Research Report
KTC 96-7

Environmentally Safe Protective Coatings for Steel Structures-New Construction and Maintenance Painting

by

Theodore Hopwood, II
Transportation Research Engineer

and

Christopher M. Oberst
Former Transportation Research Technician II

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

in cooperation with
Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
U.S. Department of Transportation

March 1996

Commonwealth of Kentucky
Transportation Cabinet
Frankfort, Kentucky 40622

Fred N. Mudge
Secretary of Transportation

Paul E. Patton
Governor

May 7, 1996

Mr. Paul E. Toussaint
Division Administrator
Federal Highway Administration
330 West Broadway
Frankfort, Kentucky 40601

SUBJECT: Implementation Statement
Research Study KYSPR 92-140
"Environmentally Safe Protective Coatings for Steel Structures"

Dear Mr. Toussaint:

Under this study, Kentucky Transportation Center (KTC) researchers assisted KYTC officials in identifying environmentally compliant protective coatings systems for steel bridges for both new construction and maintenance painting. They conducted a series of laboratory and field tests to identify suitable coatings systems and application procedures for maintenance painting by over coating. As part of this study, KTC researchers actively participated in the KYTC experimental overcoating program. They also monitored overcoating projects on 18 bridges to determine the performance of experimental coatings systems and application specifications. KYTC and KTC researchers formed a team to oversee all aspects of the experimental overcoating program and to ensure its success.

The study has met the stated objectives of the study work plan. KTC researchers have assisted KYTC in a difficult transition in maintenance painting procedures from total removal of existing lead paints by open abrasive blasting to the more environmentally safe overcoating method. The value of KTC work conducted under this study may be measured by the fact that the KYTC experimental overcoating program is recognized nationally as being highly innovative and successful.

Sincerely,

J. M. Yowell, P.E.
State Highway Engineer

c: W. Crace

Technical Report Documentation Page

1. Report No. KTC-96-7	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Environmentally Safe Protective Coatings for Steel Structures - New Construction and Maintenance Painting		5. Report Date March 1996
		6. Performing Organization Code
7. Author(s) T. Hopwood, II and C. M. Oberst		8. Performing Organization Report No. KTC-96-7
9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506-0281		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. KYSPR-92-140
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, KY 40622		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code 4E4A0222

15. Supplementary Notes

Prepared in Cooperation with US Department of Transportation, Federal Highway Administration
Study Title: Environmentally Safe Protective Coatings for Steel Structures

16. Abstract

The purpose of this study was to: 1) assist KyTC in identifying protective coatings for structural steel that would meet current and pending environmental regulations, and 2) to evaluate overcoating procedures that would be cost-effective and provide regulatory (OSHA and EPA) compliance.

A coatings research program was conducted that included: 1) laboratory accelerated corrosion/weathering tests, 2) field exposure tests, and 3) experimental maintenance painting of entire bridges by overcoating. Each of those tasks was intended to address different issues. Regulations concerning volatile organic compound limits for coating systems used in new construction were studied and recommendations provided to KyTC on new systems that would provide potential advantages in application and performance.

The laboratory testing was used to evaluate seven candidate overcoating systems and three new construction coatings systems. Field exposure tests consisted of coatings patches applied to bridges and scrap steel. Those tests provided useful information concerning the durability of candidate maintenance coatings and the practicality of experimental application procedures. Eighteen complete bridge maintenance painting projects were conducted the KyTC experimental overcoating program that employed experimental specifications and coatings system. Those projects were inspected prior to, during and subsequent to completion. Long-term performance of most projects has been very good.

17. Key Words Bridges, Coatings, Environment, Lead paint, Steel, Containment, Overcoating, Worker Safety	18. Distribution Statement Unlimited, with approval of the Kentucky Transportation Cabinet

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	58	

Form DOT 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY

Background

Environmental Protection Agency (EPA) and Occupational Health and Safety (OSHA) regulations are becoming more restrictive in the amounts and concentrations of particular materials that may be released into the environment by shop (new construction) and maintenance painting of structural steel. Those restrictions have caused coatings manufacturers and facility owners to discontinue the production and use of structural steel (bridge) coatings containing potentially harmful materials such as lead and high amounts of volatile organic compounds (VOCs). Coating manufacturers have developed many new environmentally compliant coatings but, most of them have not been evaluated to assure satisfactory performance on Kentucky bridges.

Coatings and application practices will continue to evolve due to a spate of new Federal laws and regulations. The resultant impacts of those laws and regulations have been to: 1) further change or restrict use of certain paint systems, 2) increase worker awareness of, and compliance with, regulations impacting the painting of structures (especially those with existing lead-based paints), 3) lead to the revision of field painting practices involving the generation of hazardous wastes, and 4) create more economic pressures related to both new construction and maintenance painting.

Lead is the most prevalent hazardous (toxic) component in existing paints on bridges in Kentucky and nationwide. As a consequence, lead paints have been a major focus of regulatory agencies and the primary concern of Kentucky Transportation Cabinet (KyTC) officials related to bridge maintenance painting. Lead paints were last employed on KyTC bridges in the early 1980s. However, of the approximately 3,300 steel bridges in Kentucky, 2,700 are believed to be still coated with lead paints. Most of those existing coatings are at least 20 years old. A majority of the KyTC bridges requiring maintenance painting are coated with lead paints.

In recent years, environmental and worker safety regulations have significantly effected KyTC maintenance painting operations on bridges with lead paint. Those regulations mandated extensive revision of painting practices to prevent discharges of pollutants such as lead or chromates into the atmosphere and to ensure worker and public safety. The new procedures included the containment, collection, storage, transport and eventual disposal of abrasive blasting wastes. Worker and public safety regulations include elaborate controls such as air monitoring, decontamination trailers and respiratory protection. The bottom line is that KyTC maintenance painting costs have increased significantly with no corresponding gain in coatings service performance.

In 1990, KyTC officials sought a more economical approach to bridge maintenance painting that would comply with regulatory mandates. The practice of painting over existing lead paint (i.e. overcoating) offered the advantages of minimal hazardous waste generation and low project costs. KyTC officials recognized the need to establish an experimental overcoating program that would ensure environmental compliance in Kentucky and that would be proactive in selecting coatings and applications practices to

assure continuing compliance with evolving regulatory mandates. The need to identify environmentally compliant coatings for new construction became more pressing as fabrication shops providing bridge steel to KyTC came under new regulations that limited VOC releases from painting operations. The VOC content in coatings assumed greater importance when it led to discontinuance of the vinyl coatings commonly specified for KyTC new construction.

KTC Coatings Research Program

To address problems created by the volatile regulatory climate, KyTC contracted with the Kentucky Transportation Center (KTC) to conduct this SPR study to evaluate structural steel coatings for new construction and to assist in developing effective, low-cost methods for bridge maintenance painting. Emphasis was placed on overcoating since it was the most pressing KyTC painting activity.

Two primary KyTC concerns related to the coating selection process were: 1) to determine which overcoating coatings systems could be best applied directly over existing lead-based paints precluding blast cleaning and hazardous waste generation, and 2) to identify application practices specific to those coatings that would provide long-term service, reasonable life-cycle costs, and regulatory (EPA and OSHA) compliance. The consideration of coatings for new construction was addressed as a secondary issue.

The coating selection process was opened to consider all generic paint types, and combinations thereof, that would comply with EPA regulations and would otherwise prove suitable for bridge use according to the application procedures selected.

A test program was developed by KTC researchers to evaluate experimental coating systems and application practices. The test program included: 1) laboratory tests, 2) field exposure tests, and 3) experimental maintenance painting of entire bridges by overcoating. Each of those tasks was intended to address different issues.

The laboratory testing consisted of accelerated corrosion/weathering tests of candidate coatings systems. Results of those tests were to be correlated with long-term exposure results from paint test patches applied in the field and with the long-term performance of experimental maintenance painting projects. Those tests were intended for initial screening purposes and for comparative evaluations of different coating systems.

Field exposure tests were comprised of paint test patches applied to existing bridges or scrap bridge steel to investigate maintenance painting by overcoating. They were employed for determining coatings application characteristics, evaluating experimental surface preparation/application methods and for assessing the long-term performance of candidate overcoating systems. The test patches were allowed to weather naturally and were evaluated annually.

Experimental overcoating projects were intended to investigate performance of specific coatings systems subject to variables such as: 1) initial service condition, 2) surface

preparation, 3) structural details, and 4) contractor application variables. During coating application, insight could be obtained concerning the practicality of experimental application specifications and the suitability of some coating systems from an operational standpoint. However, the performance of most of the coatings could only be determined after several years of service. The results of those projects were considered the most important factors for standardizing painting specifications and adopting specific coating systems for routine use.

Study Accomplishments/Findings

In 1992, KTC researchers surveyed fabrication shops, other state highway agencies and parties involved in the EPA VOC rule-making process. That effort was conducted to: 1) ascertain current VOC restrictions impacting the shops, 2) determine anticipated VOC limits in forthcoming regulations and 3) identify practical coatings systems that would conform to present VOC regulations and that would remain usable into the foreseeable future.

Based upon communications with fabrication shop and state highway agency officials, it was determined that a coatings VOC limit of 420 g/l (3.5 lb/gal) would be permissible in most fabrication shops. Specifications and qualified products lists for multi-coat systems were obtained from other state highway agencies. A future problem was anticipated in that future VOC limits for field applied coatings would probably be regulated at 340 g/l (2.8 lb/gal). That limit would eventually impact the shop coatings by requiring the same VOC content for technical reasons. KTC researchers also participated in an investigation of a coatings problem on new construction steel for the US 27 bridge at Covington. That failure was due to curing problems with inorganic zinc primers that employed a three-coat system (inorganic zinc/epoxy/polyurethane) used on that bridge. KTC researchers identified similar three-coat systems with a 340 g/l (2.8 lb/gal) VOC content that promised better shop handling, and with two-shop coats, would provide superior abrasion-resistance and recoating characteristics.

KTC researchers performed accelerated laboratory tests on seven overcoating systems and three coatings for new construction. Those coatings were provided by several different manufacturers. The test results indicated a need to revise the laboratory test program.

Field exposure tests were performed on seven bridges most of which were in the Louisville area. More extensive tests were performed on scrap steel beams and the KyTC Bailey Bridge Yard at Frankfort. Twenty-nine different coatings systems were tested there employing experimental application procedures. Those tests were helpful in identifying workable overcoating specifications and screening candidate coatings systems for eventual inclusion in the KyTC experimental overcoating program.

The KyTC experimental overcoating program encompassed all maintenance painting projects conducted between 1992 and 1995. Those projects entailed overcoating using experimental specifications and coating systems. KTC researchers recommended the

candidate coatings systems and assisted in specification preparation. They also conducted field inspections of the experimental projects prior to, during application and after completion. KyTC officials and KTC researchers reviewed the results of each experimental overcoating project. They continuously revised the experimental specifications and selection of candidate coatings systems to reflect their findings.

Ten first-phase overcoating projects were performed between 1992-4 encompassing 10 bridges. They incorporated hand tool mechanical surface preparation, power washing and application of multi-coat paint systems. The paint systems commonly consisted of a spot primer, a full intermediate coat and a full topcoat. Different coatings were used on each bridge. Each coatings system was supplied by a single manufacturer.

The bridges being overcoated varied in type, size and condition of the existing coating. Some minor problems were encountered with contractor application. Overall, most of the completed projects met the expectations of KyTC and KTC personnel. Long-term monitoring of the completed projects indicated that six of the projects were performing well. Two projects experienced minor disbonding failures of the coatings due to the combined effects of the overcoating systems employed and cold temperatures which created the stresses that lead to disbonding. One project experienced several spot failures attributed to improper surface preparation. Another project was performing well. However, its appearance was diminished by rust bleed from joints.

Four initial second-phase overcoating projects were performed between 1993-5. Specifications for those experimental projects differed from the earlier ones. Hand tool mechanical surface preparation was eliminated and the number of coats of paint was reduced. Those changes resulted from the enactment of the OSHA Final Interim Lead Rule. The coatings were commonly applied by spraying to minimize overcoating costs. The projects were completed successfully. Long-term monitoring revealed incipient failures at a few locations on all of the bridges. The cosmetic appearance of one bridge decreased dramatically due to rust bleed. On the whole, those projects were performing relatively well despite the overall lack of surface preparation prior to painting.

Four follow-on second phase overcoating projects were performed between 1994-5. Those projects differed from the initial second-phase projects primarily in the use of penetrating sealers or very surface-tolerant coatings and in the requirement for brush application of all coatings placed directly on existing alkyd paint though spraying was allowed in subsequent topcoats. Hand tool cleaning was only permitted one as the existing paint was not contain lead. The projects were all completed successfully. Long-term monitoring revealed that the projects were generally performing well. One bridge experienced a number of small spot corrosion failures. Otherwise, no major problems were observed.

Conclusions

Research related to new coatings did not provide any significant changes though KTC researchers accumulated significant knowledge that will be useful in addressing that

matter in the future. Division of Construction officials and KTC researchers have agreed upon future experimental coating systems.

The first-phase experimental overcoating projects achieved one prime KyTC objective by providing low initial costs which were estimated to range from \$10 to \$32 per m^2 (\$0.93 to \$3.27 per ft^2. The initial second-phase overcoating projects were also deemed successful in achieving low maintenance painting costs. It was difficult to determine the unit costs for the initial second-phase projects since they involved other bridge rehabilitation work. It is estimated that they were in the same cost range as the first-phase projects. In part, that was due to contractor unfamiliarity with the experimental specifications.

