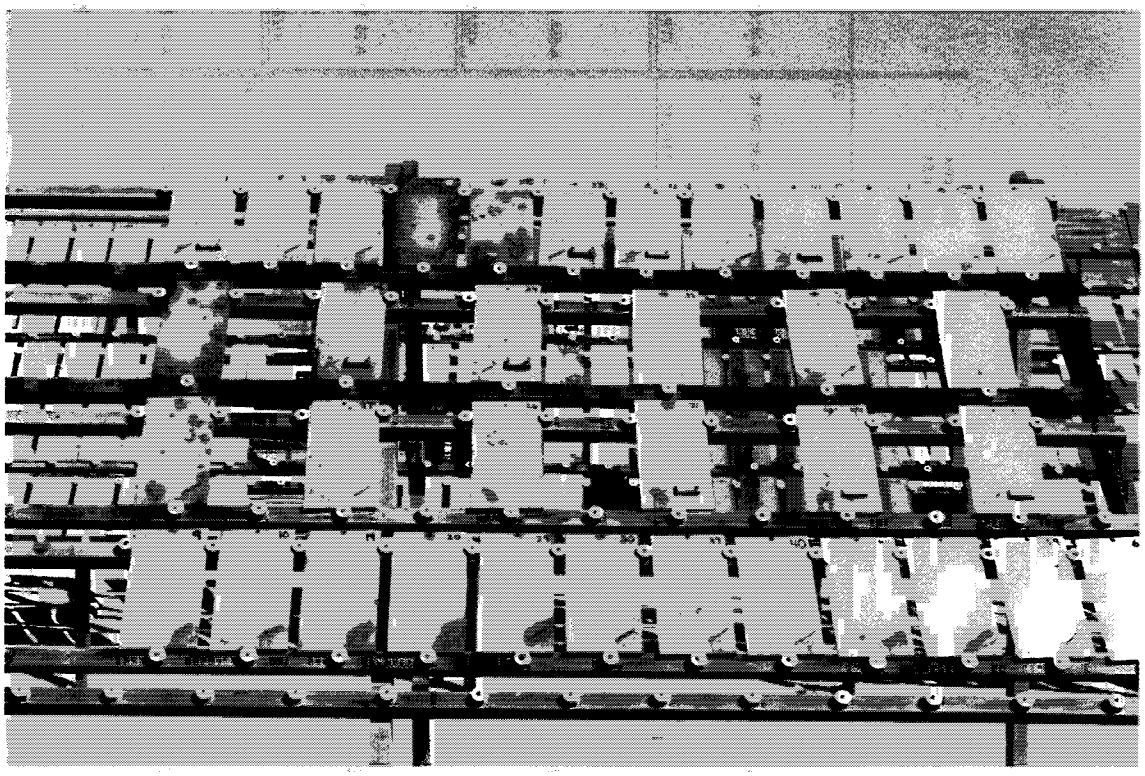


Figure 12. Overcoating test panels exposed at the marine exposure location.

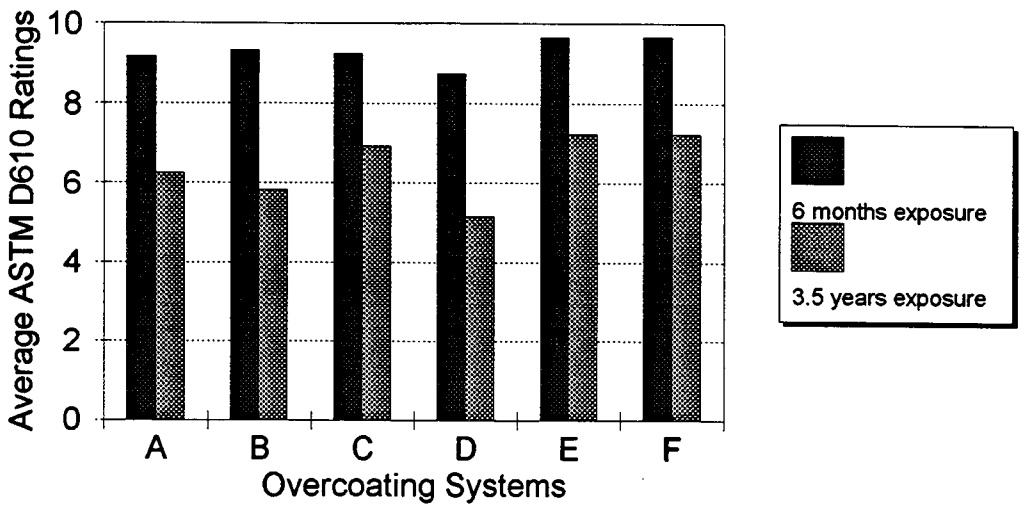
	Carboline Gridguard 2600		Devoe 162 Preprime/ BarRust 239		Chemotex Unicoat 81		Amerlock 400/ Amershield		Rohm and Haas HG-54		Miles 3-Coat Urethane (MC/ Aliphatic/ Aliphatic)	
Lead Alkyds	1 A-36 SP-10 TTP-86 /TTP-615	3 A-588 SP-10 TTP-615	15 A-588 SP-2 TTP-86 /TTP-615	16 A-36 SP-10 TTP-86 /TTP-615	22 A-36 Mill Scale TTP-615	23 A-36 SP-10 TTP-615	32 A-36 SP-10 TTP-615	33 A-36 SP-2 TTP-615	41 A-36 SP-10 TTP-86 /TTP-615	43 A-588 SP-10 TTP-615	52 A-588 SP-2 TTP-615	53 A-36 SP-2 TTP-615
Vinyl	5 A-36 SP-2 OZ/Vinyl		14 A-36 SP-10 OZ/Vinyl		24 A-36 SP-10 IOZ/Vinyl		35 A-588 SP-10 IOZ/Vinyl		47 A-588 SP-2 OZ/Vinyl		57 A-36 SP-10 OZ/Vinyl	
Urethane	7 A-36 SP-2 OZ/E/U		17 A-588 SP-10 IOZ/E/U		26 A-588 SP-10 IOZ/E/U		37 A-36 SP-10 IOZ/E/U		44 A-36 SP-10 OZ/E/U		55 A-36 SP-10 IOZ/E/U	
Al-Alkyd	9 A-36 SP-10 Al-Alkyd	10 A-36 SP-10 Al-Alkyd	19 A-36 SP-10 Al-Alkyd	20 A-36 SP-10 Al-Alkyd	29 A-36 SP-10 Al-Alkyd	30 A-36 SP-10 Al-Alkyd	39 A-36 SP-10 Al-Alkyd	40 A-36 SP-10 Al-Alkyd	49 A-36 SP-10 Al-Alkyd	50 A-36 SP-10 Al-Alkyd	59 A-36 SP-10 Al-Alkyd	60 A-36 SP-10 Al-Alkyd

Figure 13. Identification diagram for accelerated testing panels exposed in marine environment.

The most important observation from the photograph of figure 12 is the relation of the original panel condition at the time of overcoating to the current condition of the panel. The panels that are showing the most degradation were originally prepared using a hand-tool cleaned substrate (7 years ago), then allowed to degrade, then prepared and overcoated. For the most part, panels that originally began with an abrasive blasted (near white) surface are in the best condition. These abrasive blasted panels were in better condition (compared to originally hand tool cleaned panels) at the time of overcoating. These results imply that not only the surface preparation must be considered when estimating the performance of a particular overcoating system, but also the history of the surface being overcoated, and the corrosion condition of the surface at the time of overcoating.

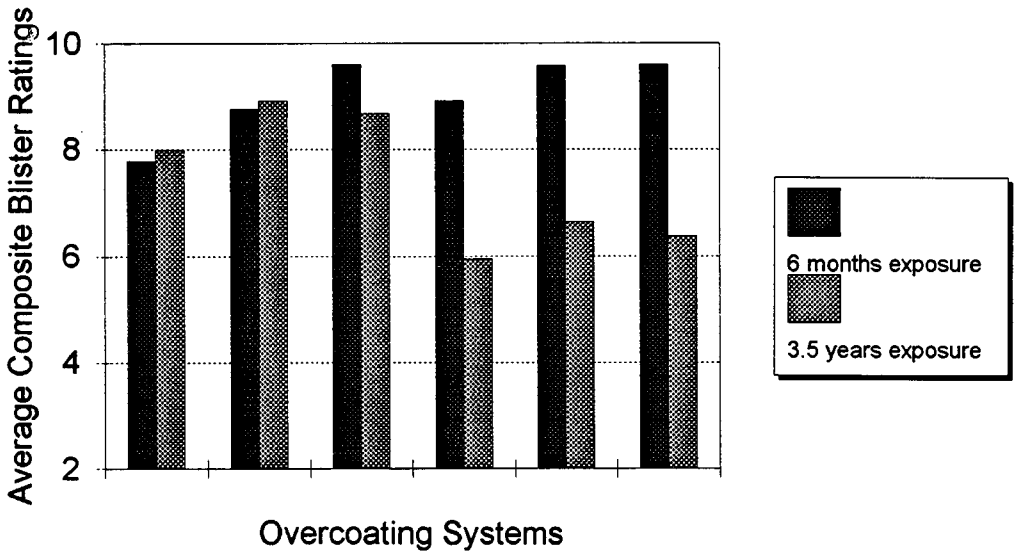
Figure 14 shows the ASTM D610 visual rusting ratings for the six overcoating systems exposed in the marine environment. Relative results between the six overcoating systems in figure 14 are similar to the relative results of the cyclic accelerated test shown in figure 6. An important observation from figure 14 is that only a short exposure time was necessary in the accelerated natural marine environment to distinguish the relative performance between the coating systems. The results after 6 months from system to system are similar to the results between the systems following 3.5 years of exposure. This may signify that a relatively short duration "patch test" can provide reliable information regarding longer term overcoating performance.

Figure 15 shows the composite blister ratings for the exposure panels. The visual blistering data does not show the same time/degradation trend seen with the visual rusting data of the same panels. The blistering of systems A and B has not advanced compared to what was observed after the first 6 months of exposure. The short time to initial blistering displayed in figure 15 indicates that coating over existing surfaces in a highly corrosive, salt-rich environment may show different blister performance in a relatively short time period. However, all of the blister results displayed in figure 15 (following marine exposure) are less severe than the blister results of the cyclic accelerated test (figure 7).



A - 2 coat Al pigmented alkyd
B - epoxy sealer/ Al epoxy mastic
C - single coat calcium sulfonate alkyd
D - 2 coat waterborne acrylic
E - Al moisture-cured urethane/ 2 coats aliphatic urethane
F - epoxy mastic/ aliphatic polyurethane

Figure 14. Visual rust ratings for the overcoating systems exposed in the marine environment.



A - 2 coat Al pigmented alkyd
B - epoxy sealer/ Al epoxy mastic
C - single coat calcium sulfonate alkyd
D - 2 coat waterborne acrylic
E - Al moisture-cured urethane/ 2 coats aliphatic urethane
F - epoxy mastic/ aliphatic polyurethane

Figure 15. Composite blister ratings for panels exposed in the marine environment.

FIELD TESTING

During this phase of the research, field surface preparation methods and application techniques were used on actual bridges. Each of the four field sites was selected based on the criteria (existing coating type, geographical location, etc.) outlined in the Technical Approach section of the report. The following subsections provide detail on the initial conditions of the bridges, the surface preparation and coating application techniques, and the performance of the overcoating systems applied at each test location.

Existing Coating Conditions

Table 3 provides a summary of the existing coating and corrosion conditions at each of the field test patch locations. Data was acquired based upon the conditions of the bridge coating systems at the time of overcoating test patch applications. Efforts were made to be as quantitative as possible so that comparisons may be drawn between the initial conditions of the various bridges and the performance results of the overcoating systems. The evaluation techniques used were applicable to field inspection work so that the highway engineer or bridge inspector would be able to gather similar information.

Table 3. Existing Coating Conditions

Location		Existing topcoat type	Rust Condition (ASTM D610)	Peeling / Delamination (% area affected)	Existing Coating		Existing substrate
					DFT	Adhesion	
Chicago, IL	facia girder	lead alkyd (green)	7-8	5%	4-7	2	mill scale
	expansion joint		3 (pack rust)	70-80%	6-10	1	mill scale/ rust
New York City	vertical surfaces	lead alkyd (grey)	7	7%	7-14	2	mill scale
	horizontal facing down		6	10%	5-15	2	mill scale
Manchac Bridge, LA	facia girder	vinyl	9	0%	8-13	4	sand blasted steel
	interior girder		7	0% web 100% bot. flange			
LA Beams	embankment near lake	lead alkyd (silver)	5	20%	6-12	2	mill scale
New Hampshire	truss members	hot applied vinyl	8	20%	8-24	1	mill scale
	expansion joint		4 (pack rust)	15%	8-18	1	mill scale/ rust

Surface Preparation Methods

The technical approach section of this report outlined the surface preparation methods used for each test patch on all bridges. Comments on the performance of each surface preparation method employed in the field testing are in the following subsections.

Pressure Washing

Of the various surface preparation techniques used in this program, pressure washing was the most productive because large areas of the bridge could be cleaned in the least amount of time. The 7 to 14 MPa (1000 to 2000 psi) fresh water pressure wash effectively removed dirt, visible contaminants, and loose coating material. Only the most stubborn stains and graffiti could not be removed. The loose coating was most effectively removed by aiming the water stream at the edge of the coating/mill-scale interface and "peeling" the coating back until no more could be removed (i.e., the adhesion of the coating was good enough to withstand the pressure wash). The pressure washers used were relatively low volume, water-supplied units typically powered by a 3 to 5 hp motor. All debris was collected in tarpaulins and disposed of with the assistance of the local departments of transportation.

Pneumatic Power Tools

Following the pressure wash, hand-held pneumatic power tools were used to prepare the surfaces to the specified cleanliness. Three types of tools were used. These included a "roto-peen" or "flush plate" type tool with rotating flappers, a needle gun, and a disk grinder. Each tool was best used for cleaning a specific geometry on the bridges. The relatively flat areas were most efficiently prepared using the rotary peening tool. The corners, angles, and edges of beams were best cleaned using the needle gun tool. The disk grinder was used when "feathering" of the existing layers of coating was necessary.

The areas requiring an SP-3 (power tool-cleaned) surface preparation that were made up of intact mill scale and old coating required very little power tooling. Those areas with light corrosion were tool cleaned enough so that a dull metal color showed. The areas that were cleaned to the best attainable SSPC SP-11 "Power Tool Cleaned to Bare Metal" were originally covered with mill scale. These areas were cleaned using the rotary peening tool. The cleaning of these areas did not typically result in the "white" metal appearance attainable with abrasive blasting, but had a dull metallic look as if much of the mill scale was still in place and beat into the surface. Figure 16 shows an example of the surface preparation at the Chicago bridge site.

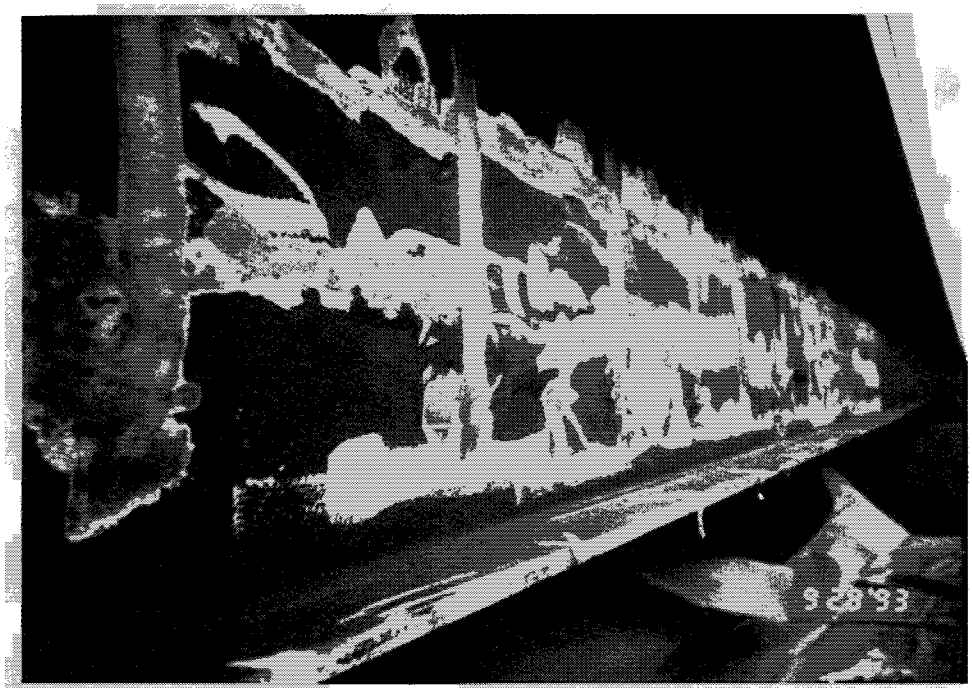


Figure 16. Chicago bridge site following surface preparation of facia beam.

None of the power tools used were able to completely remove tightly adherent or "pack" rust typical of SSPC initial surface condition D. Areas with this level of corrosion were effectively cleaned of all loose rust, but the resulting surface was typically pitted, uneven, and covered with tightly adherent rust. Figure 17 shows a photograph of the New Hampshire bridge site surface preparation of the expansion joint area. The steel in this area was heavily corroded and difficult to clean using the hand-held pneumatic power tools.

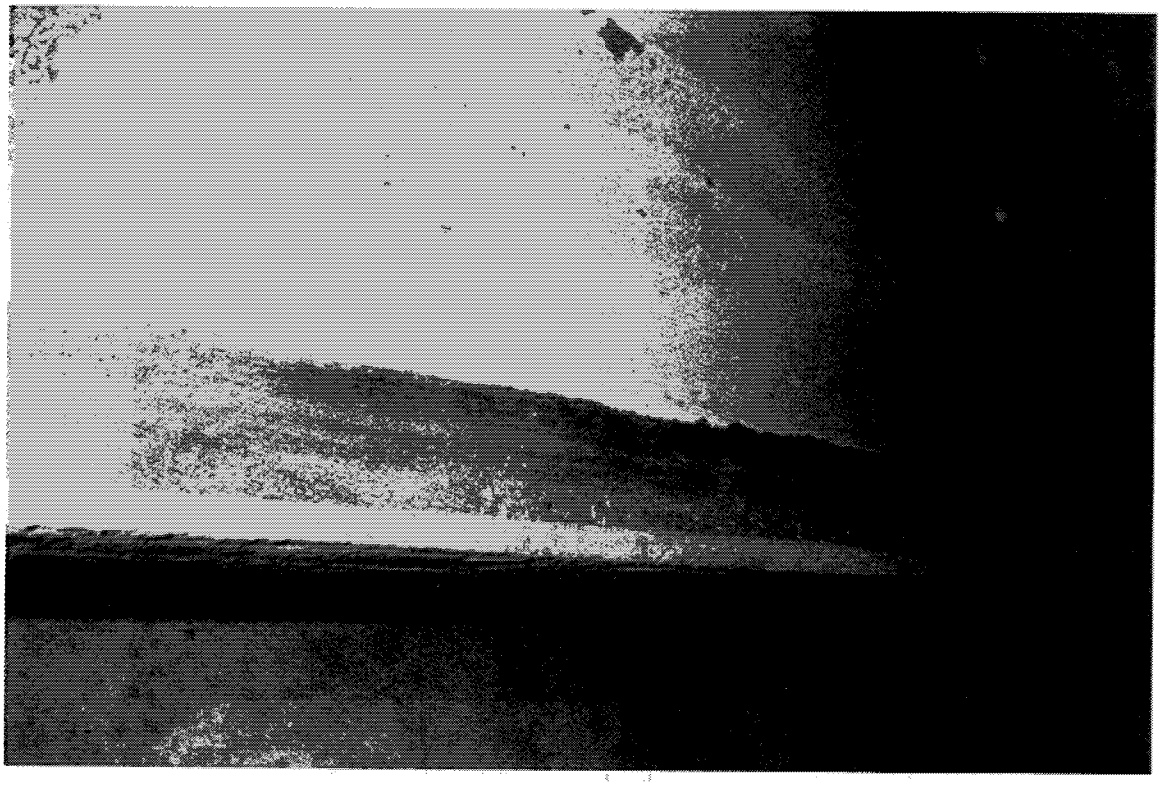


Figure 17. Surface preparation of New Hampshire expansion joint area.

Lead Paint Removal with Power Tools

Lead exposure monitoring was conducted at the initial field test location. This was done to verify that the protective measures being taken for the small scale painting operations were sufficient enough to protect the workers. It was not within the scope of this project to study the dust collection efficiency of vacuum shrouded power tools, so the following information is presented for information purposes only and should simply be considered representative for the contractor's power-tool cleaning surface preparation activities.

A professional air sampling firm was hired to conduct the monitoring. A certified industrial hygienist was on site for the air sample collections. Table 4 shows the data collected for the breathing zone of three workers, the surrounding area, and blank samples. Since some of the beams that were power tool cleaned on the day the samples were collected were coated with an inorganic zinc coating, the samples were analyzed for both lead and zinc concentrations.

Table 4. Air sampling results[1] from Manchac, LA, 2/22/94

Worker #	Sample #	Test Location		Pump flow rate (LPM)	Sample Time (min.)	Zinc mg/m³*	Lead μg/m³**	Lead 8 HR TWA μg/m³
		Bridge over water	Beams on land					
1	4	✓		3.6	61	<.001		
2	3	✓		2.65	62	.035		
3	2	✓		2.9	60	.010		
area	1	--	--	2.4	297	.002		
1	6		✓	3.6	pump failure	--	--	--
2	7		✓	2.65	34	--	133	9.4
3	5		✓	2.9	48	--	45	4.5
blank 1	14	--	--	--	not exposed	.001	<2	
blank 2	10	--	--	--	not exposed	--	<2	

* OSHA PEL for zinc oxide fume is 5 mg/m3, as an 8 hour time weighted average (TWA)
** OSHA PEL for lead is 50 μg/m3, as an 8 hour time weighted average (TWA)

The conditions during air sampling were windy. This may have affected the accuracy of collected samples. Worker number 2 had the most exposure to lead dust, while exposures for workers 1 and 3 were much lower. This fact demonstrates the variability of dust exposure that can be attributed to different personnel and the different tools used in the program.

If worker number 2 had worked 4 hours during the day at the same dust exposure pace that is shown in table 4, then his 8-hour TWA would have been 469.4 $\mu g/m^3$. This is above the action level (AL) of 30 $\mu g/m^3$ and the personal exposure limit (PEL) of 50 $\mu g/m^3$ as a TWA for lead exposure. However, with the 10X protection factor afforded by the properly fit half-mask HEPA respirator his theoretical exposure would have been 47 $\mu g/m^3$, just under the PEL.

A few conclusions may be drawn from the consultant's experience with the power-tool cleaning and air monitoring.

[1]Reprinted from subcontractor's industrial hygiene test report.

- A half mask respirator (properly fit with a protection factor of 10X) would be required for anyone working more than a few hours with these tools.
- The operators observed that the 90 degree disk grinder tool released the most dust (i.e., the configuration of the vacuum shroud did not contain some of the dust).
- All workers were exposed to airborne lead dust less than the action level.
- All workers were exposed to minimal amounts of airborne zinc dust.

Paint Application Results

As outlined in the technical approach section of this report, all coatings were applied using 15 cm (6 in.) natural or synthetic bristle brushes. Different types of coating materials may vary greatly in their application properties (sprayability, brushability, etc.). The applicators noticed differences in the brushability between materials tested in this program.

Brushing the coatings ensured that sufficient coating material was applied to cracks and irregularities on the surface of the bridge; however, the film thickness was difficult to control with several of the coatings. The coatings were first applied to the point of "coverage" or when the color of the new paint was uniform, then the wet film thickness was measured. The very viscous epoxy mastic coatings were sometimes applied too thick at this point. The "thinner" waterborne coatings were sometimes applied at a film thickness less than what was recommended. Since these materials were not all applied to the correct film thickness upon "coverage," applicators on a production scale should pay special attention to the applied film thicknesses.

The two component materials were susceptible to variations in temperature which affected the pot life and cure times for these materials. During the applications in Louisiana, the pot life and cure times were significantly accelerated (less than 30 min. pot life for the system 6 epoxy on a warm sunny day). During the applications in both Chicago and New Hampshire the cure schedule for the sealer of system 6 was a minimum of 2 days due to colder ambient conditions. The New Hampshire location was also detrimental to the curing of some alkyd coatings. These coatings developed wrinkling from the extended cure at the relatively low (10 to 16 degrees C (50 to 60°F)) ambient temperatures.

Production rates for test patch surface preparation and coating application were monitored. Weather and accessibility conditions permitting, a team of four persons was able to prepare the surface and apply up to 13 multicoat patches in four field days. Day one was typically used for setting-up scaffolding and surface preparation, and the remaining days for the application of the coatings. The resources required to apply test patches would be a relatively small expense compared to the cost associated with painting an entire bridge. The information obtained relating surface preparation and coating choices would be well worth this effort for bridge owners.

Field Exposure Results

All field test patches were evaluated after roughly 2 years. All patches will remain exposed for several more years except for the New York test patches which were partially removed for a painting contract in the spring of 1996. The other three structures coated do not have any painting planned in the immediate future. The results presented in this report are from the most recent inspections at each exposure site. Readers must be aware that the surface overcoated in this program were not as uniform or as well defined as those seen in typical laboratory research studies. For this reason the longest exposure possible under natural conditions was used to provided the best data for estimating the differences in performance between overcoating systems. The exposure times for each test site are listed below:

- Chicago Bridge - 2.5 years, 3 winter seasons.
- New York City Bridge - 2.5 years, 3 winter seasons.
- Louisiana Bridge Site - 2.5 years (rarely freezes).
- New Hampshire Bridge - 1.5 years, 2 winter seasons.

Specific data and results from each of the four field testing sites are presented in the following subsections. A discussion section follows these and relates the general results among the various overcoating systems tested.

Chicago Location

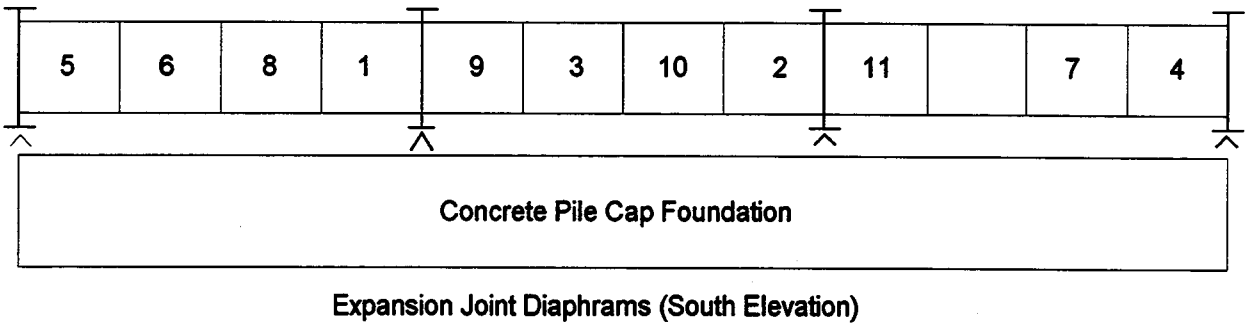
Figure 18 shows a schematic diagram of the test patch locations in Chicago. As noted in the technical approach, coating patches were applied in two locations under the bridge. The facia location was a milder location in terms of corrosiveness as evidenced by the condition of the existing coating system and the results of the test patch inspections following the 2.5-year exposure. The expansion joint diaphragms at this site were subject to frequent wetting from the leaking expansion joint. This micro-environment was highly corrosive to the existing coating system as well as the overcoating test patches applied. Figure 19 shows the condition of the existing coating system in the expansion joint area of the Chicago bridge before surface preparation.

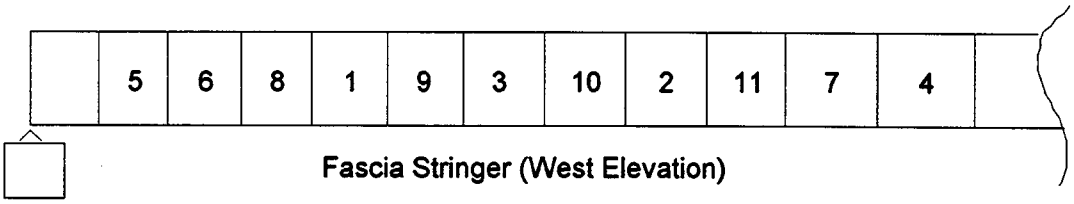
The overcoating applications in the expansion joint area of this bridge were minimally successful. Corrosion was the failure mode of all coating systems applied in this location. None of the tested coating systems were completely effective at "sealing" out the environment to prevent corrosion over the minimally prepared surfaces. After the 2.5-year exposure, all of the coating systems were showing breakdown in a fashion similar to that initially discovered in the area. Figure 20 shows coating systems 5 (epoxy sealer/epoxy/polyurethane), 6 (epoxy sealer/Al-epoxy/Al-alkyd), 8 (oil-alkyd/oil-alkyd/Si-alkyd), and 1 (3-coat WB acrylic) after the 2.5-year exposure.