The follow-on second-phase KyTC experimental overcoating projects continued to provide low maintenance painting costs. The resulting project unit costs for US 42 and US 31W bridges were approximately \$ 13.34/m^2 and \$25.18/m^2 (\$1.24/ft^2 and \$2.34/ft^2), respectively. Those low unit costs indicate that the current KyTC approach to bridge maintenance painting is effectively containing maintenance painting costs. KTC researchers have been appraised that the KyTC experimental overcoating project costs are as low as any obtained by other state highway agencies throughout the US.

The KyTC experimental overcoating program is, of necessity, a reactive one that must respond to the dictates of environmental and worker protection regulatory agencies and will also evolve in response to new regulations. The program will also respond to internal needs such as improving field inspection and attracting quality-oriented contractors. KyTC will continue to develop and adopt innovative approaches to achieve cost-effective, environmentally-compliant maintenance painting of steel bridges.

METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO METRIC UNITS					APPROXIMATE CONVERSIONS FROM METRIC UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in.	inches	25.40000	millimetres	mm	mm	millimetres	0.03937	inches	in.
ft	feet	0.30480	metres	m	m	metres	3.28084	feet	ft
yd	yards	0.91440	metres	m	m	metres	1.09361	yards	yd
mi	miles	1.60934	kilometres	km	km	kilometres	0.62137	miles	mi
		AREA					**AREA**		
$in.^2$	square inches	645.16000	millimetres squared	mm^2	mm^2	millimetres squared	0.00155	square inches	$in.^2$
ft^2	square feet	0.09290	metres squared	m^2	m^2	metres squared	10.76392	square feet	ft^2
yd^2	square yards	0.83613	metres squared	m^2	m^2	metres squared	1.19599	square yards	yd^2
ac	acres	0.40469	hectares	ha	ha	hectares	2.47103	acres	ac
mi^2	square miles	2.58999	kilometres squared	km^2	km^2	kilometres squared	0.38610	square miles	mi^2
		FORCE					**FORCE**		
kip	pound-force	4.44822	kilonewton	kN	kN	kilonewton	0.22481	pound-force	kip
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57353	millilitres	ml	ml	millilitres	0.03381	fluid ounces	fl oz
gal.	gallons	3.78541	litres	l	l	litres	0.26417	gallons	gal.
ft^3	cubic feet	0.02832	metres cubed	m^3	m^3	metres cubed	35.31448	cubic feet	ft^3
yd^3	cubic yards	0.76455	metres cubed	m^3	m^3	metres cubed	1.30795	cubic yards	yd^3
		PRESSURE					**PRESSURE**		
psi	pound-force per square inch	6.89476	kilopascal	kPa	kPa	kilopascal	0.14504	pound-force per square inch	psi
		MASS					**MASS**		
oz	ounces	28.34952	grams	g	g	grams	0.03527	ounces	oz
lb	pounds	0.45359	kilograms	kg	kg	kilograms	2.20462	pounds	lb
T	short tons (2000 lb)	0.90718	megagrams	Mg	Mg	megagrams	1.10231	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	(°F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	(1.8C) + 32	Fahrenheit temperature	°F

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ACKNOWLEDGMENTS

The authors would like to thank the members of the Study Advisory Committee for their efforts related to this study. They took time from busy schedules to assist in preparation of this report and in periodic review of the study's progress. The Study Advisory Committee members were W.A. Crace, Don Herd, Bob Banta, J.R. Lile, Scott Kring, Steve Goodpaster, Marcie Mathews and Barbara Kelly of the Kentucky Transportation Cabinet and Ray Greer of the Federal Highway Administration.

INTRODUCTION

Background

Environmental Protection Agency (EPA) and Occupational Health and Safety (OSHA) regulations are becoming more restrictive in the amounts and concentrations of particular materials that may be released into the environment by shop and maintenance painting of structural steel. The regulated materials are considered harmful to the environment, workers and the general public. Those restrictions have caused coatings manufacturers and facility owners to discontinue the production and use of structural steel (bridge) coatings containing potentially hazardous materials such as lead and chrome. Further EPA restrictions on volatile organic compounds (VOCs) contained in those coatings are having a similar effect on generic coatings such as vinyls and chlorinated rubbers.

To address those constraints, coating manufacturers have developed or are developing many new environmentally compliant coatings for structural steel. At the onset of this study, most of them had not been evaluated sufficiently to assure satisfactory performance on Kentucky bridges.

Coatings and application practices will continue to evolve due to a spate of new Federal laws and regulations including: the 1990 Amendments to the Clean Air Act, the OSHA Final Interim Lead Rule and, possibly, EPA Title X. The resultant impacts of those laws and regulations have not been completely established but, in the main, they are expected to: 1) further change or restrict use of certain paint systems, 2) increase worker awareness of, and compliance with, regulations impacting the painting of structures (especially those with existing lead-based paints), 3) lead to the revision of field painting practices involving the generation of hazardous wastes, and 4) create more economic pressures related to both new construction and maintenance painting. It is anticipated that Federal regulatory agencies will continue to press for more stringent regulations. That assumption is supported by the recent unsuccessful attempt by the EPA to regulate zinc as a hazardous waste.

Review of Past KyTC Bridge Coatings

The impetus and direction of this study is best understood by a review of Kentucky Transportation Cabinet (KyTC) coatings and application practices for steel bridges prior to the onset of this study. Due to the significant age of many of those structures and to the durability of structural coatings in Kentucky, a review encompassing many years is appropriate.

<u>Lead-Based Alkyd Coatings</u> - Most steel bridges built in Kentucky were originally painted with drying-oil and alkyd paints. Lead was commonly used as a pigment in those paints functioning both as a drier and a

corrosion inhibitor (2). The earliest paints on Kentucky bridges employed boiled linseed oil mixed with lead oxide (white lead primer). The 139 year-old the Roebling suspension bridge at Covington originally employed that primer inside its original main cables and suspender ropes.

In the 1940s, Kentucky Department of Highways steel paint specifications included red, white and blue lead-based alkyd primers (3). Aluminum and lead-pigmented alkyds were specified for topcoats. Subsequent Kentucky Department of Highways specifications for alkyd paints and/or primers conformed to Federal specifications TT-P-141 and, later, TT-P-615, Type II for the basic-lead-silico-chromate (BLSC) primer (4,5). Non-leafing and leafing aluminum-pigmented alkyd paints were commonly employed as intermediate- and topcoats over the latter primer. Those coatings did not contain significant quantities of lead.

For new construction, a shop coat of red lead primer was usually applied directly over untreated mill scale found on the surface of structural steel. The red lead primer wetted out well on the slick mill scale surface and yielded a very adherent coating. The primed steel was topcoated after erection.

Until the adoption of other coatings, bridge maintenance painting entailed hand tool cleaning of substrates followed by the application of fresh paint, typically a red primer and one or two alkyd topcoats. That form of maintenance painting is termed overcoating. Many older steel bridges throughout Kentucky have been repeatedly overcoated and some coatings have thicknesses exceeding 1,000 microns (40 mils). The wetting properties of lead paint enhanced its performance in overcoating applications.

One KyTC bridge maintenance painting project incorporated both abrasive blasting and recoating with lead paints. In 1980, the I-64 twin bridges over the Kentucky River in Franklin County were abrasive blasted 10 feet from bearing areas and deck joints. Those areas were subsequently primed with inorganic zinc. Spot abrasive blasting was used to clean other locations on those bridges. The inorganic zinc primed areas and the balance of the existing lead paint were subsequently overcoated/ topcoated with an alkyd paint.

Lead paints were last employed on KyTC bridges in the early 1980s. However, of the approximately 3,300 steel bridges in Kentucky, 2,700 are believed to be still coated with lead paints. Most of those existing coatings are at least 20 years old. A majority of the KyTC bridges requiring maintenance painting are coated with lead paints. Lead is the most prevalent hazardous (toxic) component in existing paints on bridges in Kentucky and nationwide. As a consequence, lead paints have been a major focus of regulatory agencies and the primary concern of KyTC officials related to bridge maintenance painting.

High-Performance Coatings - In the 1980s, a growing awareness of potential environmental problems with lead paints prompted KyTC officials to begin supplanting them with the so-called "high-performance" inorganic zinc/vinyl and epoxy mastic systems. By the early 1990s, KyTC had completely adopted those coatings. The change in coating types also required adoption of new application practices.

New construction painting using the inorganic zinc/vinyl system began in the early 1980s. In the shop, steel was abrasively blasted to a near-white finish to remove mill scale and to provide with a roughened profile or "tooth" to enhance primer adhesion. After abrasive blasting, the steel received with one coat of an inorganic zinc primer applied by spraying. Upon erection, bridge steel was topcoated with one spray coat of vinyl paint. Some coatings manufacturers required that a mist coat be applied over the inorganic zinc prior to topcoating with the full vinyl coat to prevent problems with bubbling.

The inorganic zinc/vinyl system worked well. During field application, the excellent "dry fall" characteristics of the vinyl allowed unrestricted use of spraying. The use of inorganic zinc/vinyl coatings for new construction continued successfully until 1995, when VOC concerns forced KyTC officials to adopt other systems. That change will be discussed later in this report.

Inorganic zinc/vinyl coatings were first used for maintenance painting in 1979 on the US 62 bridge at Maysville. Maintenance projects involved removal of the existing alkyd paint to the greatest extent possible by open abrasive blasting with disposable abrasives. As the inorganic zinc primer would not adhere to non-blasted substrates, epoxy mastic coatings were used in areas where abrasive blasting was impractical (e.g. inside laced, riveted box beams).

Epoxy mastics are considered the first modern "surface-tolerant" paints intended for application over marginally-prepared surfaces. During the period that inorganic zinc/vinyl systems were widely used for maintenance projects, a few bridges were painted solely with epoxy mastic coatings applied substrates previously prepared by to spot or complete abrasive blasting (6). Epoxy mastics continue to be employed on overcoating projects. Due to past chalking problems experienced by uncoated epoxy, current epoxy mastic applications are used in conjunction with acrylic polyurethane topcoats that possess better weathering properties.

Some 500-600 bridges are currently in service that still employ the inorganic zinc/vinyl and/or epoxy mastic paints. Most of them were painted between 1980 and 1995. While they are less common than lead paints, their numbers include many large bridges including most of the Ohio River bridges.

Effects of Kentucky Weather - Weather can have a significant effect on coating durability. The relatively mild climate in Kentucky has resulted in fewer applications of de-icing salts on bridge decks than in the more northern states. That has minimized chloride-related corrosion problems enhancing the durability of bridge coatings.

Lead paints have exhibited several problems more directly associated with the weather. Those coatings were usually applied on slick mill scale substrates. Extremely cold temperatures will create thermal stresses between the paint and mill scale due to differential thermal expansion. That may result in disbonding failures in which large sheets of paint fall off a bridge. Older steel bridges possessing thick, multi-layered coats of lead paint are particularly prone to that type of failure. In other cases, mill scale may disbond from bridge steel lift the paint. Alkyd resins in lead paint will chalk when exposed to direct sunlight and the paint may gradually weather away if subjected to frequent exposure to wind and rain.

Sunlight causes vinyl topcoats to chalk leading to their discoloration and depletion by weathering. The discoloration problem is most evident on deep colors such as blues and is less evident on grays and greens. Chalking is probably more of a concern with truss bridges where the vinyl topcoat is subject to direct exposure from wind and rain.

Condition of Existing Bridge Coatings - Lead paints on most KyTC bridges remain in good condition with little corrosion except at areas under deck joints or at splash zones on thru-trusses. Paint on thru-truss bridges of riveted construction are probably most deteriorated due to several factors including age, exposure to elements and the consequences of structural complexity.

While most of the inorganic zinc/vinyl projects have performed excellently, chalking problems may require that eventual overcoating to preserve the inorganic zinc primers. The worst-performing examples of that coating system are maintenance projects involving riveted truss bridges that proved difficult to properly abrasive blast. Severe coating depletion and corrosion are most commonly encountered at bearing areas and splash zones.

KyTC Maintenance Painting Projects Incorporating Containment

In recent years, environmental and worker safety regulations have significantly effected KyTC maintenance painting operations on bridges with lead paint. Those regulations mandated extensive revision of painting practices to prevent discharges of pollutants such as lead or chromates into the atmosphere and to ensure worker and public safety. The new procedures included the containment, collection, storage, transport and eventual disposal of abrasive blasting wastes. Worker and public safety regulations include elaborate controls such as air monitoring, decontamination trailers and respiratory protection. The bottom line is that KyTC maintenance painting costs have increased significantly with no corresponding gain in coatings service performance.

In the early 1990s, those regulations began to take effect, forcing KyTC officials to abandon open abrasive blasting for bridge maintenance painting. KyTC officials sought to identify and employ maintenance painting procedures that would comply with environmental and worker safety regulations.

Containment Projects - During that period, two maintenance painting projects were conducted incorporating procedures for complete removal of existing lead paints by abrasive blasting, containment of all debris generated and collection of the debris followed by its disposal as a hazardous waste. One project, the I-75 bridge over the Ohio River at Covington, incorporated wind screens and disposable abrasives (Figure 1). A second project, the US 23 bridge over the Ohio River at Ashland, employed enclosures with impermeable curtains and recyclable steel abrasives. Unit costs for those projects were 3-4 times greater than previous projects using open abrasive blasting.