The facia girder at the Chicago location was much less corroded than the expansion joint area. Figure 21 shows the test patches following the 2.5-year exposure. Most systems have provided better corrosion protection and appearance than other areas of the facia girder that were

not overcoated; however, some coating systems have shown incompatibilities with the existing alkyd coating. The system 9 (epoxy polysiloxane) coating cured to an extremely brittle state. Following the third winter season at this location the back side of the facia test patch completely disbonded from the original mill-scale substrate. Differences in the expansion properties of the aged alkyd and the overcoat coupled with thermal cycling are believed to have caused this failure. The system 11 (WB epoxy/WB acrylic) coating also showed an incompatibility. This system peeled away from the existing alkyd following one winter season.

Table 5 presents the results of the 2.5-year test patch inspection. Ratings were assigned to each test patch for rusting, coating thickness, and cross-cut adhesion. The rusting data was taken in accordance with ASTM D610 for the web and bottom flange of the test patch beams. The data shown in table 5 is an average for the entire test patch. The coating system adhesion was taken at both test patch micro-environments. The numbers presented represent the coating system's average adhesion. The coating system dry film thickness (DFT) was determined using a paint inspection gauge (PIG or Tooke) on the facia test patches.





Sketches Not to Scale

Coating System Key

1 - 3-coat WB acrylic
2 - 3-coat WB acrylic
3 - 3-coat MCU
4 - epoxy/polyurethane
5 - sealer/epoxy/polyurethane
6 - sealer/Al-epoxy/Al-alkyd
7 - calcium sulfonate alkyd
8 - oil-alkyd/oil-alkyd/Si-alkyd
9 - epoxy polysiloxane
10 - MCU/polyurethane
11 - WB epoxy/WB acrylic
12 - 3-coat MCU
13 - 2-coat oil-alkyd
14 - 3-coat oil-alkyd
15 - higher VOC, 2-coat MCU
16 - 2-coat WB acrylic

Figure 18. Schematic diagram of Chicago test patch locations.

Figure 19. Initial condition of existing coating system at Chicago expansion joint.

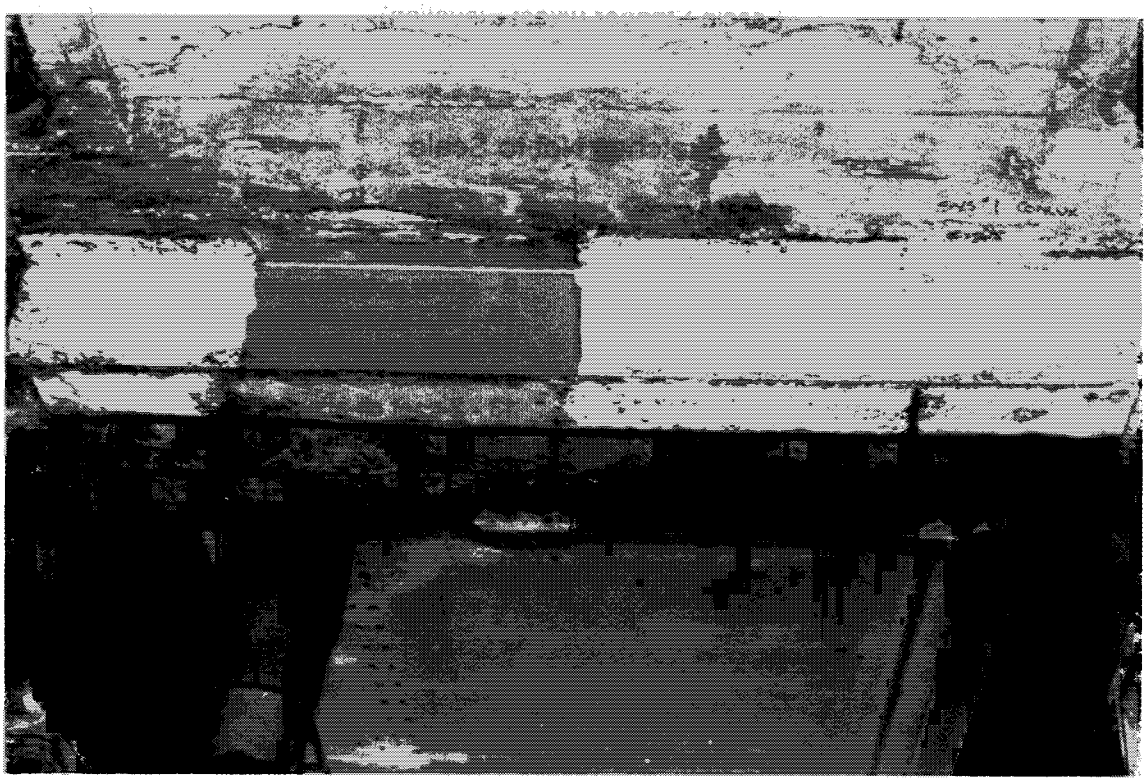


Figure 20. Chicago test patches applied to expansion joint area (2.5-year exposure, systems 5, 6, 8, and 1 from left to right).

Figure 21. Overcoating test patches applied to Chicago facia girder (2.5-years exposure, ordered from left to right as in figure 18).

Table 5. 2.5-Year inspection results from Chicago test patch exposures.

System Number	Average ASTM D610 Ratings		Adhesion (ASTM D3359 A)	Overcoating system DFT (approximate)
	expansion joint	facia		
1 - 3-coat WB acrylic	5	10	2.7	5-7
2 - 3-coat WB acrylic	4.5	9.3	2	5-7
3 - 3-coat MCU	6.5	10	1.7	6-9
4 - epoxy/polyurethane	6.5	9.3	1.8	5-7
5 - sealer/epoxy/polyurethane	5	10	3	7-10
6 - sealer/Al-epoxy/Al-alkyd	6	10	3	10-20
7 - calcium sulfonate alkyd	7	9.3	2.7	7-9
8 - oil-alkyd/oil-alkyd/Si-alkyd	5.5	9.3	1.7	5-7
9 - epoxy polysiloxane	2	6	1	3-5
10 - MCU/polyurethane	6.5	8.7	1.7	5-7
11 - WB epoxy/WB acrylic	6	8	1.7	4-6
Existing Control Surface	3	7.5	1.5	4-10

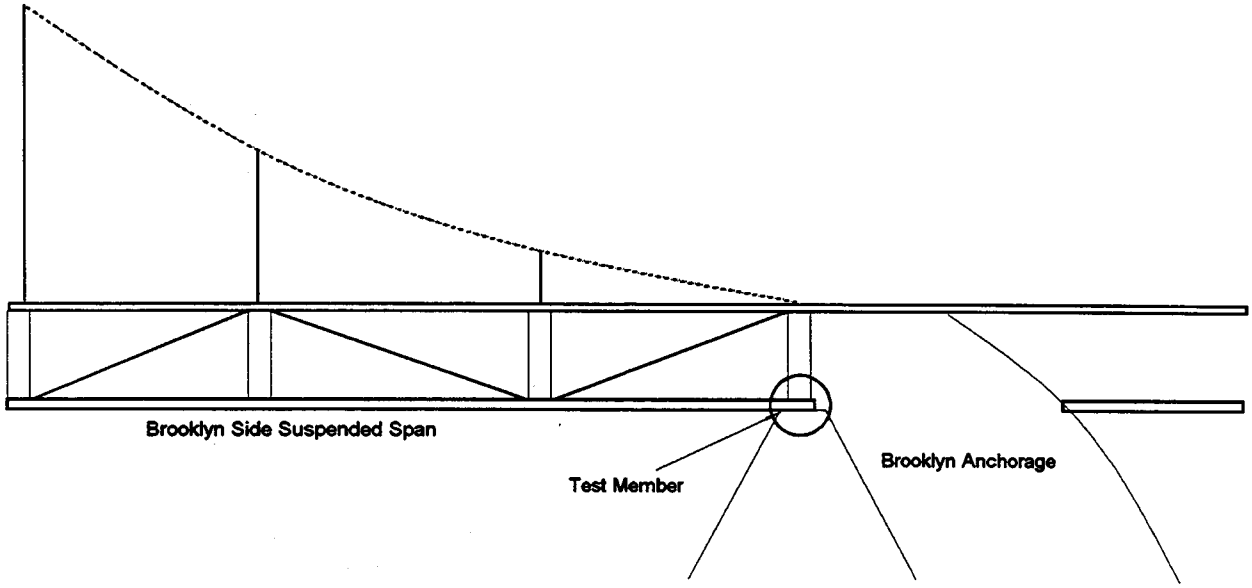
New York Location

Figure 22 shows a schematic diagram of the test patch locations on the New York City Bridge. As noted in the technical approach, coating patches were applied in two locations under the bridge. The inspection results have confirmed that the interior of the box-beam was a milder location than the exterior of the box-beam. The exterior anchorage side of the beam was subject to frequent wetting from a large expansion joint and was originally corroding along the top edge. The bottom of the box-beam was the only surface with notable corrosion. Figure 23 shows the condition of the existing coating system on the bottom of the box-beam.

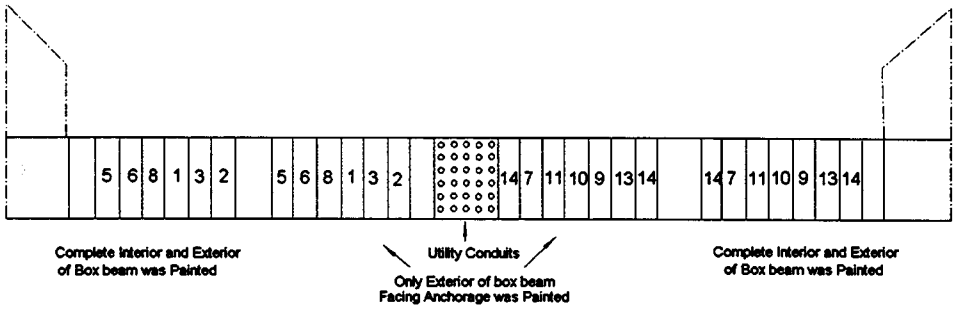
Figure 24 shows four test patches on the exterior of the box-beam following the 2.5-year exposure. The only areas of breakdown in figure 24 are along the top edge of the beam and on selected rivet heads where the old coating system was allowing corrosion. Most of theses overcoating systems have provided better corrosion protection and appearance than other areas of the box-beam that were not overcoated.

The overcoatings applied to the interior of the box-beam have remained in good condition. This relatively sheltered environment has not resulted in corrosion of any overcoating systems.

Table 6 presents the results of the 2.5-year test patch inspection. Ratings were assigned to each test patch for rusting, coating thickness, and cross-cut adhesion. The rusting data was taken in accordance with ASTM D610 for the test patches covering each flat face of the box-beam. The data shown in table 6 is an average for the entire test patch. The coating system adhesion was taken on the side of the beam facing the anchorage and on the opposite side of the beam (facing the suspension tower). The numbers presented represent the coating system's average adhesion. The coating system dry film thickness (DFT) was determined using a PIG gauge at one location on each test patch.



Location Diagram of Test Memeber



Floortruss Lower Chord at Brooklyn Anchorage

Sketches Not to Scale

Coating System Key

1 - 3-coat WB acrylic
2 - 3-coat WB acrylic
3 - 3-coat MCU
4 - epoxy/polyurethane
5 - sealer/epoxy/polyurethane
6 - sealer/Al-epoxy/Al-alkyd
7 - calcium sulfonate alkyd
8 - oil-alkyd/oil-alkyd/Si-alkyd
9 - epoxy polysiloxane
10 - MCU/polyurethane
11 - WB epoxy/WB acrylic
12 - 3-coat MCU
13 - 2-coat oil-alkyd
14 - 3-coat oil-alkyd
15 - higher VOC, 2-coat MCU
16 - 2-coat WB acrylic

Figure 22. Schematic diagram of New York City test patch locations.

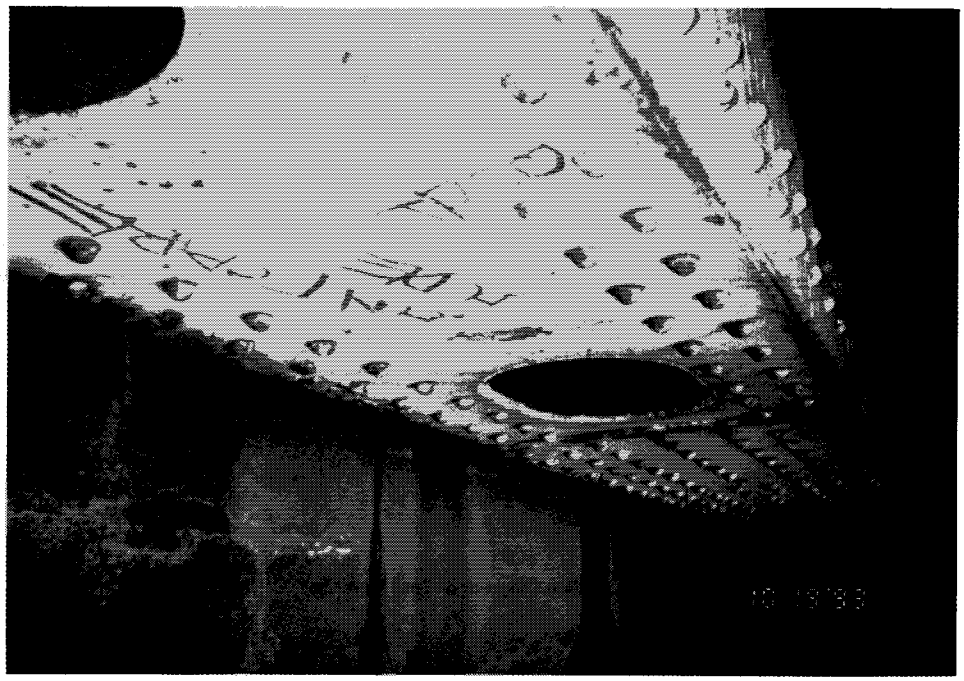


Figure 23. Initial condition of coating system on the bottom of the box-beam at the New York City location.