KTC field inspections conducted at both projects revealed operational deficiencies. At the I-75 bridge, large quantities of dust was observed to be leaking at open seams between the wind screens. Several workers on that project experienced high blood lead levels and citations were issued due to improper handling and disposal of abrasive blasting wastes. At the US 23 bridge, dust leakage was also observed at gaps in the seams. The painting contractor on that project complained about high losses of steel abrasives. However, that problem is usually indicative of poor containment practice.

In reviewing those projects, KyTC officials recognized the need for improved engineering and operational controls. A KyTC-funded HPR study conducted by KTC researchers identified "best available control technology" for maintenance painting incorporating containment (7). That technology included: 1) continuous ambient air monitoring, 2) total containment, 3) impermeable containment walls with negative pressure and 4) use of recyclable abrasives. These practices were expected to increase maintenance painting costs over the previous containment projects. Unit painting costs were anticipated to be in the order of $108-129.^{2} ($10-12/ft2). Those costs were unacceptable to KyTC officials.

Need for Alternative Maintenance Painting Procedures - An immediate effect of the environmental and worker safety regulations on KyTC maintenance painting operations is reflected in the fact that between 1990 and 1994 less than 25 bridges were painted. That low number was not uncommon for state highway agencies during that period. Several highway agencies had completely ceased maintenance painting activities or had entertained bridge replacement as a viable alternative to maintenance painting. KyTC could not long sustain such a meager level of bridge maintenance painting. Even an optimistic maintenance painting life cycle of 20 years requires that some 150 KyTC bridges be painted yearly. Regardless of the approach to maintenance painting, the KyTC funding level would need to increase. It was evident that the regulatory environment would not abate in the future and a major effort was needed to: 1) align maintenance painting costs, 2) bridge painting needs, 3) regulatory constraints and 4) available funds. Low-cost maintenance painting was considered vital to any rational future KyTC maintenance painting program.

In 1990, KyTC officials sought a more economical approach to bridge maintenance painting that would comply with regulatory mandates. By then, several other state highway agencies had reverted to the earlier maintenance painting practice of overcoating. KyTC officials investigated several overcoating projects conducted by the Tennessee DOT and found them to be satisfactory from the standpoints of initial project cost, appearance, performance and, most importantly, regulatory compliance. KyTC officials recognized the need to establish an overcoating program that would ensure environmental compliance in Kentucky and that would be proactive in selecting coatings and applications practices to assure continuing compliance with evolving regulatory mandates.

Kentucky Transportation Center Coatings Research

To address problems created by the volatile regulatory climate, KyTC contracted with the Kentucky Transportation Center (KTC) to conduct this SPR study to evaluate structural steel coatings for new construction and to assist in developing effective, low-cost methods for bridge maintenance painting.

The formal objectives of the KTC study were to:

1) Identify EPA-compliant candidate overcoating coatings systems for use on KyTC bridges.

2) Determine laboratory and field exposure test methods and evaluation procedures for candidate overcoating and new fabrication paint systems.

3) Select field exposure (bridge) sites and characterize their environments in relation to similar bridge sites throughout the state.

4) Perform laboratory tests of candidate paint systems to qualify them

for field exposure testing.

5) Perform field exposure tests of coatings to qualify them for provisional acceptance on experimental bridge applications.

6) Monitor contractor and fabrication shop applications of experimental coatings and evaluate coating performance for eventual acceptance in a KyTC qualified products list.

7) Compare laboratory and field results to assure that viable correlations were being obtained and to seek service performance predictions from laboratory data.

8) Identify alternate coating procedures that offer cost and\or performance advantages over conventional paint systems and coating practices (including overcoating systems).

Research Aims - The study objectives addressed two principle KyTC painting needs: 1) to evaluate overcoating procedures, and 2) to identify low-VOC coatings that matched or exceeded the performance of those currently employed. Emphasis was placed on overcoating as it was the most pressing KyTC painting activity.

Considerable effort was expended on developing overcoating application specifications. That work was considered to fall within the study objectives as the specifications drastically impacted the paint systems employed and as they had to conform with current environmental regulations.

Two primary KyTC concerns related to the coating selection process were: 1) to determine which overcoating coatings systems could be best applied directly over existing lead-based paints precluding blast cleaning and hazardous waste generation, and 2) to identify application practices specific to those coatings that would provide long-term service, reasonable life-cycle costs, and regulatory (EPA and OSHA) compliance. The consideration of coatings for new construction was addressed as a secondary issue. The coating selection process was opened to consider all generic paint types, and combinations thereof, that would comply with EPA regulations and would otherwise prove suitable for bridge use according to the application procedures selected.

KTC Coatings Test Program - The test program was needed to evaluate experimental coating systems and application practices. The program's scope was determined, in part, by a comprehensive survey on highway agency painting practices previously conducted by KTC researchers (1). They concluded that a optimum coatings research program include: 1) laboratory tests, 2) field exposure tests, and 3) experimental maintenance painting of entire bridges by overcoating. Each of those tasks was intended to address different issues.

The laboratory testing consisted of accelerated corrosion/weathering tests of candidate coatings systems. Results of those tests were to be correlated with long-term exposure results from paint test patches applied in the field and with the long-term performance of experimental maintenance painting projects. Accelerated laboratory tests offered the advantage of providing a rapid method for assessing new coating systems for new construction or maintenance painting. Those tests were intended for initial screening purposes and for comparative evaluations of different coating systems.

Field exposure tests were comprised of paint test patches applied to existing bridges or scrap bridge steel. KTC researchers use field exposure tests to investigate maintenance painting by overcoating. The patches would be allowed to weather naturally and were evaluated annually. The performance of the coatings would closely mirror results obtained from the experimental overcoating projects.

When this study began, KyTC officials immediately proceeded with complete experimental overcoating projects. A progressive test program where coatings evaluation would begin with accelerated laboratory tests and, then, field exposure tests would take too long to identify promising coatings systems for experimental overcoating projects. So, the field exposure tests were not initially employed for that purpose. Once the initial backlog of KyTC experimental overcoating projects was addressed, field test patches began to be employed as a screening tool. Early on, however, field tests patches were employed solely for determining paint application characteristics and for evaluating experimental surface preparation/application methods.

Experimental overcoating projects were intended to investigate performance of specific coatings systems subject to variables such as: 1) initial service condition, 2) surface preparation, 3) structural details, and 4) contractor application variables. During coating application, insight could be obtained concerning the practicality of experimental application specifications and the suitability of some coating systems from an operational standpoint. However, the performance of most of the coatings could only be determined after several years of service. The results of those projects were considered the most important factors for standardizing painting specifications and adopting specific coating systems for routine use.

VOC-COMPLIANT COATINGS FOR NEW CONSTRUCTION

Initial Information Gathering

When the study work plan was prepared, KyTC officials requested that KTC researchers investigate the issue of VOC content for coatings used for new construction. KyTC officials were concerned that some fabrication shops bidding on KyTC were being disadvantaged by local VOC restrictions. As the study progressed, that issue became more pressing as several paint manufacturers notified KyTC that they would no longer manufacture vinyl coatings due to their high VOC content [i.e. typically greater than 480 g/l (4 lb./gal)].

KTC VOC-related Coatings Surveys of Fabrication Shops - In 1992, KyTC officials at the Division of Materials surveyed commonly used fabrication shops to determine if they were operating under VOC restrictions. They provided KTC researchers with a list of those shops. KTC researchers also contacted the shops to obtain information concerning current VOC impacts on coatings. KTC researchers also sought to identify anticipated VOC limits and practical coatings systems that would conform to present VOC regulations and remain usable into the foreseeable future.

KTC researchers contacted representatives of 7 fabrication shops. They ranged in size from small shops that only did rolled-beam work to some of the largest bridge fabrication shops in the U.S. including Stupp Brothers Inc. in St. Louis, MO, and High Steel Structures in Lancaster, PA. The shops were located in the Midwest, the Southeast and the Northeast. All of them worked for highway agencies of other states. High Steel officials stated that they did fabrication work for over 20 states.

The KTC interviews indicated that some shops were impacted by VOC restrictions while others were not. One shop stated it was unsure whether it was regulated. The variance in responses was due to differences between the regulations the states and local governments where the shops were located. A High Steel representative stated that they were subject to both a VOC limit for coatings of 420 g/l (3.5 lb/gal) and a total annual limit on the weight of VOCs that could be released by painting operations. The representative stated that High Steel had employed water-based coatings when permitted. He stated that the annual VOC weight restriction had proved extremely troublesome to High Steel. A Stupp Brothers representative stated that his shop was subject to a county VOC limitation of 420 g/l (3.5 lb/gal). The representative stated that the regulation had placed Stupp Brothers at a disadvantage in bidding on certain projects where competing shops were permitted to apply coatings with higher VOC limits.

The fabrication shop representatives also described the coatings that they had used for specific state highway agencies.

KTC VOC-Related Coatings Surveys of State Highway Agencies - To gain further insight concerning VOC-compliant coatings for new construction, KTC researchers contacted state highway agency officials from 5 northern and eastern states (Michigan, Virginia, Connecticut, New Jersey and Ohio). Those states used one or more of the fabrication shops previously contacted. Several of those states were employing complete shop painting. Officials from those highway agencies provided copies of their new construction coatings specifications. Most of those specifications for three-coat systems including organic- or inorganic zinc primers, epoxy intermediate coats and acrylic polyurethane topcoats. Several of those officials provided qualified products lists that included coatings with 420 g/l (3.5 lb./gal) VOC limits to allow use in fabrication shops with state or local restrictions. Those lists also included coatings systems with higher VOC limits for use at fabrication shops where VOC limitations were not a problem.

REGNEG Impacts - In May 1993, a representative of a resin-manufacturing firm was contacted seeking further clarification of VOC regulations for shop-applied coatings(9). That individual was a participant in on-going negotiations between environmentalists, state and local regulatory agencies, coating manufacturers, users, the US EPA and others in a negotiated rule-making process for coatings used in maintenance painting (i.e. the REGNEG). That negotiated regulation process was mandated by the 1990 amendments to the Clean Air Act to obtain consensus-based VOC regulations impacting that category of coatings. However, they did not directly impact coatings applied in fabrication shops. Those were in a different Clean Air Act category termed "Miscellaneous Metal Parts."

KTC researchers learned that variations in VOC regulations were based upon what were termed "ozone non-attainment areas." Those were areas throughout the U.S. where air testing had indicated high ozone concentrations partly ascribed to VOCs released during painting operations. Attainment of lower VOCs in those areas was the assigned to state and local regulatory agencies by the US EPA accounting for the variability in regulations impacting fabrication shops. Unlike VOC regulations for shop-applied coatings, regulations impacting the VOC contents of field-applied coatings were to be addressed on a national basis.

The resin-manufacturer representative stated that the REGNEG Committee was considering a VOC limit of 340 g/l (2.8 lb./gal) for most structural steel coatings applied in the field. The VOC regulatory situation has been well reviewed elsewhere (10, 11). Recently, the REGNEG process failed and the US EPA is proceeding with promulgation of VOC regulations. Nationally, the regulation of maintenance coatings has become somewhat fractious and several states have independently enacted VOC limits for structural coatings (12). It is likely that EPA regulations will limit the VOC content most field-applied coatings to 350 g/l (2.92 lb./gal). The representative informed KTC researchers that solvent compatibility problems might arise the VOC content of shop-applied coatings differed from those of topcoats applied in the field.

Current KyTC Coatings for New Construction

Some field painting was anticipated on KyTC new construction projects for repairs and topcoating. KTC researchers appraised KyTC officials of the information gathered in May 1994 noting that final decision on new construction coatings should await REGNEG-derived VOC regulations for field painting. As a replacement for the inorganic zinc/vinyl systems, KyTC officials adopted a three-coat system consisting of a shop-applied inorganic zinc primer, a shop-applied high-solids epoxy and a field-applied acrylic polyurethane topcoat. All of those coatings were specified with a 340 g/l (2.8 lb./gal) VOC content to give fabricators equal opportunities when bidding on KyTC bridge steel.

Coating Problems on the US 27 Bridge at Covington - In October 1993, the US 27 bridge was being erected over the Ohio River between Covington, KY and Cincinnati, OH. The superstructure was being shipped by barge from one of two fabrication shops providing steel for the truss superstructure. The steel was shipped with two shop-applied coats, the inorganic zinc primer and the epoxy intermediate coat. The acrylic polyurethane topcoat was to be applied in the field. Inspectors at the job site detected many spot failures of the coating.

KyTC and KTC personnel conducted an inspection at the job site to investigate the problem. They observed what initially appeared to be cases where epoxy was flaking off the inorganic zinc primer at points where the steel had been lifted or incidentally scrapped (Figure 2). Closer inspections also revealed a few failure locations where the inorganic zinc had disbonded from the abrasive-blasted steel substrate. Probing exposed paint edges at failure locations indicated a low cohesive strength within the inorganic zinc. Low tensile adhesion test values at various locations 0.9-3.6 MPa (100-400 psi) confirmed that suspicion. KyTC and KTC personnel concluded that the moisture-cure inorganic zinc primer was incompletely cured when the epoxy was applied.

KyTC officials checked with the fabrication shop inspector who confirmed that the inorganic zinc had passed the curing test (ASTM D-4752, 50 MEK double-rubs). This curing test had been recommended by the fabrication shops prior to the onset of shop painting and had been incorporated into the contract. In the past, KyTC officials had specified a one-day cure for inorganic zinc prior to application of subsequent coats. Curing had not been a problem with earlier projects as that application of the top coat was commonly field-applied providing a suitable curing time.

KyTC officials determined that incomplete curing of the inorganic zinc should not result in further problems beyond those incurred at the time of erection. The second shop was notified about the problem. The decision was made to repair the chipped paint after all of the bridge steel was erected, prior to topcoating.