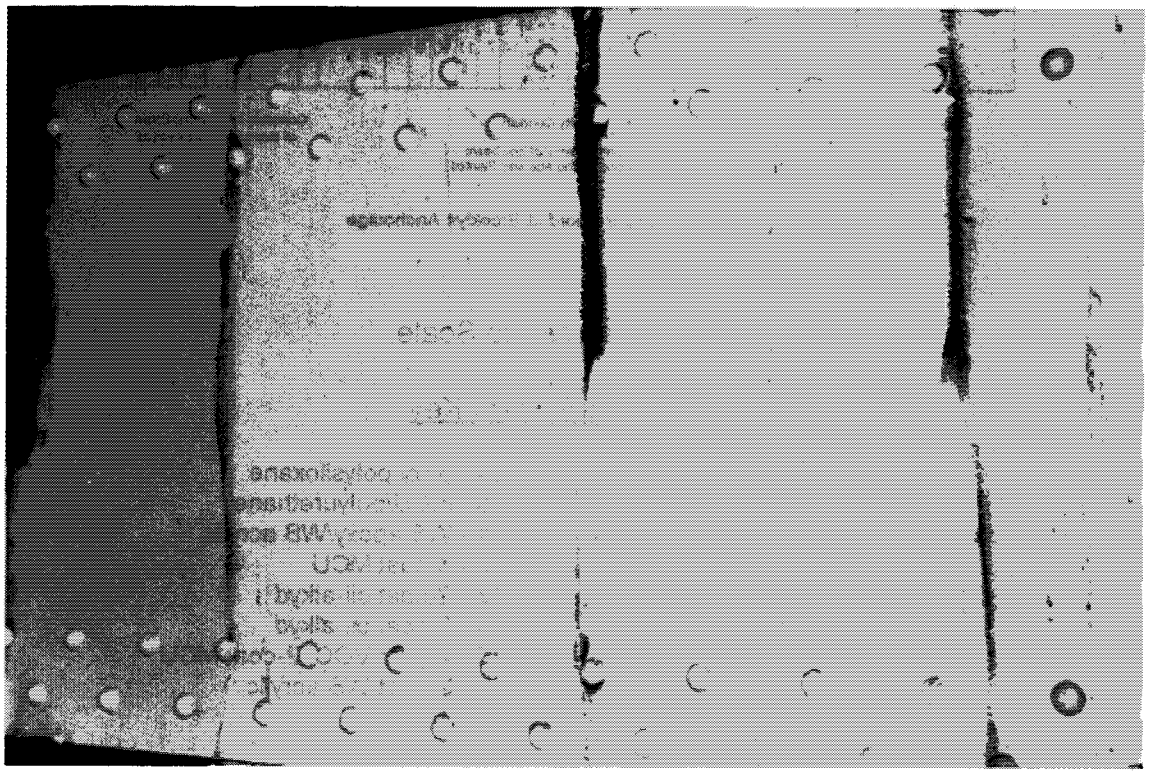


Figure 24. New York City test patches applied to expansion joint area (2.5-years exposure, left to right - systems 3, 1, 8, and 6).

Table 6. 2.5-Year inspection results from New York City test patch exposures.

System Number	Average ASTM D610 Ratings		Adhesion (ASTM D3359 A)	Overcoating system DFT
	box beam exterior	box beam interior		
1 - 3-coat WB acrylic	9.5	10	1.5	3-5
2 - 3-coat WB acrylic	7.7	10	1.5	4-6
3 - 3-coat MCU	9	10	2	7-9
4 - epoxy/polyurethane	8	10	1	5-8
5 - sealer/epoxy/polyurethane	8.5	10	1	6-8
6 - sealer/Al-epoxy/Al-alkyd	9.25	10	2	9-11
7 - calcium sulfonate alkyd	8	10	2	4-10
8 - oil-alkyd/oil-alkyd/Si-alkyd	9.25	10	1.5	9-16
9 - epoxy polysiloxane	6	10	2	4-6
10 - MCU/polyurethane	7.75	10	1	4-5
11 - WB epoxy/WB acrylic	6.25	9.6	2	8-12
13 - 2-coat oil-alkyd	7.75	10	3	5-7
14 - 3-coat oil-alkyd	8.5	10	2	8-10
Existing Control Surface	6	9	2	7-14

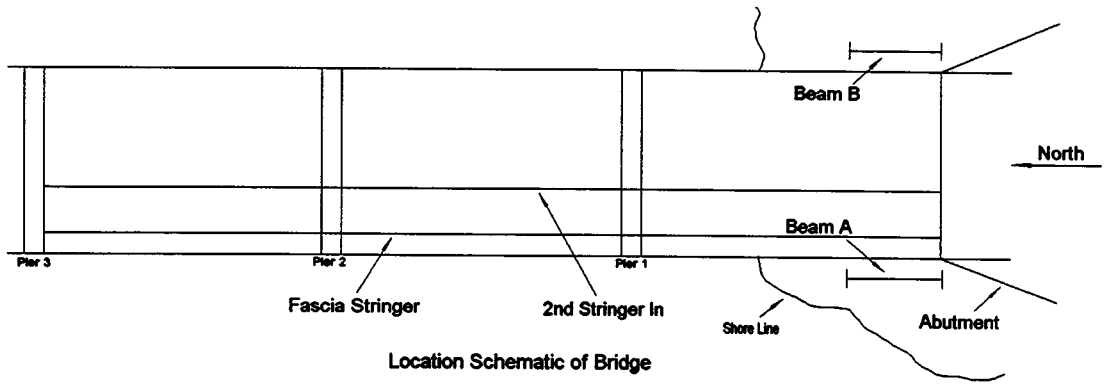
Louisiana Bridge Location

Figure 25 shows a schematic diagram of the test patch locations in Louisiana. As noted in the technical approach, coating patches were applied in two locations under the bridge, and on the beams shown near the abutment in the diagram in figure 25. Coating applications were completed in February of 1994, so the patches had been exposed for roughly 2.5 years at the time of the last inspection in June of 1996.

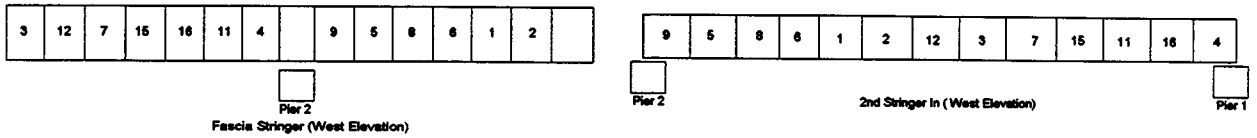
Figure 26 shows the bottom flange of a bridge girder following the surface preparation. This area was the most deteriorated before application of the test patches and consequently was the area of the most breakdown of the overcoating systems. Figure 27 shows the upper side of a similar girder member. The webs of these members were essentially free of corrosion.

Figure 28 shows a worker performing surface preparation on one of the relocated beams referenced in figure 25. The monitoring data presented earlier in this discussion was obtained during these activities. The initial condition of the two test beams can be seen in figure 28. The coating system was damaged and the steel was corroding over much of the beams.

Table 7 presents the results of the 2.5-year test patch inspection. Ratings were assigned to each test patch for overall rusting. The rusting data was taken in general accordance with ASTM D610 for all test patches at this location.



Location Schematic of Bridge



Detail of Bridge Test Patches

Detail of Beam Test Patches

Sketches Not to Scale

Coating System Key

1 - 3-coat WB acrylic
2 - 3-coat WB acrylic
3 - 3-coat MCU
4 - epoxy/polyurethane
5 - sealer/epoxy/polyurethane
6 - sealer/Al-epoxy/Al-alkyd
7 - calcium sulfonate alkyd
8 - oil-alkyd/oil-alkyd/Si-alkyd
9 - epoxy polysiloxane
10 - MCU/polyurethane
11 - WB epoxy/WB acrylic
12 - 3-coat MCU
13 - 2-coat oil-alkyd
14 - 3-coat oil-alkyd
15 - higher VOC, 2-coat MCU
16 - 2-coat WB acrylic

Figure 25. Schematic diagram of Louisiana test patch locations.

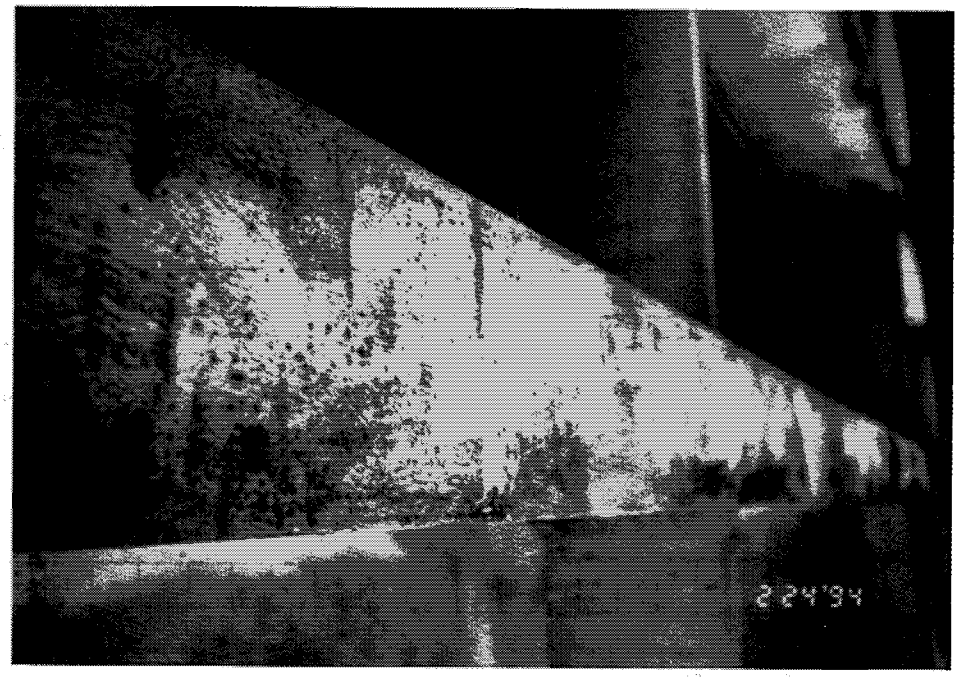


Figure 26. Bottom flange of Louisiana bridge girder following surface preparation.

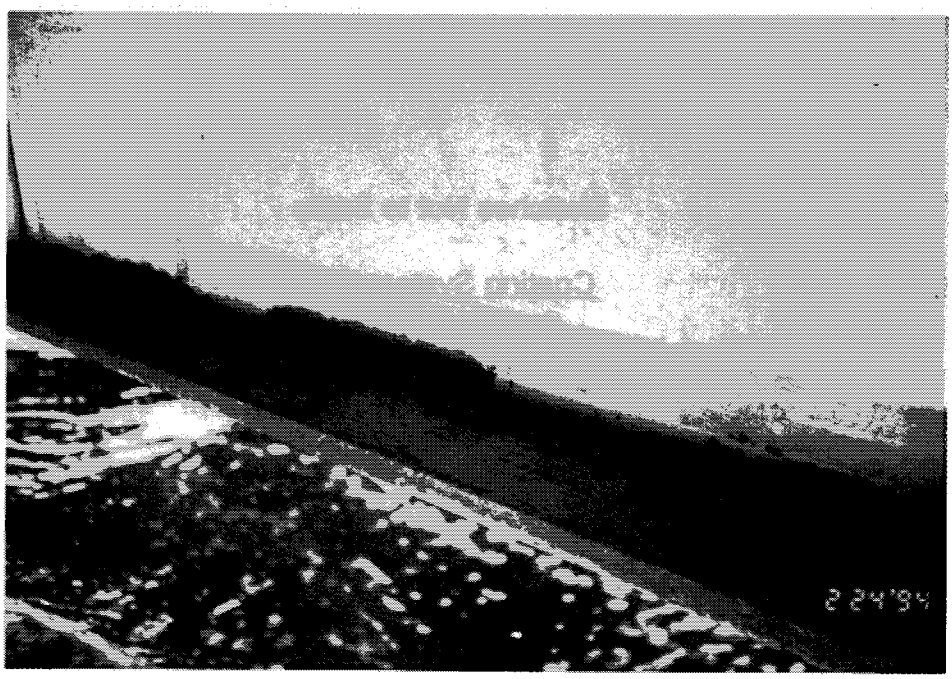


Figure 27. Top view of girder flange following surface preparation.

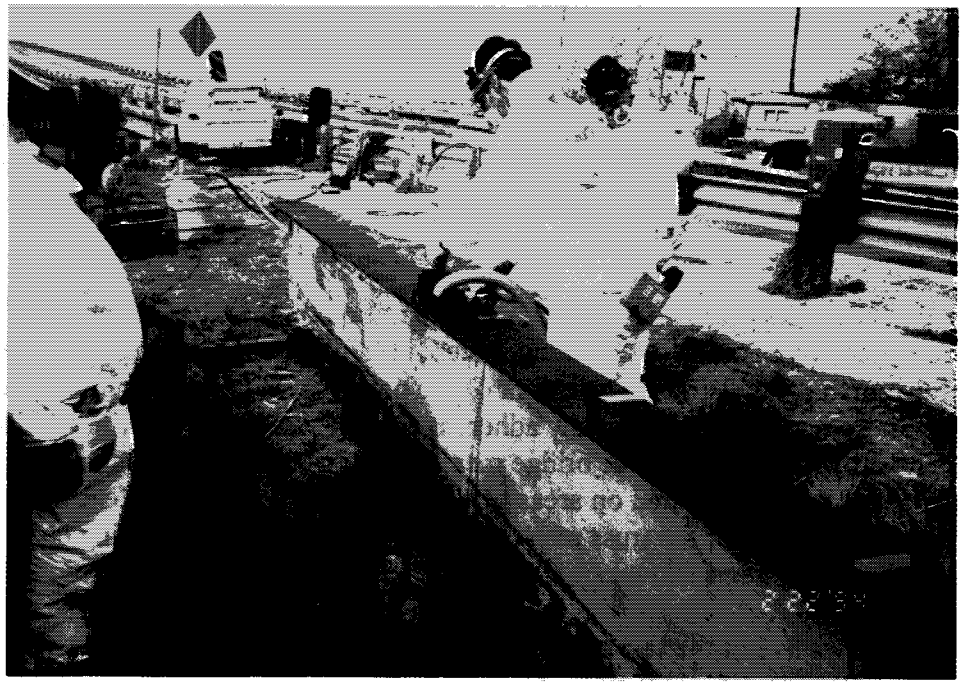


Figure 28. Surface preparation on test beams.