In February 1994, KyTC and KTC personnel visited the second fabrication shop. Some of the steel had been completed and was being stored outside awaiting shipping. The temperature was extremely cold and, as a consequence, the air was dry hindering the curing of the inorganic zinc primer. A significant portion of the primed steel stored in a heated shop waiting for it to properly cure. The shop was spraying water into the air in an attempt to promote the curing process. The primer was proving difficult to cure. Some of the steel had been primed for over 30 days without passing the MEK-rub curing test. Scheduling had become critical as the construction firm was nearly ready for the partially painted steel.

Inspection of completed steel in the shop's storage yard revealed additional paint chipping indicating incomplete curing problems. Eventually, all of the steel was painted and shipped though further epoxy disbonding was encountered. The disturbed areas were subsequently cleaned and coated with epoxy mastic prior to application of the polyurethane topcoat.

KTC-Proposed Coatings for New Construction - Having observed the shop painting problems related to the curing of inorganic zinc, KTC researchers sought to identify multi-coat systems for new construction that would cure rapidly in fabrication shop environments and that could be completely shop-applied if so desired by KyTC officials. Three coatings manufacturers were contacted who were willing to provide somewhat similar coatings that could be applied advantageously in fabrication shops.

The proposed systems somewhat resembled those previously specified by the 5 state highway agencies previously contacted by KTC researchers. They consisted of: 1) organic zinc-rich primers incorporating moisture-cure polyurethane or polyurethane-modified epoxy resins, 2) MIO-pigmented intermediate coats incorporating moisture-cure polyurethane or polyurethane-modified epoxy resins, and 3) high-gloss or MIO-pigment flat topcoats incorporating moisture-cure or acrylic polyurethane resins.

The primers proposed were relatively fast curing and would accommodate topcoating in 4 to 8 hours under most conditions. As those coating would need to be used in bearing areas, they would need to pass AASHTO Class B slip coefficient tests. The MIO-pigmented intermediate coat would also cure rapidly (in 4 to 8 hours) facilitating shop through-put of steel and minimizing handling. The coarse surface produced by the MIO would provide superior abrasion resistance and thereby minimize handling damage. It would also would significantly extend the recoat window for application of the topcoat if field painting was desired. The topcoats would be relatively fast curing and the MIO-pigmented systems would prove ideal for complete shop painting. Information about the proposed shop systems was provided to KyTC officials.

Revised KyTC Procedures for Application of New Construction Coatings - KyTC officials elected to retain the inorganic zinc/epoxy/polyurethane system for new construction. In the near future, most new steel bridge construction will involve large structures and KyTC officials wanted to stay with a proven coating system. To overcome fabrication shop painting problems, they elected to limit shop painting to the inorganic zinc primer and to have intermediate and top coats applied in the field. That will allow the inorganic zinc primer to cure properly. Also, inorganic zinc is abrasion resistant and it has a coarse surface texture facilitating future topcoating.

Ironworkers at the US 27 bridge at Covington complained that when wet, the epoxy became very slick and provided a dangerous walking surface. With the new painting procedure, a bridge would not receive the epoxy and polyurethane topcoats until personnel other than painters were finished with structure. Ironworkers would not have problems walking on the coarse surfaces provided by the inorganic zinc. That change was adopted for use during construction of the three I-75 bridges over the Kentucky River at Clays Ferry. The only drawbacks to this approach are 1) that the field-applied intermediate coat would prove more costly than if it were shop-applied and 2) that inspection would also be prove difficult to accomplish.

KTC ACCELERATED CORROSION/WEATHERING TESTS

Background

Laboratory accelerated corrosion/weathering tests were used for two reasons. First, KTC researchers believed that a rapid means of evaluating coatings might be needed to respond to unforseen changes in regulations that might impact KyTC coatings or application methods. Second, KyTC officials and KyTC researchers intended to pursue the preparation of an open (non-generic) qualified products list of acceptable maintenance and, possibly, new construction coatings.

KTC researchers intended to use accelerated laboratory testing as a method of screening out lower-performing coatings. It was anticipated that all proposed (experimental) coatings would subjected to accelerated weathering tests. Testing would not be performed to some predetermined performance threshold, but rather to actual failure. That would be of significance as coatings failure tests would constitute more severe test criteria than fixed performance thresholds. Consideration be given to restricting the qualified products list(s) by accepting only the top 3-5 performing coatings or coatings performing within 5 percent of the best-performing coatings system. Consequently, qualified coatings systems would need to perform similarly to the top-rated coating.

The accelerated laboratory tests would provide benchmark test values for coatings performance that could be gradually "racheted upward" as better performing coatings were evolved. By restricting inclusion in qualified products list(s) to a few of the best performing coating systems, coatings manufacturers would be encouraged to provide the best coatings and would be awarded for measurable performance gains.

This approach required assurance that accelerated corrosion/weathering tests of coatings would accurately reflect their field performance. At the onset of this study, accelerated laboratory testing of structural coatings was in a state of flux. The conventional salt fog test, ASTM B-117, was under considerable criticism for not accurately reflecting coatings performance related to either inland or marine exposures. Other researchers had conducted extensive tests of various coatings systems (13). Their results indicated that a combination of cyclic condensation and evaporation combined with exposure to ultraviolet (UV) degradation provided a better measure of coatings weathering.

Test Design - The KTC accelerated corrosion/weathering tests employed flat painted steel coupons made from low-carbon steel plate measuring 10 cm (4 in.) by 15 cm (6 in.) by 0.5 cm (3/16 in.) with a mill scale surface for overcoating paint systems and an abrasive blasted surface to coatings manufacturer specifications for new construction coating systems. To achieve coupon consistency, they were provided from a single vendor who stamped KTC- designated numbers that identified the coatings manufacturer, the coating type, and each specimen tested.

KTC researchers lacked a facility for painting the coupons. Coatings manufacturers were requested to furnish 25 coated specimens of each of their candidate coatings systems. The specimens were to meet the specifications on their product data sheets. KTC researchers subjected each specimen to thickness and gloss tests (if high-gloss coatings were employed). Thereafter, a 5-cm (2-in.) long scribe mark was cut through the paint along the 15 cm (6 in.) dimension using a 1X Tooke cutter. The thicknesses of individual coating layers were measured using a Tooke gage (ASTM D-1483). Any variations in dry film coating thicknesses from those specified in the coatings manufacturers' product data sheets would result in rejection of the coupons. The scribe mark served as a baseline for film undercutting measurements to be performed throughout the tests.

The accelerated corrosion/weathering tests consisted of: 1) 200 automated hours of cyclic Prohesion testing (ASTM G-85 Annex A5) consisting of an 1 hour of salt fog exposure to an electrolyte solution consisting of 0.05 percent sodium chloride and 0.35 percent ammonium sulfate (condensation) at room temperature, followed by an 1 hour of drying at 35 °C (95 °F) so that all visible moisture has disappeared within 45 minutes (evaporation), 2) 200 automated hours of QUV testing (ASTM G-53) consisting of alternating cycles consisting of 4 hours of UVA light exposure at 60 °C (140 °F) followed by 4 hours of condensation at 50 °C (122 °F). Initial tests were conducted alternately for 2,000 total test hours and an addition test set of 10 freeze-thaw cycles conducted after set of 400 total Prohesion/QUV test cycles (except after the final 400 cycles). The freeze-thaw tests consisted of cycling between 22 °C (72 °F) to -15 °C (5 °F) at a rate of less than 8.3 °C (15 °F) per hour with maintenance at temperature extremes for a minimum of two hours. The tests were performed by manually cycling coupons between a commercial freezer and room temperature exposure in insulated containers to retard the rate of temperature change. The coupons were manually transferred between the Prohesion, QUV and freeze-thaw tests.

After 2,000 Prohesion/QUV cycles and 40 freeze-thaw cycles, the tests were terminated. The coupons were subject to visual inspections and specific measurements related to paint failure by: 1) rust through, 2) blister frequency, 3) blister size and 4) rust undercutting along the scribe mark. A rational quantitative evaluation method was prepared that provided mixed-mode pass/fail criteria.

Initial Series of Tests - Three coatings manufacturers provided painted coupons for 7 candidate overcoating and 3 new construction systems for the KTC laboratory tests. Ten specimens from each group were selected for testing based upon conformance of coating thicknesses contained in the manufacturers' product data sheets. Once the tests were completed, the coupons were examined and rated.

Tests results revealed that all of the new construction specimens passed. However, 2 of the overcoating systems passed with the others failing by rust undercutting (Figure 3).

The test program was difficult to complete due to its excessive labor requirements and the extended duration of the tests. Modifications will be needed in the future to provide more automated tests. The manual freeze-thaw tests were especially time-consuming. The temperature extremes employed in those tests were based upon 1) the minimum temperature being the lowest provided by a small commercial freezer and 2) the maximum temperature being the average ambient laboratory temperature. Both warmer and colder temperature extremes should be used for those test to reflect actual service conditions. A programmable freeze-thaw chamber would be required to address both of those needs.

The failure mechanism of the overcoating systems raised two concerns about those tests. An abrasive blasted substrate is rational for the new construction systems as it represents the actual substrates employed by that category of coatings. However, mill scale substrates do not reflect the primary substrate encountered in overcoating. About 90-95 percent of the paint applied on an overcoating project will be placed directly over existing paint. The remaining coverage may be over either exposed mill scale or rust.

KTC researchers used a mill scale substrate because: 1) that type of coupons was available when the test program started and 2) it provided a consistent surface. After the test program was underway, coupons with rusted surfaces became commercially available. Ideal coupons would probably contain a mix of weathered alkyd paint, rust and mill scale. However, the cost would be prohibitive and it would be difficult to provide consistent substrates coated with an alkyd paint. The Northwestern University Basic Industry Research Laboratory (BIRL) recently conducted accelerated corrosion/weathering tests to study overcoating systems. Those were coated over coupons extracted from Illinois DOT scrap bridge steel that were coated with weathered alkyd paints. However, such coupons would be difficult to obtain in the large quantities needed for KTC test purposes and consistency of the existing alkyd paint would be problematic.

A different situation was encountered with the new construction coatings. KTC researchers anticipated that the testing would result in some coatings failures. As no failures occurred, the test program needed to be more severe. Subsequently, it was learned that the testing would need to be extended at least 500-1,000 more Prohesion/QUV cycles to fail those coatings. That would further extend the time to complete the test program.

The initial test series that encompassing 10 coatings consumed the capacities of the Prohesion and QUV chambers and the freezer. Those tests took almost a year to complete. Even under ideal circumstances, those tests would take about four months to complete. Extended testing would further limit the number of coatings systems that could be tested annually. That may impact the long-term goals of KTC researchers had for the laboratory accelerated test program.

Further review is needed concerning reducing the of number of test coupons while maintaining statistically correct results. This consideration is important as the accelerated corrosion/weathering tests would impact the qualification of coatings manufacturers and unfavorable test results might be challenged. The laboratory test program until decisions can be reached concerning the future direction of laboratory testing.

The laboratory test results were to be correlated with long-term service performance of the experimental bridge overcoating projects and the field test patches. However, the coatings employed in these initial series of tests were not used on successful overcoating projects or for new construction negating opportunities for comparison. Valid correlations will be sought in future laboratory tests. The tests will be of more relevance due to the recent KyTC shift to "cookbook" specifications for both overcoating and new construction coatings systems.

KTC FIELD EXPOSURE TESTS

Background

The second type of tests employed by KTC researchers entailed field applications of test patches of experimental overcoating paint systems. The application tests were considered to be a logical follow-on tests after accelerated laboratory testing for more exact screening of candidate coatings systems prior to their selection for experimental overcoating projects. During this work, It was discovered that the application of field test patches was a good method for determining coating application characteristics. That was pertinent as KyTC experimental overcoating specifications usually stipulated brush application, especially for the spot prime and intermediate coats. Coatings with poor brushing characteristics would not apply well in most field applications and they would probably not perform well either.

Those tests have also proven beneficial in formulating experimental overcoating application specifications.

Initial Bridge Work - The first test patches were applied to bridges in the Louisville area, particular on I-64 and I-65 expressway structures. Patches were originally applied to those elevated structures in March 1992. The substrates provided by those structures varied considerably.

The best substrate used in those tests was the existing lead paint on the exterior portion of a fascia girder at the 9th Street Interchange. Inspection with a Tooke gage revealed that the existing paint consisted of a red lead primer with aluminum-pigmented intermediate and topcoats providing a total thickness of about 185-235 microns (7-9 mils) thick. The existing paint showed no signs of significant deterioration. Tape adhesion testing (ASTM D-3359) provided a acceptable overcoating value of 4B.

The surface was cleaned by washing and painted under good ambient conditions. Two separate patches each about .18 m^2 (2 ft^2) area were applied, one with a single brushed-applied coat of an experimental acrylic polyurethane intermediate coat and the other with a single brushed-applied coat of an experimental high-gloss acrylic polyurethane topcoat. Each coating had a dry film thickness (DFT) of about thickness of about 75 microns (3 mils). Tensile adhesion tests (ASTM D-4541) were performed on the coatings and the existing lead paint surface some 45 days after the patches had been applied. The lead paint failed by parting between the red lead primer and the intermediate alkyd coat at breaking strengths between 2.9 MPa (400 psi) and 5.2 MPa (750 psi). Tensile adhesion tests on the overcoated patches failed between the same coast of existing paint at breaking strengths between 3.6-4.9 MPa (500-675 psi).