Table 7. 2.5-Year inspection results from Manchac, LA test patch exposures.

System Number	Average ASTM D610 Ratings		
	bridge interior girder	bridge facia girder	test beams
1 - 3-coat WB acrylic	7	7	6
2 - 3-coat WB acrylic	8	8	5
3 - 3-coat MCU	10	10	9
4 - epoxy/polyurethane	5	8	7
5 - sealer/epoxy/polyurethane	7	9	9
6 - sealer/Al-epoxy/Al-alkyd	10	10	9.5
7 - calcium sulfonate alkyd	7	8	7
8 - oil-alkyd/oil-alkyd/Si-alkyd	9	10	9
9 - epoxy polysiloxane	5	7	5
11 - WB epoxy/WB acrylic	6	8	5
12 - 3-coat MCU	9	9	10
15 - higher VOC, 2-coat MCU	6	10	8
16 - 2-coat WB acrylic	7	8	7
Existing Control Surface	7	9	N/A

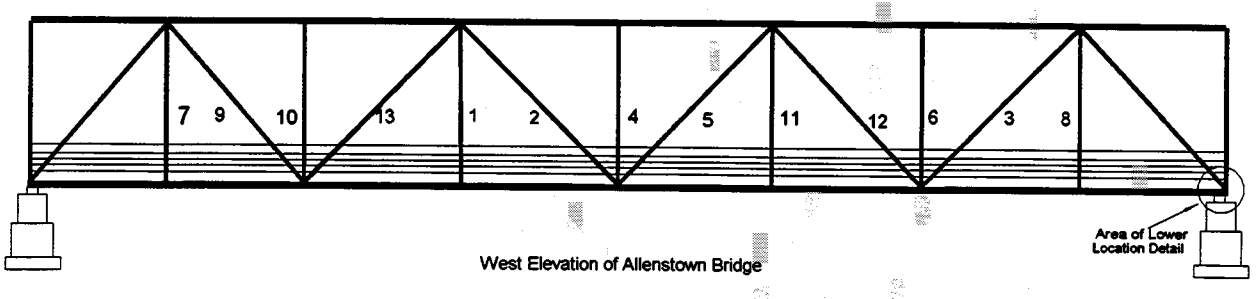
New Hampshire Location

Figure 29 shows a schematic diagram of the test patch locations in New Hampshire. As noted in the technical approach, coating patches were applied in two locations on this bridge. Coating applications were completed in the fall of 1994, so the patches had been exposed for roughly 1.5 years (including two winter seasons) prior to the latest inspection in the late winter of 1996.

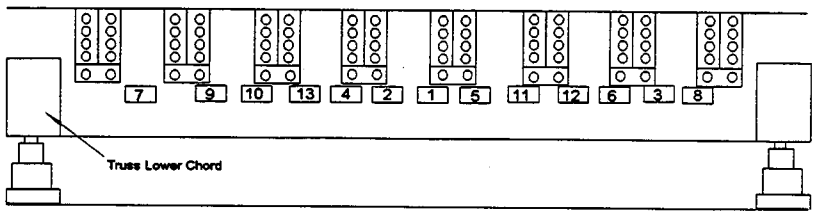
Figure 30 shows the pressure wash surface preparation on the truss members of the bridge. Before surface preparation, the coating system in this area was peeling to the red-lead primer or slightly corroded millscale. The extent of the peeling was not as significant as that shown in figure 30 as much of the marginally adherent coating was removed with the pressure wash. The overcoating systems on these bridge members have not shown much corrosion to date. The corrosion present is located on areas where the existing coating system was removed to bare steel and on the edges of the truss members. The areas where the existing coating was overcoated with the test systems show zero corrosion and minimal peeling.

Figure 31 shows five of the test patches applied to the expansion joint area of the New Hampshire bridge following 1.5-years exposure. Frequent wetting of this beam from the expansion joint above has resulted in a severe environment for the test patch exposure. Most of the areas that were originally corroded (figure 17) have begun to re-rust during the 1.5-year exposure. The inspection results presented in table 8 will help differentiate the corrosion performance of the overcoating systems.

Table 8 presents the results of the 1.5-year test patch inspection. Ratings were assigned to each test patch for rusting, coating thickness, and cross-cut adhesion. The rusting data was taken in accordance with ASTM D610 for the test patches covering each flat face of the test patch area. The data shown in table 8 are an average for the entire test patch. The coating system adhesion was taken on both sets of test patches and averaged for the coating systems. The coating system dry film thickness (DFT) was determined using magnetic film thickness measurements and a paint inspection gauge (PIG). The thicknesses obtained with the PIG were more reliable than the magnetic thickness readings because the inspector could distinguish the thickness of individual layers of paint. The magnetic thickness gauge reads the total thickness of non-magnetic coating, so it could be measuring the overcoating system alone or measuring several layers of existing paint combined with the overcoating system.



West Elevation of Allenstown Bridge



Lower Location North Elevation

Sketches Not to Scale

Coating System Key

1 - 3-coat WB acrylic
2 - 3-coat WB acrylic
3 - 3-coat MCU
4 - epoxy/polyurethane
5 - sealer/epoxy/polyurethane
6 - sealer/Al-epoxy/Al-alkyd
7 - calcium sulfonate alkyd
8 - oil-alkyd/oil-alkyd/Si-alkyd
9 - epoxy polysiloxane
10 - MCU/polyurethane
11 - WB epoxy/WB acrylic
12 - 3-coat MCU
13 - 2-coat oil-alkyd
14 - 3-coat oil-alkyd
15 - higher VOC, 2-coat MCU
16 - 2-coat WB acrylic

Figure 29. Schematic diagram of New Hampshire test patch locations.

Figure 30. Pressure wash of existing coating system at New Hampshire Bridge.

Figure 31. New Hampshire bridge test patches under the expansion joint after 1.5 years exposure (systems 11, 12, 6, 3, and 8).

Table 8. 1.5-Year inspection results from New Hampshire test patch exposures.

System Number	Average ASTM D610 Ratings		Adhesion (ASTM D3359 A)	Overcoating System DFT
	expansion joint	truss members		
1 - 3-coat WB acrylic	7	10	1.5	6-8
2 - 3-coat WB acrylic	6	10	1	4-6
3 - 3-coat MCU	8	10	2	10-14
4 - epoxy/polyurethane	7	10	1	8-11
5 - sealer/epoxy/polyurethane	7	10	2	7-9
6 - sealer/Al-epoxy/Al-alkyd	8	10	1.5	9-11
7 - calcium sulfonate alkyd	5	9.8	2.5	5-7
8 - oil-alkyd/oil-alkyd/Si-alkyd	5	10	1	8-12
9 - epoxy polysiloxane	5	7.4	1	3-5
10 - MCU/polyurethane	7	9.8	2.5	4-5
11 - WB epoxy/WB acrylic	3	8.8	1.5	5-7
12 - 3-coat MCU	7	10	2	6-9
13 - 2-coat oil-alkyd	7	9.6	2	8-12
Existing Control Surface	4	8	1	8-24

Discussion of Field Coating System Performances

It is difficult to closely analyze the data produced in this program from test patch to test patch or from location to location due to the wide variations in the surfaces that were overcoated. The results of the field inspections were presented in a general fashion, and were intended to best represent each individual test patch. The most valuable results from this program can be seen when the inspection information from all exposure locations is combined and the general trends in the data are observed.

The most valid conclusions from these exposures may be seen in the relationships between variables such as initial bridge corrosion condition, overcoating system rusting, and overcoating system peeling. By observing these factors as they pertain to each test patch at each bridge site, trends used to differentiate between the overcoating systems can be seen. Several factors that may have influenced the performance of specific coating systems are discussed in the following subsections.

Failure Modes

Rusting was the predominant failure mode for areas where the overcoating systems were applied over bare steel or corroded metal. All coating systems experienced pin point rusting in the more severe micro-environments of each exposure site. The corrosion that was not removed by the surface preparation and subsequently overcoated remained active, and eventually showed through the overcoating systems. The coating inspection results have shown this rusting. The edges of structural members were also prone to pin point rusting.

Only 2 of the 16 overcoating systems tested displayed incompatibilities with the existing aged coating systems they were applied over. The system 11 coatings (WB epoxy/WB acrylic) peeled from the aged topcoat at the three northern locations leaving the existing coating layers intact. This insufficient adhesion was the result of the epoxy primer being incompatible with the aged topcoats overcoated in this program.

The system 9 (epoxy polysiloxane) material cured very hard creating a brittle film. The coating did not disbond from the aged coating at any test location, but had a tendency to pull itself and the aged coating from the metal substrate. If corrosion was overcoated with this material the film would crack under the force of expanding corrosion products. At the Chicago location, the difference in thermal expansion of the overcoat and the existing coating was great enough to cause a catastrophic delamination of the aged, overcoated system on 50 percent of the test patch. The other three test sites showed cracks and spalls in this coating, but nothing comparable to the failure displayed in Chicago. Figure 32 shows a photograph of the delaminated coating system at the Chicago test site following the third winter of exposure.

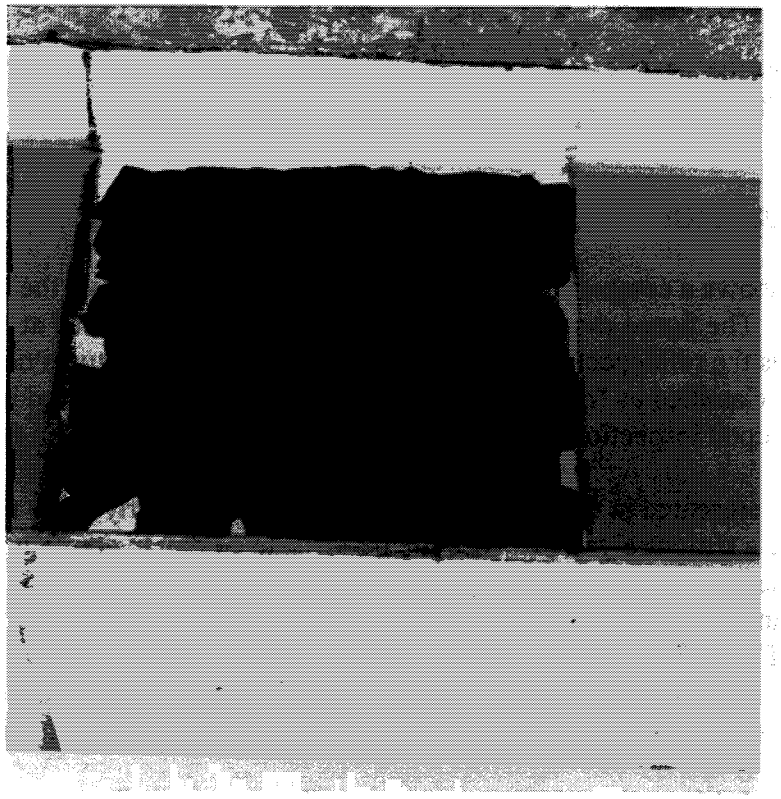


Figure 32. Area where system 9 delaminated at Chicago test site.

Exposure Time

The exposure times for the four field test locations were all less than three years. These relatively short exposure periods have produced valuable results to date. Some coating systems "failed" within this short period of time. These failure modes were typically related to incompatibilities or inappropriate physical properties of the overcoating materials as applied to existing bridge coatings (discussed above).

The incompatibility of system 11 to the existing topcoats in Chicago, New York, and New Hampshire was evidenced on the first inspection of each location (6 months to one year after applications). The Louisiana location has not caused delamination of this coating system to date, but the agreement of the other three locations strengthens the conclusion that those overcoating systems that are not compatible with existing coatings can be distinguished in a short period of time. The first inspections for the three "colder" locations were all following at least one winter season.

The trends observed in the rusting data for the accelerated marine atmosphere exposure testing indicated that systems that showed rust first ended up with the most rust following the full exposure. The inspection data for the field systems has trended in the same fashion. The field systems that were beginning to show pin point rusting at the one year field inspections performed more poorly at the final inspection than those showing no rusting at one year. This observation

vation demonstrates that results of a 1 year test patch exposure can aid engineers in making informed overcoating material choices.

Initial Corrosion Condition

Figure 33 shows a comparison of the average inspection data from the location of each set of test patches. The figure shows averages of all coating systems tested at the particular location and also shows the reference condition of similar areas of the structures not overcoated. In all cases, the areas classified as "more corrosive" on the bridges have resulted in more numerous areas of corrosion upon inspection of the test patches (third bar is lower than first bar).

The results presented in tables 5 through 8 and figure 33 clearly show that the initial corrosion condition of a structure will influence the performance of an overcoating system. Without exception, all of the more corroded expansion joint areas that were painted resulted in more coating breakdown than the facia girders or truss members on the same bridge painted with the same coating systems. The power tools used were not effective at removing the tightly adherent rust that had advanced to SSPC initial surface condition D. The coatings applied over the remaining rust were prone to early (within a year) rust through on most edges and difficult-to-clean areas.

Areas of the bridges without severe corrosion showed relatively good results when overcoated. Once the existing loose coating material was removed, the noncorroding substrate and remaining coating was suitable to overcoat. The application of the overcoat materials dramatically improved the appearance of these areas compared to similar areas of the same bridge not overcoated.

Initial Coating Adhesion

Several different types of surfaces may be painted while overcoating. An important observation from the results of this research relates to the adhesion of the coatings that were overcoated. Following surface preparation of the existing coatings to remove any loose or non-adherent coating, the ASTM adhesion ratings or pull-off (psi) values of intact coating adhesion did not have a direct barring on the success or failure of the overcoating application.

With the test beams representing the Louisiana location, all four test sites had mill-scale substrates with a lead-alkyd primer. This primer/substrate combination is of particular concern when it is being overcoated. The average initial coating system adhesion at these test sites was 1.5 (ASTM D3359 method A). The average adhesion of all overcoating systems applied at these sites was 1.8.

There is minimal difference in these adhesion results. The following comments highlight the observations and conclusions based on the adhesion testing conducted at the field test locations over mill-scale substrates:

- There is minimal difference between the adhesion of the aged coating systems and the adhesion of the aged coating systems following overcoating. The *compatible* overcoating systems did not improve or reduce the adhesion of the coating systems as a whole.[2]

- The majority of the adhesion tests resulted in failure either at the millscale, or within the primer film (primer splitting). These are typically considered the weakest areas of the coating systems (before and after overcoating), and the areas where delamination is most likely to occur.