Test patches were subsequently applied on the exterior portion of a fascia girder of the I-65 expressway near Preston St (Figure 4). The weather was cold, about 2 ^{0}C (36 ^{0}F) with light rain and snow flurries. The existing lead paint on the fascia girders was weathered with spot corrosion. The paint thickness measured between 225-300 microns (9-12 mils).

The corroded areas were power-tool cleaned with a wire cone brush on a grinder and the areas to be painted were cleaned by dry wiping. Two separate patches with areas of about .18 m^2 (2 ft^2) were applied, one with a brushed-on coat of an experimental aluminum-pigmented moisture-cure polyurethane primer between 75-100 microns (3-4 mils) thick and the other with a brushed-on coat of an experimental zinc-pigmented moisture-cure polyurethane primer between 50-200 microns (2-8 mils) thick.

The I-65 expressway bridge at Brook and Kentucky streets possessed an experimental lead paint that began to disbond several years after it was applied. The bridge was eventually overcoated with a vinyl topcoat that apparently exacerbated the coating failure process. The total thickness of the existing coating was between 250-450 microns (10-18 mils). The exposed mill scale located where the paint had disbonded exhibited spot corrosion.

The test patches were applied during the same general time and unfavorable environmental conditions as with the Preston St. work. Interior girders were hand tool cleaned and wiped with dry rags. Four separate patches, each about .45 m^2 (5 ft^2) area, were applied. Two of those entailed a brushed-on coat of the experimental aluminum-pigmented moisture-cure polyurethane primer between 75-100 microns (3-4 mils) thick and the other with a brushed on coat of the experimental zinc-pigmented moisture-cure polyurethane primer between 50-125 microns (2-8 mils) thick. The test patches were applied over both lead paint and mill scale substrates. An effort was made to brush the primers into exposed edges of the lead paint using the brushes. Experimental acrylic polyurethane intermediate and high-gloss topcoats between 50-100 microns (2-5 mils) thick were applied over portions of each type of primer.

Steel bents on that bridge had the same existing coatings and exhibited similar distress. The existing paint measured between 185-250 microns (7-10 mils) at those locations. Test patch areas on the columns were power-tool cleaned and rag-wiped. Two columns were coated with six patches each of about .18 m^2 (2 ft^2) area were brush-applied, with one coat of the experimental aluminum-pigmented moisture-cure polyurethane primer between 75-100 microns (3-4 mils) thick. Those test patches were coated with high-gloss acrylic topcoats in June 1992. Tensile adhesion tests on existing paint and test patches failed at values between 0.6-2.9 MPa (100 to 400 psi). Most of those failures were adhesive failures between the red lead primer and the alkyd intermediate coat.

At that same time, several test patches of aluminum-pigmented moisture-cure and acrylic polyurethane were applied over the I-64 bridge between 17th and 18th streets. The experimental aluminum-pigmented moisture-cure primer was applied over a red lead at a location where the aluminum-pigmented alkyd topcoats had disbonded from the primer.

Test patches were subsequently applied to several other bridges in the Louisville area in September 1992. The first bridge was the I-65 bridge over the Ohio River. The lead paint on the bridge exhibited spot rust. Test patches of .18 m^2 (2 ft^2) were brush-applied with an aluminum-pigmented moisture-cure polyurethane primer and gray and white acrylic high-gloss topcoats. Test patches were also placed upon the US 31E bridge over the Ohio River. That bridge had an inorganic zinc/vinyl system. The coating was in generally good condition except for chalking of the vinyl topcoat. Zinc- and aluminum-pigmented moisture-cure topcoats were applied on a steel bent and several acrylic polyurethane high-gloss topcoats were brush-applied over portions of the primer test patches and directly upon the existing vinyl topcoat.

Long-Term Performance - All of the bare polyurethane primers and the two-coat systems applied in the Louisville area have performed well after field exposures of 3 years. The last inspection of those patches was conducted in November 1995. The test patches did not possess any rust-though, disbonding or blistering. At exposed edges of existing paint such as the I-65 overpass at Brook and Kentucky, the overcoating paint had "locked-down" the existing paint and had halted further deterioration. The high-gloss topcoats had excellent gloss retention.

Bluegrass Parkway Overpass - An in-depth field test application study was performed on the Bluegrass Parkway overpass bridge over US 60 in Woodford County. KTC researchers conducted the work in June 1992 with representatives from a coatings manufacturer that was providing paint for the eventual overcoating of that bridge. The bridge was a plate girder structure that employed a basic BLSC primer with aluminum pigmented intermediate and topcoats. A little spot corrosion was evident on the lower flanges and cross bracing. Some white residue was visible on the lower flanges.

Extensive surface preparation trials were performed on the existing paint on webs of fascia girders. Those included dry wiping, water washing, use of a chemical cleaner with a water rinse, scrubbing, scrubbing with a water rinse, wire-brush abrading and washing followed by application of an epoxy penetrating sealer. Tests were conducted at each surface-preparation area including: 1) control areas with no topcoat, 2) one brushed coat of an acrylic polyurethane intermediate coat and 3) one brushed coat of a moisture-cure polyurethane. Tensile adhesion tests were employed two weeks later. Two tests were performed at each test location. The test values were between 0.4-2.9 MPa (50-350 psi). The values obtained in coated areas were slightly higher than those in uncoated areas. The average value of all tests was 1.6 MPa (225 psi). Seventy percent of the failures were cohesive in the red lead and 30 percent adhesive between the primer and intermediate coat.

The representatives noted that the method of surface preparation did not significantly impact adhesion of the overcoating paints. They thought that the three-coat polyurethane system scheduled to be used was an appropriate choice for weakly-adhering lead paint substrate.

US 25 Bridge over I 75 - In August 1992, KTC researchers conducted application tests on the US 25 bridge over I 75 in Fayette County. The bridge had an a sulfonated wax coating that had been placed over an abrasive-blasted substrate in 1988. Shortly after the project was completed, extensive corrosion was observed on exterior portions of the fascia beams. Inspection of the wax coating revealed that the it was severely weathered on the exterior surfaces. On interior surfaces under the deck, the coating was performing were performing relatively well. The wax remained soft, possessing a surface hardness similar to that of crayons. Extensive graffiti was present on the side spans adjacent to the abutments.

A calcium-sulfonate alkyd was selected for test patch applications as that coating remains relatively flexible after curing and, hopefully, would not map-crack if painted over the soft wax substrate. Test patches of .18 m^2 (2 ft^2) area were used. Water- and solvent-based calcium-sulfonate coatings were brush-applied. Those coatings were recently formulated to provide rapid-drying. They dried to the touch within several hours.

The test patches were reinspected in April 1993 prior to overcoating operations. All of the test patches were performing well, remaining tightly bonded to the wax substrate and showing no signs of cracking. Concern remained about the soft wax substrate. Both the alkyd topcoat and the wax could be readily scratched off the steel substrate. As there was considerable graffiti present at the abutments, KyTC and KTC personnel believed that it would be desirable to remove the wax on the bridge side spans prior to coating those areas with the calcium-sulfonate alkyd. That was considered necessary to prevent vandals from damaging the new paint after the bridge was repainted.

KyTC and KTC personnel decided to investigate the use an alkaline paint stripper to remove the existing wax on the side spans. They believed that method might be the best choice for removing the soft coating and it would provide experience with a that another means of coating removal. In July 1993, representatives from the manufacturer of an alkaline stripper successfully demonstrated their stripping compound at the bridge.

The stripping compound was a thick material with a consistency similar to plaster of paris. It was troweled over the wax at several test locations. During the demonstration, the representatives stressed that care should be taken to prevent direct contact between the stripping compound and the applicators as the material was very caustic. After the stripping material was allowed to react with wax for about 1 hour, the it was rinsed off the bridge girders using a hand spray pump. The stripper completely removed the wax and exposed the underlying blast-profile in the steel. After that demonstration, the decision was made to specify the stripper in maintenance painting of the bridge.

Applications on Scrap Steel - Over the first two years of the study, KTC researchers had identified a significant number of candidate overcoating systems that warranted investigation. However, the progress of accelerated testing was slow and the current rate of experimental overcoating projects was insufficient to accommodate all of the candidate coatings. The decision was made to investigate them using field test patches.

By 1993, the OSHA Final Interim Lead Rule was having a significant impact on KyTC overcoating procedures and the coatings considered for use in the experimental projects. New application procedures were needed that were non-invasive to the existing lead paint. Such procedures were devised, but needed to be tested to demonstrate their feasibility. New coatings systems needed be identified. Overcoating systems used with those procedures would have to be receptive to extremely poor substrates. Also, the list of candidate overcoating systems had to be revised to incorporate those new coatings.

It would not be practical to use bridges for the large number of field tests forthcoming field tests. Most bridge locations were not protected inviting vandalism problems and access to most bridges required special equipment such as bucket trucks. Also, the test sites needed to be close to KyTC and KTC offices to facilitate travel.

Old scrap steel beams containing weathered lead paint were available at the KyTC Bailey Bridge Yard in Frankfort. Those beams proved ideal for the field tests as they possessed aged alkyd paint was in poor condition. That paint was severely chalked. The beams had extensive spot corrosion (i.e. freckle rusting) on the webs and complete corrosion on the flanges. The thickness of the alkyd paint was between 200-350 microns (8-14 mils) and provided tape adhesion test values of 0-1B. The quantity of beams available for the field patch tests was sufficient to meet KTC test requirements for several years. Also, the yard was enclosed by fences to inhibit vandalism.

Initial field test patches were applied in August 1993, the beam surfaces to be painted were cleaned with a low pressure water wash using a hand sprayer and were subsequently dry wiped with rags to remove any retained soils or loose debris. No attempt was made to remove any loose or peeling paint.

The test patches were applied on a warm, sunny day with the steel surface temperature at about 38 ^{0}C (100 ^{0}F). Experimental coatings were applied over 0.93 m^2 (10 ft^2) areas for most of the tests. For several coatings, additional test areas were provided to investigate the effects of various alkaline cleaners and phosphoric acid rust removers as additional surface preparation treatments.

The application procedures were unique in several ways. Brushing was used to apply all coats of paint. The applicators used their brushes to thoroughly work the paint onto all substrates and into all exposed edges of the existing paint by cross-brushing. The application process entailed painting over rust and deliberately forcing the brushes to break off peeling paint. The resulting paint chips were subsequently re-tacked to the girder surface by liberally slathering on the overcoating paint and allowing it to act as a bonding agent. Repeated brush strokes smoothed out the new paint and reduced its thickness. Despite the large amount of loose paint originally present on the test surfaces, very little loose paint was discharged to the ground.

The candidate coatings systems employed were typically two-coat systems similar to those used in second-phase KyTC experimental overcoating projects. They included penetrating sealers or surface-tolerant primers and topcoats. Several coatings systems consisted of two or three coats of the same material. Specified drying times were adhered to between coats and the coatings thicknesses were "as applied."

Eleven coatings systems from nine manufacturers were tested. The generic systems employed included: 1) a penetrating epoxy sealer and an acrylic polyurethane topcoat, 2) a penetrating epoxy sealer and a silicon alkyd topcoat, 3) a moisture-cure polyurethane sealer and a MIO-pigmented moisture-cure polyurethane topcoat, 4) an aluminum-pigmented moisture-cure polyurethane use as the primer, intermediate and topcoats, 5) a calcium-sulfonate alkyd used as the primer and topcoats, 6) a water-based calcium-sulfonate used as the primer and topcoats, 7) an aluminum-pigmented moisture-cure polyurethane primer and high-gloss acrylic polyurethane topcoat, 8) an elastomeric resin used as a primer and topcoat, 9) a calcium-sulfonate epoxy used as a primer and topcoat, 10) an aluminum-pigmented moisture-cure polyurethane primer and a high-gloss acrylic polyurethane topcoat and 11) a high-build polyurethane mastic applied as a one-coat system.

A second series of field test patches was applied to the scrap steel beams beginning in October 1994. The same surface preparation and application procedures were used. An additional 20 candidate coatings systems (from 9 manufacturers) were applied. Most were one- or two-coat systems.

Long-Term Performance - Inspections conducted in November 1995 revealed that most coatings systems applied on the scrap steel were performing well despite the marginal surface preparation. Four of the candidate coatings, the elastomeric resin, the calcium-sulfonate epoxy, the water-based calcium-sulfonate and the polyurethane mastic were showing signs of incipient failure. The coatings applied in late 1994 were performing well, except for two epoxy mastic coatings systems that were beginning to peel from the lead paint and one moisture-cure polyurethane topcoat paint that was peeling from a moisture-cure aluminum primer.

Field exposure tests, both on bridges and on scrap steel beams, have provided greater utility for evaluating coatings and application procedures than envisioned at the onset of this study. Those tests have been instrumental in shaping the long-term focus of KyTC officials and KTC researchers. They have enabled a large number of candidate coatings to be evaluated and have enabled KTC researchers to attempt innovative application practices.

KyTC EXPERIMENTAL OVERCOATING PROGRAM

Perceptions of KyTC Officials

Prior to the onset of the KyTC experimental overcoating program, KyTC and KTC personnel held several informal discussions concerning past and forthcoming maintenance painting work. Those meetings provided KTC researchers with insight about KyTC expectations related to overcoating and enabled them to better define their role in the forthcoming projects.

KyTC officials anticipated that maintenance painting projects entailing complete paint removal (i.e. incorporating abrasive blasting) would last about 15-20 years. Earlier overcoating projects had provided coatings service lives of about 7-10 years. They were willing to accept similar durability with future overcoating projects, but they anticipated that new overcoating systems employed in this study might provide longer service lives.

KyTC officials were completely committed to the use of overcoating for bridge maintenance painting. They realized that occasional coatings failures would occur, but were willing to accept those to obtain low initial project costs.

Due to limited KyTC funding for maintenance painting, KyTC officials desired to keep experimental overcoating project costs below \$21.50 per m^2 (\$2/ft^2). That was in the range of costs KyTC had sustained for maintenance painting projects incorporating open abrasive blasting. KyTC officials realized that environmental regulations were going to increase painting costs, either by impacting initial project costs or by increasing life-cycle costs by providing less-expense, but less-durable projects. KyTC officials also realized that the experimental overcoating projects were going to be more expensive than subsequent projects when coatings and application procedures were standardized and multiple bridges could be incorporated (bundled) into one contract.

Two KyTC concerns were inter-related: 1) low contractor quality and 2) unfamiliarity of current KyTC inspectors with overcoating. Historically, the KyTC open bidding process had resulted in extreme competition for painting work. Painting contractors would frequently submit unrealistically low bids to gain work. They would attempt to enhance their profits by short-cutting during paint application. KyTC benefitted from low maintenance painting costs. But, it created an unfavorable situation where KyTC district field inspectors had to "inspect in quality" to ensure acceptable workmanship.

All KyTC maintenance painting projects conducted in the foreseeable future were to employ experimental application practices and/or coatings systems. District inspectors were knowledgeable of maintenance painting procedures involving complete paint removal. However, they were completely unfamiliar with overcoating procedures. As those projects were usually unique, there were no guidance manuals and, even the KTC researchers were not completely sure of what situation might be encountered.

Inspectors would have to gain experience as the projects progressed. Also, they would need to be supplied with the necessary inspection tools and trained to use them. KyTC officials were aware that many inspector decisions impacting overcoating application quality would be subjective and that the quality of initial projects might be effected by inspector inexperience. KyTC officials considered inspector training to be a vital component of this experimental program.

KyTC officials emphasized that KTC researchers should give the experimental overcoating projects priority over other planned research tasks. The need to proceed with experimental overcoating projects meant that the laboratory and field tests would lag what was intended to be "final testing." KyTC officials anticipated the likelihood of frequent "fire-fighting" measures to resolve field problems and expected close, timely assistance from KTC researchers in dealing with those situations.

Overcoating Project Tasks - The tasks performed during the experimental overcoating program consisted routine functions performed by KyTC Divisions with experimental support provided by KTC researchers.

The Division of Operations prepared all project lettings and was responsible for selection of the bridges, application specifications and traffic control plans.

The Division of Construction provided project oversight once a contract was awarded. That included technical support at pre-construction meetings (held at the district offices) and throughout the project (at the job site). Thereafter, Division of Construction officials performed a final inspection and prepared a report which mandated any contractor remedial actions prior to final payment.

District offices furnished inspection personnel and field engineering and management necessary to resolve disputes.

Division of Materials personnel performed acceptance testing of coatings provided by coatings manufacturers. The coatings were sampled as they arrived at the job sites. The Division of Materials conducted routine tests of each coating (or component) sample to verify parameters such as viscosity, percent solids, VOCs, etc. As proprietary coatings were used throughout the initial phases of this program, test results were compared to data provided by coatings manufacturers in their product data sheets. Division of Materials personnel also performed infrared fingerprinting of the coating samples. That data was to be used for conformance testing if those coatings were to be specified on future projects or if they were eventually placed on a qualified products list.

The role of KTC researchers was threefold: 1) identify viable experimental coatings systems, 2) develop experimental overcoating procedures and 3) conduct field inspections. KTC work on a project began prior to its inception and continued on after it was officially completed.

KTC researchers used an informal process for the selection of candidate overcoating paint systems. Selection was based upon several factors including: 1) the willingness of prospective coatings manufacturers to participate in the KyTC program, 2) a historical record of successful performance of coatings systems and 3) a focus on specific coatings that conformed to existing or anticipated regulations (14-20). Inclusion in the KyTC experimental overcoating program was a necessary step for a coatings manufacturer to have its products qualified for regular use by KyTC.

Commonly, prospective coatings manufacturers were asked to submit a prioritized list of paint systems they recommend for overcoating applications. The highest recommended system was usually selected for eventual incorporation in a KyTC experimental overcoating project. KTC researchers compiled a list of candidate experimental overcoating paint systems. Ranking of candidate overcoating systems on the list was based primarily on order of receipt of candidate overcoating systems from the coatings manufacturers. The list was continually updated to reflect: 1) new regulations impacting paint systems, 2) revised KyTC overcoating specifications and 3) experiences with similar coatings on KyTC projects. KTC researchers provided the current list of candidate experimental coatings to Division of Operations officials prior project lettings. KyTC officials made the final decisions concerning selection of experimental coatings.

One purpose of the coating selection process was for KyTC to eventually prepare a qualified products list for overcoating paint systems. It was anticipated that the qualified products list would be open to all coatings systems that demonstrated satisfactory application and service performance on an experimental bridge overcoating project. In anticipation of REGNEG regulations, coatings manufacturers were require to provide coatings with a VOC limit of 340 g/l (2.8 lb/gal).

KTC researchers recommend procedures and wording for incorporation in the experimental overcoating specifications. KTC recommendations were based upon: 1) specifications from other state highway agencies, 2) recommendations of coatings manufacturers, 3) field tests, and 4) observations of previous KyTC experimental overcoating projects.

<u>KTC Field Inspections</u> - KTC researchers also conducted field inspections of bridges included in the experimental overcoating program. Inspections were performed prior to, during and, subsequent to overcoating projects. Scheduling conflicts kept KTC researchers from inspecting all of the selected bridges prior to or during paint application. Those conflicts were kept to a minimum as those inspection phases were considered important.

The preliminary inspections were conducted to assess the condition of the existing lead paint on bridges designated for experimental overcoating. Visual inspections were performed on the existing coatings to assess their overall condition and to identify potential problems. The bridges were photographed and, sometimes, videotaped to provide a historical record. A Tooke gage was used to assess the thickness and types of coatings present. Tape- and tensile-adhesion tests were periodically conducted to further characterize the condition of the existing coatings. Occasionally, surface chloride tests were performed to determine chloride levels. However, excessive chlorides were not encountered.

Periodically, KTC researchers monitored the paint contractors' operations. They attended pre-construction meetings to assist in interpretation of the specifications and to provide inspectors with points of emphasis in examining a contractors' work. Coatings manufacturers were required to provide representatives to view all phases of the contractor's work and to advise KyTC officials as whether that work was appropriate. KTC researchers attempted to meet with those representatives at the job sites at the onset of surface preparation and during paint application. Division of Construction personnel, the resident engineer, the district inspector and KTC researchers would review the contractor's work with the representative. They would decide whether to allow the contractor to proceed with his operations or to require changes. KTC researchers would photograph the various painting operations including any specific problems. They would also request feedback from contractors and their workers concerning the specification wording, coatings, and the surface preparation and application methods employed.

When a project was completed, KTC researchers would either attend the final inspection or visit the bridge shortly thereafter. They would inspect the completed project and photograph it. Occasionally, they would measure coating thickness with a Tooke gage or conduct tape- or tensile adhesion tests. Thereafter, KyTC officials and KTC researchers would periodic inspections.

Selected members of the Study Advisory Committee from the Divisions of Operations, Construction and Materials and the KTC principal investigator were assigned to a team to oversee the experimental overcoating program. The team met periodically to: 1) review specifications, 2) discuss the performance of past projects, 3) deliberate the impact of new environmental or worker safety regulations, or 4) plan future work. Periodically, team members would meet with district inspectors to review problems encountered on projects or with representatives of coatings manufacturers to learn about their candidate overcoating systems. Consensus decision-making was adopted by team resulting in general agreement by members concerning future actions related to the program.

First-Phase Overcoating Projects

Ten first-phase experimental overcoating projects were conducted between 1992-4 (Table 1). Most of those bridges were not inspected prior to preparation of the application specifications or selection of the experimental coating systems. Changes in KyTC funding for maintenance painting projects extended period for completion of those projects over that originally envisioned.

The experimental overcoating specifications were based upon those employed by the Tennessee DOT. Application specifications for those projects varied only slightly between the projects. They incorporated hand tool mechanical surface preparation, power washing and application of multi-coat paint systems. The paint systems commonly consisted of a spot primer, a full intermediate coat and a full top coat. Different coatings were used on each bridge. Each coatings system was supplied by a single manufacturer. The 10 projects used coating systems from 8 different coatings manufacturers. Coatings application methods were based upon a manufacturer's recommendations. When given an option, KyTC officials specified brushing or rolling in lieu of spraying. Those application methods were favored as they required that painters work paint into exposed edges of existing paint and onto flat surfaces. That promoted sealing of exposed edges and partially compensated for cleaning deficiencies.

Preliminary Field Inspections - Pre-construction inspections were conducted on: 1) Bluegrass Parkway over US 60 in Woodford County, 2) KY 152 over Harrington Lake in Garrard County, 3) KY 728 over Bacon Creek in Hart County, 4) KY 1015 over Dog Creek in Hart County, 5) KY 177 over the Licking River at Butler in Pendleton Co, 6) KY 804 over the Southern R.R. in Pulaski County, 7) KY 1812 over the North Fork of the Kentucky River in Breathitt County and 8) KY 30 over the South Fork of the Kentucky River in Owsley County.

The KY 152 and KY 177 truss bridges had been previously overcoated. Those bridges had 5-6 coats of paint measuring between 275-500 microns (11-20 mils). The alkyd topcoats of both bridges had chalked. Locations exposed to direct sunlight on the KY 177 bridge had weathered down to its primer coat (Figure 5). Spot corrosion was present in some locations on those bridges. Tape adhesion tests conducted on those bridges both provided values of 0B. Tensile adhesion breaking strengths ranged between 0.4-2.9 Mpa (50-400 psi). Most test failures occurred between the initial primer and the adjacent intermediate coat.

The other bridges inspected prior to painting were primarily plate girder structures with the exception of the KY 30 and the KY 1812 bridges which had both truss and I-beam spans.

The KY 30 bridge was unlike other bridges as its existing paint was an inorganic zinc/vinyl system. The existing paint on that bridge was in relatively good condition except for chalking of the vinyl topcoat and a little corrosion at the bearing areas. It was being repainted as part of a major renovation project.

The other bridges had 2 or 3 coats of alkyd paint (red lead primer and one or two topcoats) ranging in thickness between 150-300 microns (6-12 mils). Typically, the plate girder bridges were in fair-to-good condition with little rust except at bearing areas or under deck joints. Paint on the upper portions of the K-frame on the KY 804 bridge was completely weathered away exposing the red lead primer. Tape adhesion test values for those bridges ranged from 0B (for the Bluegrass Parkway bridge) to 3B (for the KY 728, KY 804 and KY 1015 bridges). Tensile adhesion test values ranged between 0.4-3.6 MPa (50-500 psi) with lower test values from the KY 1812 and Bluegrass Parkway bridges and higher test values from the other bridges.

KTC researchers noted the substantial variances among the bridges employed in the KytC experimental overcoating program. Those differences related not only to bridge size and type, but also to the condition of the existing coatings that would serve as substrates for the overcoating paints. Those differences would need to be taken into account as well as the quality of application provided by the various painting contractors. KTC researchers were concerned that those factors would obscure comparisons between overcoating paint systems. In discussions with KyTC officials related to those issues, it was determined that follow-on performance evaluations would have to account for those differences. A coating system would not be adversely rated if employed under conditions that were extremely unfavorable.

The primary KyTC concerns related to the subsequent performance of the experimental projects. If a coating failed due to its application over a weak coating, its future use might be limited to overcoating existing paints in better condition.

In conducting the preliminary inspections, KTC researchers accumulated sufficient test data to characterize the range of overcoating situations anticipated for most KyTC overcoating projects. Low tape- and tensile adhesion test values and high thicknesses of existing coatings would not impact decisions concerning overcoating and, therefore, those tests and measurements were largely abandoned. As most of the KyTC bridges being overcoated were on secondary routes, it was unlikely that they had experienced significant chloride applications. Unless extensive corrosion was observed that might be related to chlorides, no surface chloride tests were performed. Of greatest importance to KTC researchers were: 1) the extent and type of gross deterioration of the existing coatings, 2) the quality of application of the experimental overcoating system and 3) its subsequent performance.

Project Inspections - KTC researchers were present at various times during work on most of the first-phase projects and made observations about surface preparation, application methods, the coatings employed, district inspection and contractor quality.

Inspection of the KY 152 bridge was conducted during surface cleaning. Eight years prior, the original paint on the bridge had been overcoated using a similar alkyd coating system. The existing paint was peeling at spots, typically where rust was present. At the time of our preliminary inspection, pressure washing was being conducted at 18 MPa (2,500 psi) and a considerable amount of paint was being removed. Based upon that observation, the washing pressure was reduced to 10.8 MPa (1,500 psi) on future projects to preclude excessive paint removal. Hand tool cleaning was performed by concurrently with the painting. Due to close proximity of the bridge with boat docks and houses, the contractor employed brushing and rolling to apply the paint (Figure 6). A drape was employed under painting operations to prevent paint damage to passing boats.