- The adhesion of the compatible overcoating systems over bare steel, clean millscale, or prepared rust was always better than the adhesion of the same coatings applied over the aged coating/millscale substrate. When the overcoating systems were applied over rust the adhesion was reduced to near zero once underfilm corrosion began to advance.

- At the New Hampshire location the results of pull-off type adhesion testing (ASTM D4541) ranged from 1,400 to 3,400 kPa (200 to 500 lbf/in^2) for pulls performed on overcoating systems applied over the existing coating. The existing coating system at this test site was disbonding to millscale more severely than the New York, Chicago, or Louisiana test sites and would have been questionable to overcoat based on the peeling observations alone. The adhesion of the undisturbed existing coating system ranged from 0 to 1,400 kPa (0 to 200 lbf/in^2). The adhesion of the overcoating systems applied over bare mill-scale were significantly better, yet very inconsistent (2,750 to 7,580 kPa [400 to 1,100 lbf/in^2]). Despite the relatively low adhesion results obtained at the New Hampshire test site, significant disbondment of the *compatible* overcoating systems has not occurred to date.

Number of Coats in the Overcoating System

Figure 34 shows that less rusting was observed for overcoating systems that were comprised of three coats of paint. The data presented is from all exposure locations and includes all systems tested. Those systems not tested at all four sites are shown with an asterisk. The multi-coat systems apparently covered the substrate better because of repeated applications. The single coat systems had a tendency to pin point rust after some exposure time, evidence of weak areas or holidays in the applied film.

Correlation of the overcoating system DFT to exposure performance for the field systems was constructed using the Tooke readings obtained during the study. Figure 35 shows the results of this correlation and indicates that thickness of the overcoating system was very influential to system performance. The figure shows coating system thickness along the X-axis plotted against the average rust ratings on the Y-axis. The individual system averages are shown with a linear

[2]Coating system 9 proved to be incompatible with the aged coating systems and did cause disbondment of the original primer from the millscale. Coating system 11 proved to be incompatible with the aged coating systems and disbonded from the aged coating leaving it in place.

of the data plot. This data emphasizes the fact that a thicker barrier coating system will outlast a thinner system because less weak areas (holidays) will exist in the film.

Caution should be taken as to the extension of this observation. The rusting failure was almost exclusively limited to areas where the existing bridge coating was removed during surface preparation. Figure 35 shows that thicker films performed better at these areas. An "overly thick" overcoat may add a large amount of stress and weight to the composite coating system. This forms a basis for recommending spot primers for production scale overcoating work.

Generic Resin Type of the Overcoating System

Figure 36 shows the performance of the overcoating systems based on the generic resin type of the coating (or primer coating for multi-coat systems) and the number of coats in the system. This plot is particularly useful because it shows the average performance of each individual coating system. Those coating systems not tested at four sites are shown with an asterisk. This data shows that better performance was obtained with moisture-cured polyurethane or alkyd resin based systems applied in three coats. This result is in agreement with the thickness dependence result emphasized by the data in figure 35.

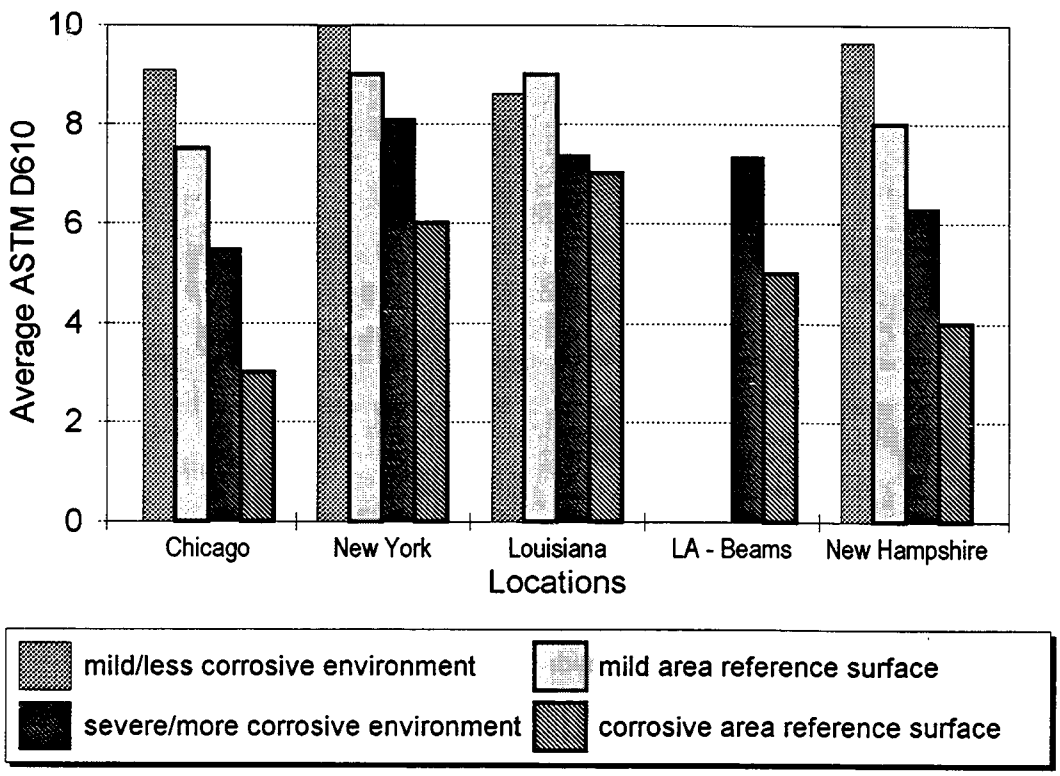


Figure 33. Overcoating performance comparison by micro-environment and site location.

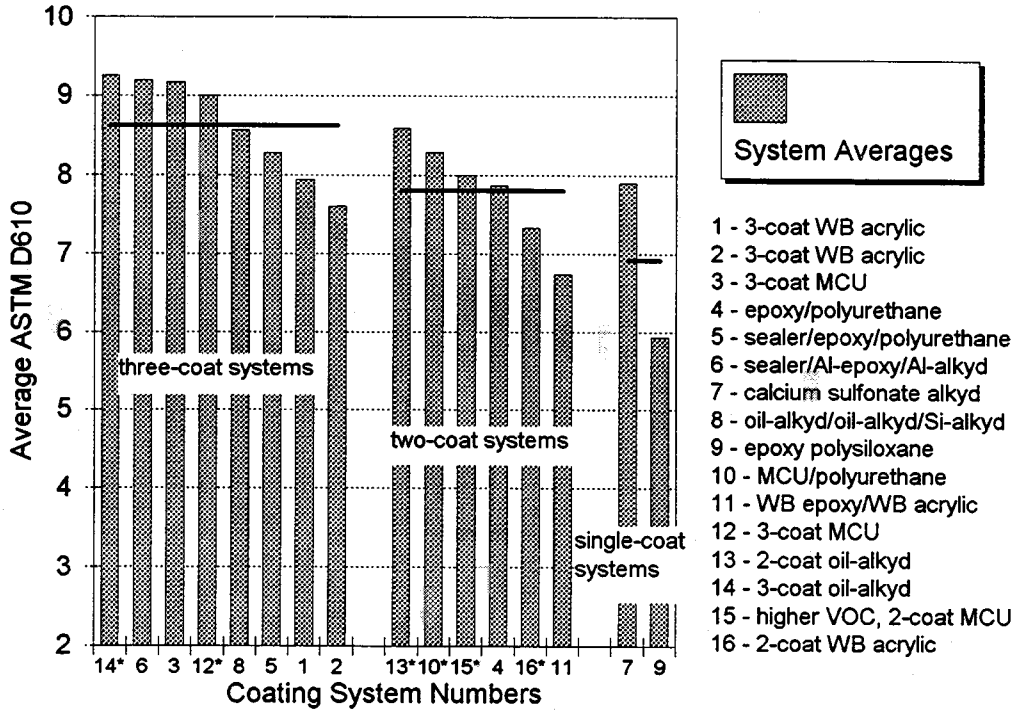


Figure 34. Comparison of the number of coats applied to the final rust ratings for all overcoating systems.

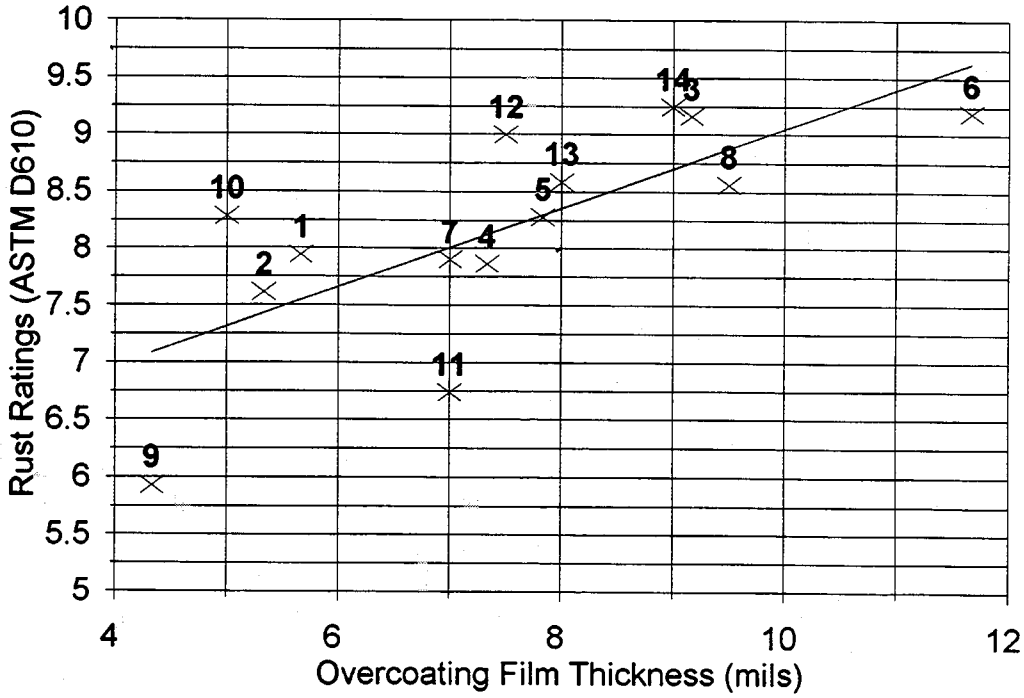
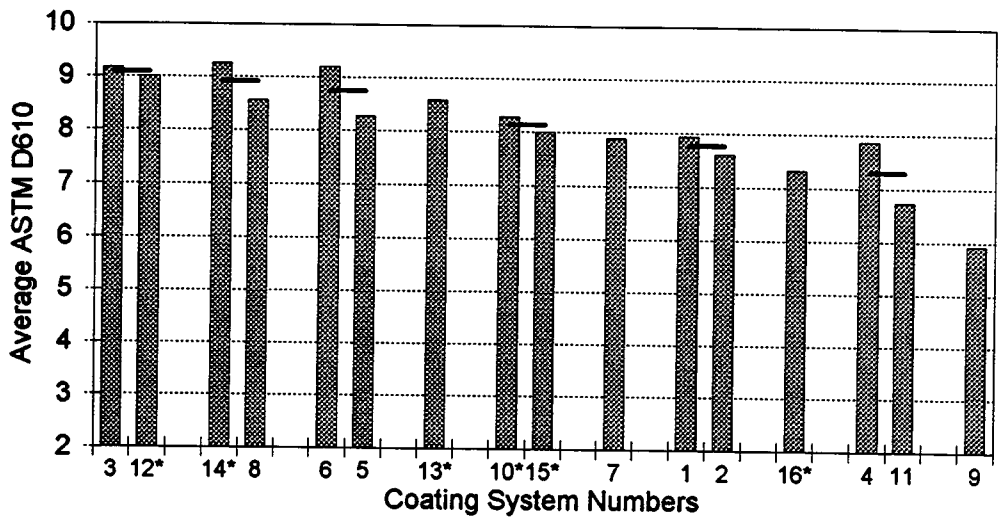


Figure 35. Comparison of overcoating system DFT versus average rust ratings.



3, 12 - Three-coat MC Urethane
14, 8 - Three-coat alkyd
6, 5 - Three-coat epoxy
13 - Two-coat alkyd
10, 15 - Two-coat MC Urethane
7 - Single-coat calcium sulfonate
1, 2 - Three-coat WB Acrylic
16 - Two-coat WB Acrylic
4, 11 - Two-coat epoxy
9 - Single-coat epoxy

Figure 36. Comparison of the generic overcoating type to rusting performance for all overcoating systems.

Specific Coating System Performance Comments

Other results of this program related to the performance of specific or groups of similar coating systems include the following:

- The 3-coat moisture-cured polyurethane systems have performed well at all sites to date. They covered edges well and were less susceptible to rust "bleeding" during application over partially or fully rusted substrates than the waterborne coatings.

- Aside from relatively major application problems with system 6, the systems employing the low-viscosity epoxy sealer coat with an epoxy intermediate coat have performed well to date. These systems have not cracked or promoted disbondment of the existing coating systems from the substrate at any of the exposure locations. The difference in corrosion performance between systems 4 (E/U) and 5 (sealer/E/U) seems to indicate that the extra sealer coat was beneficial to the coating system performance in overcoat applications. (see figure 36).

- The two, 3-coat alkyd systems tested performed very well. Although not the most durable system in some of the more aggressive micro-environments, these materials ranked consis-

ranked consistently among the best performers in exposures during this program. These coatings are easy to apply and are single-package materials which may aid in maintenance painting.

- The single coat calcium sulfonate system has performed reasonably well at all sites to date. This coating material is relatively easy for contractors to apply in a single high-build coat. It must be noted that this coating requires an extended period to cure hard and may collect dirt or be damaged easily within the first several months.

- The waterborne acrylic systems tested have shown some early breakdown over the bare metal/rusted areas, but have not shown any compatibility problems or widespread failure when applied over existing coatings.

- The waterborne epoxy system tested (system 11) disbonded from the existing topcoat following one winter season at the three northern locations.

- The single coat epoxy polysiloxane has qualitatively retained superior gloss compared to the aliphatic polyurethane topcoats. However, the coating did not cover well in a single coat as evidenced by pin point rusting. The coating is qualitatively very hard and brittle and has cracked when corrosion products begin to accumulate below the film. In the Chicago location the unique physical properties of the film most likely propagated the coating's disbondment.

So that detailed comparisons may be made by readers, a summary of the final inspection data for all test locations has been provided. Table 9 displays summarized rusting inspection results from all nine of the test patch application sites. The table shows a final rust rating for each of the individual test patch applications completed during the program.