Most of the painters employed by the contractor were hired locally and many did not have commercial painting experience. That did not result in observable defects in the completed coating. The high-gloss acrylic polyurethane topcoat was applied by rolling and had an excellent initial appearance. All exposed edges of the existing paint appeared to have been properly sealed. However, thickness measurements of the overcoating system revealed that it was excessive measuring between 275-375 microns (11-15 mils). The aluminum-pigmented epoxy mastic used as a spot primer and full intermediate coat accounted for most of the excessive thickness. Total coating thicknesses of up to 800 microns (40 mils) were measured raising concerns about eventual disbonding failure.

KTC researchers were not present during the painting of the KY 143 bridge over Vaughn Ditch in Webster County. However, they were informed that the contractor had not sufficiently cleaned the structure prior to painting operations. The coatings manufacturer representative stated that the overcoating system thickness was insufficient in some areas. Extensive re-working was mandated in the Division of Construction final inspection report. Division of Construction officials did state that the small truss bridge was in very poor condition prior to painting.

An inspection was conducted shortly after the contractor had affected repairs specified in the final inspection. The patches of existing alkyd paint were evident under to overcoating system. It appeared that additional hand tool cleaning would have been appropriate prior to initial paint application. Application of the overcoating paint appeared to be inadequate at some locations such as rivet heads where rust was observed. The calcium-sulfonate alkyd had been applied by spraying. However, that did not appear to have been a source of problems and most of the new coating appeared to be satisfactory. However, the coating was very slow drying and was found to be tacky when inspected some 8 weeks after the project had been completed. The coating manufacturer was informed that the coating needed to be re-formulated to provide more rapid curing.

The same painting contractor had been awarded contracts to paint the KY 728, the KY 1015, the KY 804 and the KY 177 bridges.

Surface preparation on the KY 728 bridge was relatively straightforward. The existing paint was tight and there was little corrosion that required hand tool cleaning. The contractor set up pick boards and cables and rapidly worked across the structure performing surface preparation and power washing.

The coating manufacturer on that project stipulated spraying for all coats of paint (Figure 7). After a full coat of ceramic gray acrylic primer was applied, the paint was observed to be disbond (lift) at several locations. Lifting appeared as tears or cracks in the coating. At those locations, the solvent in the primer reacted with the existing alkyd paint causing it to part from the mill scale substrate and to tear. The tears acted as cracks which reflected through succeeding topcoats. As the epoxy and polyurethane topcoats were applied by spraying, the new paint was not worked into the exposed lifted edges (Figure 8). At locations where lifting occurred, the paint was completely disbonded from the steel increasing the likelihood of incipient failure.

The final inspection revealed numerous defects in the coating related to runs in the topcoat, lifting and improper cleaning. Those defects are the result of poor workmanship. They should have been detected by the district inspector and resolved prior to final inspection. The contractor was subsequently required to correct the defects.

The contractor's work on the KY 1015 bridge was better. That bridge was in slightly worse condition than the KY 728 with spot corrosion present throughout the existing coating. The contractor had problems with brushing or rolling the MIO-filled moisture-cure polyurethane used for the spot prime and intermediate coats. Spray application was subsequently permitted on both the intermediate and topcoats. Final inspection of the painted bridge revealed very few problems.

The KY 804 bridge project was also completed without significant problems.

The epoxy used for the spot prime and intermediate coats was applied by brushing and the topcoat was applied by rolling. KTC researchers were very satisfied with the completed project.

Painting operations on the KY 177 bridge were more difficult to affect than the plate girder bridges due, in part, to the greater complexity of that structure. The district inspector was handicapped by lack of a wet-bulb thermometer and surface temperature gages needed to measure relative humidity. The representative of the coatings manufacturer assisted with that procedure and on one occasion prevented the contractor from applying the epoxy primer on moist steel. The contractor had conducted relative humidity tests on the bridge deck that indicated painting operations could be performed. But, in the sheltered areas under the bridge, visible moisture remained on the surfaces of the floor beams. The contractor's personnel were beginning to apply paint on those surfaces even though they could see that the steel was not ready for painting.

During application of the epoxy, used as a spot primer and intermediate, lifting was observed in many locations. KTC researchers advised the inspector to have the contractor repair those locations areas by applying additional epoxy and by working it into the tears with brushes. That contributed to the excessively thick coat of epoxy with a DFT between 300-400 microns (12-14 mils). As with the KY 152 bridge, the potential for future disbonding was a concern. The final inspection did not reveal other significant problems.

Painting of the Bluegrass Parkway bridge was complicated by the fact that it was part of a renovation project involving replacement of the expansion joints and bridge piers. That resulted in a staggering of the painting operation over the winter of 1992-3 whiled other work was being performed.

Inspection of the interior portions of the bridge after power washing revealed the presence of tight chalk on the aluminum-pigmented alkyd. That was removed by dry wiping. Most of the hand tool cleaning was performed properly. However, the contractor's personnel were observed to be painting on the lower flanges at a time when the district inspector was not at the job site. KyTC and KTC personnel believed that insufficient hand tool cleaning had been conducted prior to priming at those locations. To prevent similar occurrences, the resident engineer was requested to keep the inspector at the bridge when the contractor was working.

The aluminum-pigmented moisture-cure polyurethane and the succeeding acrylic polyurethane topcoats were applied by rolling. The high-gloss topcoat had a very attractive appearance (Figure 9).

The bulk of the painting operation was completed prior to those repairs.

Areas adjacent to the repairs was primed with the intent to apply the succeeding coats once the other repairs were completed. In several areas, repair work resulted in thermal and mechanical damage to the primer. Those areas were topcoated without needed hand tool surface preparation which led to a few spot failures. Tooke tests revealed resulting DFT of the polyurethane coating system was in the range between 150-200 microns (6-8 mils). That was not considered excessive. A tape adhesion test produced a value of 0B indicating the overcoating system had not improved the adhesion of the total coating system.

Inspection of painting on the KY 1812 bridge indicated the work was progressing satisfactorily. Few defects were detected and the thickness of the overcoating system was not excessive, 125 microns (5 mils) average for the epoxy mastic and 75 microns (3 mils) for the acrylic polyurethane topcoat. No lifting problems were encountered and all exposed edges of the existing paint were properly sealed.

Long-Term Inspections - Inspections of all of the first-phase experimental overcoating projects except, the KY 595 over West Fork of Silver Creek, were conducted in 1994. Most of those bridges, including the KY 595 bridge, were inspected in 1995. Seven of the overcoating projects, the KY 728 bridge, the KY 1015 bridge, the Blue Grass Parkway bridge, the KY 804 bridge, the KY 152 bridge, the KY 595 bridge and US 30 bridge were performing well, most after two to three years service. No coating failures or corrosion were detected. All of those projects except the KY 1015 bridge employed high-gloss polyurethane top coats. The gloss retention on those top coats was excellent. The MIO-pigmented paint on the KY 1015 bridge had a flat finish that blended well with its rural surroundings (Figure 10). Most paint on the KY 152 bridge, a deck truss structure, was performing well. However, rust bleed from joints stained some bridge members detracting from the paint's overall aesthetic appearance.

At the time of the 1994 inspection, the overcoat system on the KY 143 bridge was performing well despite the previously observed deficiencies. The coating had hardened sufficiently to permit walking on the steel. While the calcium-sulfonate alkyd had picked up some soil, it remained intact on the severely deteriorated existing alkyd substrate. Practically no corrosion was observed. However, a follow-up inspection in 1995 revealed several failed areas on horizontal surfaces on the upper and lower chords of the truss. Soils were observed under loose paint at those locations indicating that the failures might be due to inadequate cleaning. Also, corrosion was observed of a number of rivet heads. The coating had continued to pick-up dirt detracting from the bridges aesthetics. The overcoat remained in very good condition at locations under the bridge despite the obvious poor substrate provided by the existing alkyd paint.

Inspections conducted in March 1994, on the KY 177 bridge over the Licking River in Pendleton County (high solids epoxy/acrylic polyurethane) and the KY 1812 bridge over the North Fork of the Kentucky River in Breathitt County (epoxy mastic/acrylic polyurethane) revealed premature disbonding failures (Figure 11). Both of those bridges were truss/I-beam structures. The KY 177 bridge had been in service for 18 months and the KY 1812 bridge about nine months when the failures were first detected. Both coatings failed during the severely cold winter of 1993-1994.

On both bridges, paint that disbonded had completely detached from the mill scale substrates. Disbonding failures were observed on both horizontal and vertical surfaces. On the KY 177 bridge, the most frequent and severe disbonding occurred inside the laced boxes that comprised upper chord members and vertical posts. On the KY 1812 bridge, disbonding was observed both on truss members and stringers of an approach span. Paint chips from both bridges were observed to be bowed in a convex manner suggesting that the overcoating paint had imparted shrinkage stresses to the existing alkyd paint. Apparently, those stresses, combined with thermal stresses due to cold weather, contributed to the failures. Solvents used in the epoxy paints also may have had a role in the failure process. The failures were not excessive, being estimated at less than 5 percent on the KY 177 bridge and less than 2 percent on the KY 1812 bridge.

Initial Second-Phase Overcoating Projects

Four initial second-phase projects were initiated in the spring of 1993 and the last project was completed in the fall of 1995. They included: 1) the KY 20 bridge over Woolper Creek in Boone County, 2) the KY 974 over Upper Howard Creek 3) the US 431 over Green River and 4) the US 31E bridge over the Beech Fork River near Bardstown in Nelson County (Table 2).

Specifications for those experimental projects differed from the earlier ones. Hand tool mechanical surface preparation was eliminated and the number of coats of paint was reduced. Those changes resulted from the enactment of the OSHA Final Interim Lead Rule. That regulation severely impacted mechanical surface preparation of existing lead paints. On those projects, surface preparation was limited to low pressure (50 psi) water rinsing. Spot priming was not employed. The coatings were commonly applied by spraying to minimize overcoating costs. The KY 30 bridge over the South Fork of KY River might be considered a second-phase project as the surface preparation on that project was primarily pressure washing and the overcoating system was applied by spraying.

<u>Preliminary Field Inspections</u> - A preliminary field inspection was conducted on the KY 20 bridge. The inspection revealed debris accumulations on the girders indicating that they were occasionally under

water when Woolper Creek rose. Paint on the girders possessed large blisters which were probably caused by the periodic immersion. Peeling paint and extensive corrosion were also present. The existing coating on the bridge was in very poor condition and KTC researchers considered it a severe test for the second-phase approach to overcoating.

Project Inspections - The KY 20 bridge experimental overcoating specification originally required two coats of paint (epoxy mastic/acrylic polyurethane) to be applied by spraying. The cleaning was found to be sufficient to remove soil and debris. However, the paint blisters remained unaffected. When the epoxy mastic was being applied, the blistered paint was observed to be breaking off, probably due to shrinkage stresses imparted by the curing epoxy. Division of Construction officials elected to revise the painting procedure. The contractor was asked to defer from applying further epoxy mastic and to apply only the acrylic polyurethane topcoat by brushing. The painters were told to apply firm pressure with the paint brushes to break the paint blisters. They were to thoroughly work the polyurethane paint into the broken blisters and to tack and incorporate any loose paint chips into the topcoat.

The project was completed successfully and many of the blisters were properly treated as requested by Division of Construction officials. Most of the exposed edges of the existing alkyd paint had been adequately penetrated and sealed by the brush-applied polyurethane.

The US 31E bridge was inspected during cleaning and application of the single spray-applied coat of acrylic polyurethane. The contractor demonstrated that the washing pressure was inadequate to properly remove surface dirt. The contractor encountered problems when spraying the polyurethane paint on grimy surfaces. Typically, that resulted in paint runs. The existing paint was in poor condition with significant corrosion and islands of remaining weathered alkyd paint. The spray application properly sealed upward-facing exposed edges of the alkyd paint, but did not adequately seal other edges.

The completed project had a fair appearance when viewed from a distance. As this bridge was scheduled for replacement in 6 years, the quality of the completed overcoating project was considered to be adequate. Its sole function was cosmetic.

Inspection of the US 431 bridge revealed that the contractor was adhering to the overcoating specifications. At locations where the existing paint was firmly adherent, the epoxy mastic/polyurethane overcoating system was performing well. Where the existing paint was peeling, the overcoating system had failed to properly penetrate or seal the exposed edges. Those locations were more prevalent on the upper chord, especially in the box girders.

Long-Term Inspections - The KY 20 and US 31E bridges were inspected in the spring of 1994 and all of those projects were inspected in late 1995.

The KY 20 bridge was performing satisfactorily on both inspections. Peeling paint was observed at a few locations where the painters had failed to properly work in the polyurethane paint (Figure 12).

The US 31E bridge was performing satisfactorily in 1994. Some corrosion was evident at a few locations on the bridge, but those did not significantly detract from its appearance. However, in 1995 the appearance deteriorated appreciably due to rust bleed from exposed edges of the existing paint that were not adequately sealed. KTC researchers believed that the project would have been improved if the polyurethane had been applied by brushing to more completely penetrate and seal the exposed edges.

The KY 974 bridge over Upper Howard Creek was inspected in 1995. The small truss bridge was in generally good condition. Only a few failure locations were observed on the lower portions of the bridge where the existing alkyd paint had corroded prior to overcoating. At those locations, the overcoating paint was beginning to blister and rust stains were visible. Vandals had applied a large amount of painted graffiti over the newly overcoated bridge.

The initial second-phase projects constituted a radical approach to overcoating. KyTC and KTC researchers were generally dissatisfied with those results and decided to attempt further revisions to application procedures based upon the initial field exposure tests performed at the KyTC bridge yard in 1993.