Table 9. Final ASTM D610 rust ratings for all test patch applications.

System Number	Location								
	Chicago, IL		New York City		Manchac, LA			Allenstown, NH	
	expansion joint	facia	box beam exterior	box beam interior	bridge interior girder	bridge facia girder	test beams	expansion joint	truss members
1 - 3-coat WB acrylic	4	8.5	9	10	9	9.5	6.5	7	10
2 - 3-coat WB acrylic	4	9	9	10	8	9.5	5.5	6	10
3 - 3-coat MCU	6	8.5	9.6	10	10	10	9	8	10
4 - epoxy/polyurethane	5	8.5	9	10	8.25	8.5	7	7	10
5 - sealer/epoxy/polyurethane	4	8	9.6	10	9.25	10	9	7	10
6 - sealer/Al-epoxy/Al-alkyd	5	9	9.6	10	10	10	9.5	8	10
7 - calcium sulfonate alkyd	5	7.5	9.5	10	8.25	8.5	7	5	9.8
8 - oil-alkyd/oil-alkyd/Si-alkyd	5	8.5	9.6	10	10	10	9	5	10
9 - epoxy polysiloxane	4	5.5	8.3	10	8	8	5.5	5	7.4
10 - MCU/polyurethane	6	8.5	8.3	10				7	9.8
11 - WB epoxy/WB acrylic	4	5	5.7	9.6	7.5	8	5.5	3	8.8
12 - 3-coat MCU					10	10	10	7	10
13 - 2-coat oil-alkyd			9	10				7	9.6
14 - 3-coat oil-alkyd			9.5	10					
15 - higher VOC, 2-coat MCU					9	10	8		
16 - 2-coat WB acrylic					8	8	7		

APPENDIX I. DISCUSSION OF OVERCOAT COMPATIBILITY

As a starting point in the material selection process, the chemical compatibility between various types of overcoating materials and various types of existing coatings was investigated. Six potential overcoating systems were considered based on their resin chemistry. The compatibility of these systems was discussed for application over existing coatings. Three different resin types were considered in evaluating existing topcoats of aged coating systems; these were thermoplastic (i.e., vinyl), oxidizing thermoset (i.e., alkyd) and chemical cure thermoset (i.e., polyurethane). These three topcoats were selected to represent the majority of the topcoat materials currently on existing bridge structures.

When a bridge is overcoated, the maintenance coating system will be applied over non-uniform surfaces. This surface can typically include areas of intact existing topcoat, existing intermediate or primer coatings (topcoat has delaminated), varying degrees of rust (packed, light, etc.), clean mill scale, partially rusted mill scale (SSPC initial surface condition B), and the boundaries or transition areas between all of these conditions. The variability of the substrate for an overcoating situation means the overcoat must perform well over all of these substrates. Previous researchers have addressed coating performance over pre-rusted and power- or hand- tool cleaned, and mill scale surfaces.[1,2,3] This section will address compatibility issues that may exist between aged topcoats and the overcoating system primer.

EXISTING TOPCOATS

In evaluating existing bridge coating topcoats three different resin types will be considered, these are thermoplastic, oxidizing thermoset, and chemical cure thermoset.

Thermoplastic Resin Based Topcoats (e.g. Vinyls and Acrylics)

Thermoplastic coatings cure through solvent evaporation (e.g., vinyls, acrylics and chlorinated rubbers). Thermoplastic resins that are used in industrial coatings generally have a high molecular weight. These systems will degrade when exposed to sunlight, losing molecular weight and chalking. The effect of ultra violet light on a pigmented coating is mostly limited to the surface since the pigments and additives such as antioxidants protect the interior of the

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[1]B.R. Appleman, J.A. Bruno, and R.E. Weaver, *Performance of Alternative Coatings in the Environment (PACE)*, Report Nos. FHWA-RD-89-127, FHWA-RD-89-235, and FHWA-RD-89-236, Federal Highway Administration, Washington, DC, September 1990.

[2]J.A. Ellor, R.A. Kogler, and A.R. Parks, *Evaluation of Selected Maintenance Coatings Over Hand and Power Tool-Cleaned Surfaces*, Journal of Protective Coatings and Linings, Volume 7, No. 12, December 1990, pp. 46-52.

[3]R.A. Kogler, and W. Mott, *Environmentally Acceptable Materials for the Corrosion Protection of Steel Bridges: Task C, Laboratory Evaluation,* FHWA-RD-91-060, Federal Highway Administration, Washington, DC, September, 1992.

coating film. Loose chalk from the degraded binder should be removed before recoating, but the intact system should provide a good substrate for painting.

Thermoplastics can be re-softened by solvents. The type of solvent(s) in an overcoating system can affect the adhesion of the repair system to the existing system. A solvent that re-softens the thermoplastic topcoat too easily can cause delamination. A solvent that does not re-soften the thermoplastic at all can not achieve optimum adhesion. In topcoating thermoplastics, the best adhesion is obtained with overcoats that slightly re-soften the existing topcoat. In general, vinyls need strong oxygenated solvents such as ketones and esters to be re-softened. Chlorinated rubbers need aromatic hydrocarbon solvents and acrylics can be softened by solvents as weak as aliphatic hydrocarbons.

Because thermoplastics use high molecular weight resins they often contain plasticizers to improve flexibility. During aging, these plasticizers can migrate through the film to the surface, which may create difficulty for recoating. The aged film can be brittle and vehicle poor. If the coating still has reasonable cohesive strength, it probably will provide a reasonable substrate for recoating; however, it may absorb vehicle (resin) from the next coat applied. Consequently, the overcoat should not be formulated at or beyond the critical pigment volume concentration so that resin absorbed into the existing topcoat does not affect the performance of the coating by leaving behind excessive pigment in the overcoat.

By definition, thermoplastic systems expand and contract with temperature. The amount of expansion and contraction of these coatings is dependant on the resin and on the pigment concentration. The higher the pigment concentration, the less the expansion and contraction. If such a coating is repaired with a system of substantially different expansion and contraction properties, long term adhesion can be affected. This can lead to detachment, but also may lead to voids at the interface of the two films, allowing moisture and oxygen a more direct path to the substrate.

Oxidizing Thermoset Resin Based Topcoats (e.g. Alkyds)

Oxidizing resins cure by reaction with oxygen in the air (e.g., alkyds, oleoresinous systems). These resins continue to cross-link throughout the lifetime of the coating and can leave a brittle film. Coatings based on oxidizing resins offer a wide range of performance traits based on formulation variables. The unmodified oxidizing resin system is more susceptible to breakdown by UV and water than the thermoplastic and chemical cure systems. Sunlight causes chalking of the film and loose chalk should be removed from the surface before repairs are made. Oxidizing resins are soluble in weak solvents such as aliphatic hydrocarbons. The dry film is susceptible to attack by more aggressive solvents causing the existing film either to lift or curl from the substrate. When repairing such a coating with a coating containing stronger solvents it is advisable to check for this condition by applying a test patch.

Modification of oxidizing resin based coatings can improve their corrosion protection characteristics. In the past, lead-based anticorrosive pigments were commonly used in oxidizing resin systems. In this type of system, reaction of the lead pigments with the oxidizing resin substantially changes the binder by producing a lead soap. The lead soap is water soluble, so if it

is not recoated with the same system, a good barrier coating should be used to minimize the chance of osmotic blistering.

Another modification used with oxidizing resins is a calcium sulfonate/carbonate complex. This complex can be used with no resin modification to provide good resistance to corrosive environments. However, the films produced are soft with poor mechanical properties, and consequently are modified with oxidizing resins to improve these properties. Coatings based on this type of resin system are generally less susceptible than unmodified systems to lifting by stronger solvents, embrittlement by aging and chalking. Calcium sulfonate modification provides a highly hydrophobic surface. This surface can be difficult for future maintenance coatings to wet and can lead to poor adhesion between the existing calcium sulfonate coating and repair coatings. This limits the calcium sulfonate maintenance coating systems to a one coat application. This is a greater problem with a new film, as when the film ages the surface becomes less hydrophobic and easier to wet. If the existing film is well aged most solvent based systems should be compatible.

Chemical Cure Thermoset Resin Based Topcoats

Thermoset resins cure by reaction of two components having reactive functionality (e.g., epoxy and polyurethane). They produce films with high cross-link densities and have very good barrier properties. These systems generally maintain their properties over time better than the thermoplastic and oxidizing systems. The affect of sunlight on these coatings is dependant on their component types, but they will all degrade over time by loss of molecular weight and chalking. Loose chalk should be removed before recoating. The high cross link density of the film produces a solvent resistance which may inhibit adhesion of a maintenance coating. In some cases roughening of the surface may be necessary for proper adhesion.

Thermoset resin based coatings generally have low coefficients of thermal expansion, and as stated in the section on thermoplastics repair by coatings of substantially different expansion properties may lead to adhesion problems.

REVIEW OF REPAIR SYSTEMS

This section discusses the chemical make-up of six possible overcoating systems. The characteristics of the coating types are discussed as they may relate to compatibility and performance issues. The following presents some insight into the formulation parameters and material selection issues associated with typical overcoating systems.

System A: Leafing Aluminum Pigmented Alkyd

This system has a linseed oil/calcium sulfonate resin system in combination with a leafing aluminum pigment. Linseed oil is a good film former, but the film does not have the barrier properties achieved with chemical cure or thermoplastic type resins. Calcium sulfonate is added to the system to improve this property because of its hydrophobicity. Calcium sulfonate

also has good wetting properties that can provide compatibility to poorly prepared substrates and many different existing systems. Calcium sulfonate also acts as a corrosion inhibiter for metallic substrates. These products are formulated with a moderate to high pigment volume concentration but their performance should not be affected by application to a resin poor substrate. The leafing aluminum pigment is added to improve barrier properties. This type of coating will have a moderate coefficient of thermal expansion, so long term adhesion to most existing systems should be minimally affected.

The solvent system is generally a mixture of aliphatic and aromatic hydrocarbons. This combination will be compatible with oxidizing resin types and is not normally strong enough to lift or wrinkle such existing systems. This solvent combination should soften most thermoplastic systems, but may not be strong enough to soften some vinyl coatings. It is recommended that a test patch be applied over vinyl systems. This solvent system will not soften most thermoset coatings, so the aged coating surface should be roughened prior to repair. This type of resin system will provide little chemical bonding with other resins but the calcium sulfonate will chemically bond with metallic substrates.

System A is applied in two coats. This system should have good compatibility with most existing systems, should have good performance over poorly prepared metal substrates, and has moderate barrier properties. It will have fair performance on exposure to sunlight, as the linseed oil will chalk and yellow on exposure to ultraviolet light.

System B: Epoxy Low Viscosity Sealer/ Aluminum Epoxy Mastic

Epoxy rust penetrating sealers are generally 100-percent solid resin systems containing no solvents and no pigments. They are low in viscosity and use the good wetting properties of epoxy resins for penetration and adhesion to poorly prepared substrates. They are applied in thin films, and should be compatible with oxidizing resins systems. Since they contain no solvent they should not produce a lifting or wrinkling problem. Penetrating sealers are also compatible with most thermoplastic systems; however, since they contain no solvents they may have difficulty in softening the existing topcoat to obtain maximum adhesion. This type of product also has a low coefficient of expansion. The lack of pigmentation means that when topcoating resin poor systems absorption of the resin into the existing system will not affect the properties of the remaining film. This type of coating will be compatible with thermoset systems, though such existing systems should have a roughened surface. A chalked surface that has had the loose chalk removed may be rough enough for good adhesion since this type of coating will generally provide some chemical bonding. This can be determined by application of a test patch.

High build aluminum epoxy coatings are high solids systems with excellent barrier properties. Their pigment volume concentration is normally in the medium to high range to give good barrier properties. Aluminum pigment is added to improve barrier properties. The level of pigment is normally enough below the critical pigment volume concentration not to have their performance affected by application to resin poor systems.

High build epoxies are typically formulated with a mixed solvent system that allows compatibility and adhesion to most existing systems. The main component is normally an

aromatic hydrocarbon with some strong oxygenated solvents. This allows softening of most thermoplastic systems to achieve maximum adhesion. This type of solvent system, though formulated to be moderate, can be too strong when topcoating aged oxidizing systems and cause lifting or wrinkling. It is recommended that a test patch be applied to test for this problem. The coefficient of expansion is moderate and this property should not cause problems in topcoating most systems.

System B has good compatibility with most resin systems and should give good performance over poorly prepared metal substrates. It is a high build system that has excellent barrier properties and should provide good performance over existing systems that contain soluble components. The performance of this system when exposed to sunlight is fair, as epoxy will chalk and yellow in ultraviolet light. The aluminum pigmentation improves this property but it will not perform as well as other topcoats such as silicone alkyds, acrylics, or polyurethanes.

System C: Calcium Sulfonate Modified Alkyd

The main constituent of the resins in these coatings is calcium sulfonate. This improves the barrier and corrosion resistance properties of the resin system over typical alkyds. However, it also produces a soft film that is not suitable for areas that have mechanical wear or abrasion. The wetting properties of this system are excellent and provide good performance over poorly prepared surfaces and compatibility with most existing systems. The pigment volume concentration of this type of system is low or it contains no pigment. Consequently, performance is not affected by application to resin poor substrates.

The solvent system is typically made up of only aliphatic hydrocarbons. This solvent system is compatible with most oxidizing resin systems and should not lift or wrinkle such systems. This solvent system will not in many cases soften existing thermoplastic or thermoset systems. Ideally, these existing systems should be roughened prior to application of the repair system. It is recommended that a test patch be applied to such existing systems. Calcium sulfonates will provide little chemical bonding with existing topcoats but will form chemical bonds with metallic substrates.

System C is applied in a single coat at 0.254 to 0.356 mm (10 to 14 mils) as multiple coats may not adhere to one another. This system should have good compatibility with most existing systems, has good barrier properties, and should provide good performance over poorly prepared metal substrates. It will have good performance on exposure to sunlight, as it contains only a small amount of alkyd resin that may chalk and yellow.

System D: Two-Coat Waterborne Acrylic

Waterborne resins used in industrial environments are generally based on acrylics. These systems are thermoplastics and are normally compatible with most other resin types. This type of resin does not offer the level of barrier protection that most thermoset materials can, but generally the barrier properties are greater than those offered by unmodified oxidizing resin systems. These coatings are applied at moderate film thickness.

Waterborne primers are pigmented to a moderate pigment volume concentration. To improve corrosion resistance they may contain an inhibitive pigment such as zinc phosphate. Topcoats are pigmented at a low pigment volume concentration and typically have a smooth semi-gloss appearance. Both the primer and topcoat can be applied to resin poor systems without affecting performance.

The solvent system is mainly water with a co-solvent for coalescing the resin film. The co-solvent is generally a glycol ether with a slow evaporation rate and is designed to remain partially in the film after the majority of the water has evaporated. This allows the film to coalesce and also soften many types of existing coatings. However, existing thermoset systems should be roughened prior application of this type of repair system as they may not be softened. Water has a high surface energy and does not wet surfaces well, so these coatings contain surfactants in combination with the co-solvent to improve the wetting characteristics of the coating. As a result the penetration properties of these coatings may not be as good as the solvent based systems.

System D is compatible with most existing systems and should perform well as a repair system. It can be applied to poorly prepared metal substrates and has reasonable barrier properties. It will have excellent performance when exposed to sunlight as acrylics have good resistance to ultraviolet light.

System E: Aluminum Moisture–Cure Polyurethane/Aliphatic Polyurethane

Aluminum moisture-cure polyurethanes are high solids, low to moderate build coatings. The urethane resin cures by reaction with moisture in the air. It forms a film of high cross link density with good barrier properties. This resin system has good wetting properties, and is compatible with most types of existing systems as well as poorly prepared metallic substrates. This resin type has functionality that can form chemical bonds with many existing systems. This particular system is pigmented with aluminum to a moderate pigment volume concentration to improve barrier properties. Its performance will not be affected by application to resin poor systems.

The solvent system is primarily made up of aromatic hydrocarbons though it can contain small amounts of oxygenated solvents. This solvent system is compatible with oxidizing resin systems and is generally not strong enough to lift or wrinkle such existing systems.

System E is applied with a prime coat of moisture-cure polyurethane followed by two coats of aliphatic polyurethane topcoat. The system is compatible with most existing systems and should perform well over poorly prepared metallic substrates. It has excellent barrier properties and will give good performance over existing systems with soluble components. The aliphatic polyurethanes have good resistance to ultraviolet light, so this system should provide excellent performance on exposure to sunlight.

System F: Epoxy Mastic/Aliphatic Polyurethane

The high build epoxy coating is similar to the high build epoxy aluminum coating described earlier, except that the aluminum pigment is replaced with a combination of extender pigments to provide barrier performance. This allows the formulation of various colors and finishes. These high build epoxy coatings will wet poorly prepared substrates, should provide good adhesion, and should provide corrosion protection of metallic substrates.

The high build two component polyurethanes are formulated with flexible resins and have moderate coefficients of expansion. Polyurethane resin systems are compatible with most existing systems and have functionality that can form chemical bonds with many resin systems. Polyurethanes are highly cross linked films that have good barrier properties. Like the high build epoxies, they are normally formulated with mixed solvent systems; however, they generally contain higher levels of strong oxygenated solvents and smaller quantities of aromatic hydrocarbons.

System F has good compatibility with most resin systems and should provide good performance over poorly prepared metal substrates. It is a high build system and has excellent barrier properties. The system should provide good performance over existing systems that contain soluble components. The performance of this system when exposed to sunlight will be excellent, as urethanes have good resistance to the effects of ultraviolet light.

APPENDIX II. GUIDELINES FOR MAINTENANCE PAINTING BY OVERCOATING

The following recommends practices for maintenance painting of bridge structures using overcoating. The recommended practices are drawn primarily from FHWA research studies. These guidelines are a synopsis. The reader is referred to the subject report or industry standards for more detail.

Maintenance painting is any application of paint to a previously painted structure with the goal of improving the appearance or corrosion-resistance of the existing paint system. *Overcoating,* a subset of maintenance painting, is generally defined as recoating with minimal surface preparation over nonuniform surfaces that may include prepared bare steel, mill scale, tightly adherent rust, or remaining coating. The remaining coating may include small coating "islands" within prepared areas of steel, or broad expanses of "intact" coating. This guide is not intended to reflect the recommended procedures for recoating when completely removing old coatings through abrasive blasting or extensive hand-tool cleaning.

Overcoating has increased in popularity in recent years and even become the primary maintenance painting choice for some agencies. This has occurred due to: (1) increasing costs associated with removal of hazardous (lead-containing) existing coatings, and (2) fixed annual maintenance budgets.

This increase in overcoating has spawned several questions concerning optimal overcoating practices. The answers to these questions affect the real cost advantage of overcoating, the expected performance of overcoating systems, and procedures to minimize the risks associated with the process. Substantial questions include:

1. **How does an engineer determine if a particular structure is "overcoatable?"**
2. **What surface preparation should be specified?**
3. **What type of coating system should be specified and how should it be applied?**
4. **What performance life should be expected from my overcoat?**

Answers from the Research Program

1. How does an engineer determine if a particular structure is "overcoatable?"

Overcoating is the lowest initial cost maintenance painting strategy currently used on bridges. It is not necessarily the lowest life-cycle cost strategy. The judicious use of overcoating can save agencies considerable portions of maintenance budgets. It also allows for more repainting (i.e., total ft^2) in a given year. However, overcoating carries some risk of poor performance. An assessment of the structure must be conducted prior to specifying overcoating. This assessment should include:

- **Evaluate the severity and distribution of corrosion on the structure**

The most common failure mode for overcoating in the current program was through-film rusting after only 6 months to 1 year of service. This type of failure occurred in areas where existing coatings had failed and *heavy corrosion, pack rust,* or *pitted steel* were painted over. Even after low pressure water washing and power-tool cleaning, these areas remain contaminated. Even "surface tolerant" coatings failed after short periods in these areas. *Areas with significant metal loss, pack rust, or heavy pitting represent a high risk of early rusting failure for overcoating. An agency should not expect more than 2 years of service in such areas. Realize that overcoating will not mitigate active (pack rust) corrosion in faying surfaces.*

Structures with localized, definable areas of high-corrosivity (e.g., under joints, drainage areas) can often be painted with good performance after more intensive surface preparation. Then overcoating, as defined herein, can be used for the remainder of the structure. This approach is often called *Zone Painting*. Zone painting can result in low overall maintenance costs with good corrosion control performance.

- **Evaluate the adhesion of the existing coating system**

Prior to specifying overcoating, the adhesion of the existing paint must be assessed. Adhesion can be measured in two ways. Cross-cut adhesion (ASTM D3359, method A) or pull-off adhesion (ASTM D4541) provide a measure of adhesion and can easily be performed in the field. It is difficult to define a "magic number" for adhesion of the existing coating that ensures it is acceptable for overcoating; however, the subject research program did not observe disbondment failures for existing coatings with pull-off adhesion strengths above 200 psi. Using the cross-cut method, if the coating is easily peeled off with an inspection knife, or if it tends to crumble away from the steel as the cuts are made, it probably represents a high risk to overcoat. Certainly, if the coating is peeling from the structure on its own, adding the weight of an overcoating may only cause it to peel more.

- **Evaluate the environment of the structure**

Structures in harsh marine or industrial environments, or structures which receive heavy deicing salt applications in winter are less likely candidates for overcoating. Coating systems for severely corrosive environments almost always require more surface preparation than is generally used in overcoating jobs.

- **Consider the age and history of the structure.**

While not exhaustivly studied in the current program, structures that have been overcoated several times, with ever-increasing film builds subjected to oxidation and repeated thermal or mechanical stresses probably pose an increased risk. In the current program, the maximum film thicknesses overcoated were 24 mils, were about 20 years old, and had a maximum of two previous recoats.

- **Consider the consequences of failure.**

When considering overcoating, think about the cost of failure. If the structure is a simple overpass bridge, the net effect of some paint failure many not be that significant and may be repaired at little cost. For a highly complex suspension/truss bridge, where repainting costs are dominated by logistics, traffic control/restrictions, etc., the potential effect of failure is significantly more. Thus less risk should be tolerated on complex structures.

2. What surface preparation should be specified?

Most successful overcoating jobs involve the use of two basic surface preparation steps: water washing (or steam cleaning in some cases) and mechanical tool surface cleaning. The primary variable to specify in the washing step is pressure. Higher pressures tend to remove more contamination from the surface. The key is to find a sufficient pressure to clean dirt, debris, and loose rust and paint from the surface while leaving intact, adherent existing paint. The subject research program used a 900 to 1000 psi pressure washer. This should be viewed as a minimum. Other bridge research has found that increasing the pressure to 3000 to 5000 may reduce the risk of failure by removing more marginally adherent existing paint.

For mechanical tool surface cleaning of the substrate, a variety of specifications are available. As discussed earlier, in highly corrosive areas the best reasonable practices with hand-tools will not be sufficient to provide an owner with long-term coating life. If the existing steel is heavily corroded or pitted with packed-rust, suggesting frequent exposure to a highly corrosive electrolyte, the coatings applied over SP-3/SP-11 surfaces may only last for 2 years before the coating has again "failed" (i.e., ASTM D 610 rating <7). Usually, this level of performance will be uneconomical on a life-cycle basis exceeding five years. Such areas should be completely cleaned, abrasive blasted (SP-10), and coated with a high performance coating system in order to obtain the best return on the coating investment.

By eliminating the most corrosive areas as overcoating candidates, one focuses on the less corrosive areas where paint deterioration is largely a cosmetic problem; the local environment is not very corrosive. (On many bridges, such areas constitute the majority of the surface area so considerable costs savings are still available.) In the less corrosive areas, power tool clean the visible surface rust and feather loose paint edges. Specifying SSPC SP-3 (power-tool cleaning) is most common; however, SSPC SP-11 (power-tool cleaning to bare metal) specified in the bare steel and corroded areas provides a higher level cleanliness. (Note: specifying SSPC SP-11 for large areas of a structure is often impractical due to the labor intensive nature of this process). In the current program, SP-11 did not offer a significant advantage over SP-3 in the more benign areas.

3. What type of coating system should be specified and how should it be applied?

There is certainly not one coating system that is superior for overcoating performance. Better performing systems included moisture-cured urethane, alkyds, and sealer/epoxy systems. Given the similar, yet not perfect, performance of a variety of coating types in similar exposures, one may conclude that factors other than coating chemistry are more important to complete performance for the better systems. An owner's time is better spent concentrating on adequate surface preparation techniques than selecting the "best-of-the-best" coatings.

The research program clearly shows that multiple coat, high build systems offer an advantage in the most corrosive environments, e.g., expansion joints with packed-rust. However, this advantage is not sufficient to provide long term (>2 years) service with overcoating. This advantage is not significant in more benign areas over the test period. Longer-term, the advantages observed in the more corrosive areas may also appear in the more benign areas. Prudence suggests using multi-coat (2-3 coat) systems exceeding 0.203 mm (8 mils) dry film thickness.

A patch test is highly beneficial to the selection of the best overcoating system. At a minimum, the patch test should be applied by your intended field practices to a 10 ft^2 area in the more corrosive areas of the bridge structure. The system should be allowed to weather at least six months and through at least one winter season.

The following table summarizes of the corrosion control performance of each field test system.

System Number - Description - Manufacturer	ASTM D610 Ratings/Location, nominal 2-year exposure								
	A	B	C	D	E	F	G	H	I
1 - 3-coat WB acrylic - Con-Lux	4	8.5	9	10	9	9.5	6.5	7	10
2 - 3-coat WB acrylic - Berkley Prod.	4	9	9	10	8	9.5	5.5	6	10
3 - 3-coat MCU - Wasser Coatings	6	8.5	9.6	10	10	10	9	8	10
4 - epoxy/polyurethane - Devoe Ctngs	5	8.5	9	10	8.25	8.5	7	7	10
5 - sealer/epoxy/polyurethane - Devoe Coatings	4	8	9.6	10	9.25	10	9	7	10
6 - sealer/Al-epoxy/Al-alkyd - Carboline	5	9	9.6	10	10	10	9.5	8	10
7 - calcium sulfonate alkyd - CPC Corp.	5	7.5	9.5	10	8.25	8.5	7	5	9.8
8 - oil-alkyd/oil-alkyd/Si-alkyd - Con-Lux	5	8.5	9.6	10	10	10	9	5	10
9 - epoxy polysiloxane - Ameron	4	5.5	8.3	10	8	8	5.5	5	7.4
10 - MCU/polyurethane - Tnemec	6	8.5	8.3	10				7	9.8
11 - WB epoxy/WB acrylic - Sherwin Williams	4	5	5.7	9.6	7.5	8	5.5	3	8.8
12 - 3-coat MCU - XymaX Coatings					10	10	10	7	10
13 - 2-coat oil-alkyd - Keeler & Long			9	10				7	9.6
14 - 3-coat oil-alkyd - Keeler & Long			9.5	10					
15 - higher VOC, 2-coat MCU - Superior Protective Coatings					9	10	8		
16 - 2-coat WB acrylic - Sigma / Rohm and Haas					8	8	7		

Location Key:
A - Chicago, IL - expansion joint
B - Chicago, IL - facia girder
C - New York City - box beam exterior
D - New York City - box beam interior
E - Manchac, LA - bridge interior girder
F - Manchac - bridge facia girder
G - Manchac - test beams
H - Allenstown, NH - expansion joint
I - Allenstown, NH - truss members

Note: Specific product names are included above for information. Performance of coating systems has clearly been shown to be formulation specific. General trends regarding performance of generic classes of coatings should only be inferred with the knowledge that performance of different products within generic classes often varies widely.

4. What performance life should be expected from my overcoat?

It is critical to determine the expected service life of the overcoat to formulate a cost-benefit analysis of the overcoating process vs. other maintenance painting options. The subject program only exposed coatings for two to three years, so long term performance data is not directly available. The most reasonable predictions for coating performance can be made using research results for coatings applied over less than ideal surfaces. In the current program, two basic failure modes were observed: (1) failure due to coating chemical or mechanical incompatibility, and (2) through-film rusting over less-than-ideal, bare steel or rusted surfaces. Failure mode (1) can be addressed through the use of test patches to avoid early incompatibility failures. Failure mode (2) can be predicted based on patch or panel testing of coatings over similar surface preparations in similar environments. Such testing has shown that coatings designed to be "surface tolerant" do often provide some performance benefit over less-than-ideal surface preparations; however, this advantage is never equal to the benefit gained from obtaining a truly clean abraded surface using abrasive blasting, particularly in more severe exposures.

In less severe environments, overcoating applications may provide many years (e.g., 10+ years) of service; however, in salt-rich environments, testing results indicate that even the most successful overcoating applications may only provide 2 years of performance.

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