Follow-on Second-Phase Overcoating Projects

Four follow-on second-phase projects were initiated in the spring of 1994. The projects included: 1) the US 25 overpass over I 75 in Fayette County, 2) the KY 52 bridge over the Beech Fork River in Nelson County, 3) the US 42 bridge over the Kentucky River in Carroll County at Carrollton and 4) the US 31W bridge over the Green River in Hart County at Munfordville (Table 3). Those projects differed from the initial second-phase projects primarily in the use of penetrating sealers or very surface-tolerant coatings and in the requirement for brush application of all coatings placed directly on existing alkyd paint though spraying was allowed in subsequent topcoats. Hand tool cleaning was only permitted on the US 25 bridge as the existing paint was not contain lead.

Preliminary Field Inspections - Preliminary inspections were conducted on all of the follow-on second-phase projects. The preliminary condition of the US 25 bridge over I 75 has been previously described.

The existing alkyd paint on the KY 52 bridge over the Beech Fork River was in relatively good condition. The only significant corrosion was on steel directly under deck joints. However, the bridge was covered with a large amount of soils.

The existing alkyd paint on the US 42 bridge over the Kentucky River at Carrollton was in fair condition with spot corrosion and peeling paint at many locations. The existing paint on the floor system was in good condition with little observable rust.

The existing paint on the US 31W bridge over the Kentucky River was found to be in similar condition to the paint on the US 42 bridge. In some locations the existing paint was covered with a significant amount of mildew. That was the first bridge in the KyTC experimental overcoating program having that problem.

Project Inspections - For the US 25 bridge, KyTC officials elected to remove the wax on the end spans using a chemical stripping agent and to overcoat the central spans over the roadways. The alkaline paint stripper successfully removed the wax exposing the previously blast-cleaned surface. The contractor was to remove the stripper within 24 hrs of its application using a low-pressure wash. His painting facilities limited the areas that could be treated and stripped in one day. The contractor elected to cover a larger area in several days and risk removing the stripper by power washing after the stripper had remained in place for 3-4 days. While that approach worked, it resulted in significant stripper-contaminated overspray. In part, that was contained by drapes that the contractor had suspended from the bridge. However, personnel at the job site were exposed to the caustic spray and a number of persons experienced caustic burns. The exposed steel had to be recoated within 24 hours to prevent rust bloom.

Hand tool cleaning was conducted on all rusted areas on the bridge. All surfaces on the central spans were given a 27 MPa (3,000 ps)i power wash. The cleaned surfaces could be painted 24 hours after cleaning.

Two district inspectors were employed on the project. Both inspectors were relatively unfamiliar with painting operations and one inspector was physically incapable of climbing onto a truck the contractor used to access the bridge steel away from the abutments.

Two coats of calcium-sulfonate alkyd paint were subsequently applied by spraying. The primer coat was tinted white and the top coat dark blue

(Figure 13). The paint was a fast-drying formulation developed by the same coatings manufacturer who supplied paint for the KY 143 bridge. The white primer dried rapidly, but the blue topcoat took about three weeks to harden sufficiently to permit thickness testing. The final inspection disclosed several deficiencies including insufficient topcoat on fascia beams and uncoated areas in bearing areas at bridge piers. The contractor subsequently affected the specified repairs.

The good condition of the existing alkyd paint on the KY 52 bridge allowed the contractor to employ a 13.5 MPA (1,500 psi) power washing on the bridge. The power washing operation was repeated once and a detergent employed to properly clean the steel. The cleaned surfaces could be painted 24 hours after washing. The overcoating system was a single coat of calcium-sulfonate alkyd applied by brushing. While the contractor completed to project satisfactorily, the DFT of the overcoat was slightly less than the minimum specified by the coatings manufacturer - 125 microns (5 mils) versus the specified minimum of 150 microns (6 mils). The coatings manufacturer's representative stated that it was difficult to achieve a consistent build-up of the calcium-sulfonate alkyd in less than two coats by brushing. However, he stated that the coating could be built-up to 10 mils in one spray coat.

The inspector working on the KY 52 bridge was borrowed from another district. He was experienced with painting practices and was able to climb on the bridge and properly inspect all phases of the contractors work.

The paint contractor working on the US 42 bridge initially used the specified 100 psi wash for surface cleaning. When that did not prove sufficient to properly clean the existing paint, he was allowed to increase the water pressure to 13.2 MPa (1,500 psi) in areas where no existing paint was removed. In other areas, washing at a lower water pressure or wiping with wet rags were required. The cleaned surfaces were to be painted 24 hours after washing.

The paint system consisted of a single coat of an MIO-pigmented moisture-cure polyurethane penetrating sealer brush-applied completely over the bridge followed by an MIO-pigmented moisture-cure polyurethane top coat applied by spraying. The contractor was allowed to apply the topcoat by spraying.

Problems were encountered in brushing penetrating sealer onto locations where large paint peels were present. Additionally, the painters did not properly work the penetrating sealer into exposed edges of existing paint. In part, that was due to mis-communication with coating manufacturer's representative on to how to properly apply the paint. Exposed edges of the existing paint were found that were not properly penetrated or sealed by the penetrating sealer. That problem was resolved by requiring the contractor to apply the top coat by brushing onto incompletely sealed areas.

The district inspector was able to climb and properly inspect the project. He was experienced with overcoating having worked on the KY 177 project. The inspector was sometimes frustrated by frequent discussions concerning surface preparation and coating application with the painting contractor.

The contractor painting the US 31W bridge was permitted to use a variable pressure power wash as long as no existing paint was removed. In other areas, the contractor was required to use the lower water pressure or wiping with wet rags to achieve proper surface cleaning. No mechanical surface preparation was employed. The cleaned surfaces were to be painted 24 hours after washing.

A 10-ft^2 paint test patch area was placed upon a representative portion of the bridge containing freckle corrosion and peeling paint. The painters brushed the aluminum-filled moisture-cure penetrating sealer to used as a spot primer over the entire area. The intermediate coating, was brushed on two-thirds of the test patch. Half of that area was brushed with the top coat. The application was witnessed and approved by the coating manufacturer's technical representative and by the district inspector. The test patch was to be used to resolve any controversies related to coating application. However, no such problems arose.

The aluminum-pigmented moisture-cure polyurethane penetrating sealer was to be brushed on distressed areas as a spot primer. It was also to be applied on areas of the bridge that contained extensive mildew. An intermediate coating of a MIO-pigmented moisture-cure polyurethane paint was to be applied by brushing. Spraying was permitted in interior portions of laced box members. A top coat of MIO-pigmented polyurethane was applied by spraying.

As with the US 42 bridge, some problems were encountered in painting around large peels. During application of the penetrating sealer, KyTC inspection personnel and KTC researchers had concern that the penetrating sealer was not being properly applied. The exposed edges were observed not to be sealed after application of the penetrating sealer. In several representative areas, the existing paint was probed by stripping it away with a knife. In those locations, the penetrating sealer had properly wicked under the exposed edges and had penetrated to bonded existing paint. It was determined that sealing would be provided by the intermediate coat.

Officials from the National Institute of Occupational Safety and Health (NIOSH) visited the job site while work was in progress. They were invited by KyTC officials who wished to determine whether the new specifications would be sufficiently non-invasive to the existing lead-based paint as to not require the engineering controls specified in the OSHA Final Interim Lead Rule. The NIOSH officials believed that the specification would not require the imposition of engineering controls to protect workers from lead exposure. KyTC officials plan to invite NIOSH representatives to inspect subsequent overcoating projects and to allow them to monitor painters to determine their exposure to lead.

Long-Term Inspections - All of the follow-on second-phase experimental overcoating projects were inspected in 1994 and 1995. Inspections of the US 25 bridge revealed that it was in good condition except on the bearing areas at the abutments. Close inspections of those locations revealed that the contractor had not properly removed all of the paint stripper from those areas causing the new paint to fail.

Inspections of the KY 52 bridge found the overcoating system to be in excellent condition.

The overcoating system on the US 42 bridge was in excellent condition when inspected in 1994. However, when inspected in 1995, numerous small spot failures were observed on the bridge, In part, those failures may be due to the failure to achieve a proper application of the penetrating sealer. It may also be related to the use of an "austere" two-coat overcoating system. Better performance might have been achieved if the overcoating system had incorporated a full intermediate coat to achieve higher build.

In contrast to the US 42 bridge, the coating system on the US 31W bridge has performed extremely well through 1995 (Figure 14). One small spot failure was detected on that bridge which may have been the result of vandalism.

CONCLUSIONS

The KTC research has been successful in meeting most of the objectives set forth in its work plan. Some changes in emphasis and modifications to objectives resulted. However, the basic work plan remains viable and a blueprint for future KTC coatings research work. It is anticipated that the project will be fully resurrected in the future. Until then, KTC researchers will continue research under construction-related studies.

Research related to new coatings did not provide any significant changes though KTC researchers accumulated significant knowledge that will be useful in addressing that matter in the future. Division of Construction officials and KTC researchers have agreed upon future experimental coating systems.

The main objectives of this study and main areas of progress are related to the selection of experimental overcoating systems and the KTC support of the KyTC experimental overcoating program.

The KTC laboratory corrosion/weathering tests showed promise but, as indicated in the first series of tests was in need of further refinement. In the future, those tests will vital for evaluating the new coatings employed by KyTC.

The field exposure tests proved very useful. Current plans are for KTC researchers to employ a barricaded bridge in Frankfort as a test bed for future coatings and applications research.

Most of the first-phase KyTC bridge overcoating projects remain both durable and attractive. Failures of a few experimental projects were anticipated prior to the initiation of this work. None of the failures encountered were either severe or widespread. Eventually, they may be repaired. The low initial project costs permit such repairs without significant detriment to average unit overcoating costs.

The first-phase experimental overcoating projects achieved one prime KyTC objective by providing low initial costs were estimated to range from \$10 to \$32 per m^2 (\$0.93 to \$3.27 per ft^2.

The initial second-phase overcoating projects were also deemed successful. KyTC officials intended to investigate the use of low-cost, minimal overcoating systems as a means to offset an anticipated loss of coating durability due to the elimination of mechanical surface preparation. It was difficult to determine the unit costs for the initial second-phase projects as they involved other bridge rehabilitation work. It is estimated that they were in the same cost range as the first-phase projects. In part, that was due to contractor unfamiliarity with the experimental specifications.

The follow-on second-phase KyTC experimental overcoating projects continued to rely solely on washing for surface preparation. An emphasis was been placed on achieving adequate cleaning while not removing any existing lead paint.

If variable-pressure washing does not prove effective, other approaches to cleaning that do not entail mechanical surface preparation (e.g. hot water washing, steam cleaning, detergents, alkaline cleaners, etc.) will be evaluated. Consideration will be given to using mechanical surface preparation on bridges where conventional brushing techniques are ineffective. Vacuum-shrouded hand- or power tools will be considered for use in those instances. Overcoating projects involving large bridges will probably incorporate mechanical surface preparation to enhance overcoating durability. On smaller projects, especially those involving overpass bridges, mechanical surface preparation will probably not be used or be limited to bearing areas.

The impact on overcoating costs may be determined by reviewing several recently completed overcoating projects. The US 42 and US 31W bridges had approximately 1,200 and 1,100 tons of steel. Those projects were let for \$186,000 and \$322,000. In part, the cost difference was related to the types of structures and also to the specific overcoating systems employed. The resulting project unit costs were approximately \$ 13.34/m^2 and \$25.18/m^2 (\$1.24/ft^2 and \$2.34/ft^2), respectively. Those low unit costs indicate that the current KyTC approach to bridge maintenance painting is effectively containing costs. KTC researchers have been appraised that the KyTC experimental overcoating project costs are as low as any obtained by state highway agencies throughout the US.

The current performance of the experimental overcoating projects indicates that they will prove at least as durable as similar work performed prior to 1980. It is likely that they will perform much better. Eventually, plans will be needed for long-term maintenance (spot painting) of those coatings to allow them the last at least 20 years. Thereafter, those coatings will be completely overcoated and the coating cycle will be repeated until the bridges are replaced.

The KyTC district inspection was of varying effectiveness. Further training is needed and Division of Construction and KTC researchers have discussed formal overcoating training. The contractor situation and the nature of KyTC specifications require inspectors that are active and assertive in ensuring proper contractor work. The inspectors must be willing and able to climb and to spend considerable time on pick boards to oversee contractor quality. To date, few of the inspectors provided by the districts have had those qualities.

The Division of Construction has a limited number of inspectors available that can be expected perform inspections as desired. In the future, maintenance painting projects may be conducted on a much large scale necessitating more capable inspectors. Inspection is critical to the success of KyTC overcoating projects and efforts must be made to provide qualified inspectors.

In Fiscal Year 1995, four phase-three KyTC experimental overcoating projects were performed. They will be reviewed in a forthcoming report. Those projects represent a significant departure in program philosophy as KyTC chose to adopt cookbook/performance specifications incorporating polyurethane coatings systems. Application specifications entailed the brush-application of a spot primer over distressed areas followed by one or two full top coats. Where a full intermediate coat were applied by brushing, the contractor was allowed to spray the top coat. Those projects are of interest as they presage several very large maintenance painting projects scheduled in fiscal years 1997 and 1998 in the Louisville area.

The KyTC experimental overcoating program is, of necessity, a reactive one that must respond to the dictates of environmental and worker protection regulatory agencies and will also evolve in response to new regulations. The program will also respond to internal needs such improving field inspection and attracting quality-oriented contractors. KyTC will continue to develop and adopt innovative approaches to achieve cost-effective, environmentally-compliant maintenance painting of steel bridges.

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FIGURES

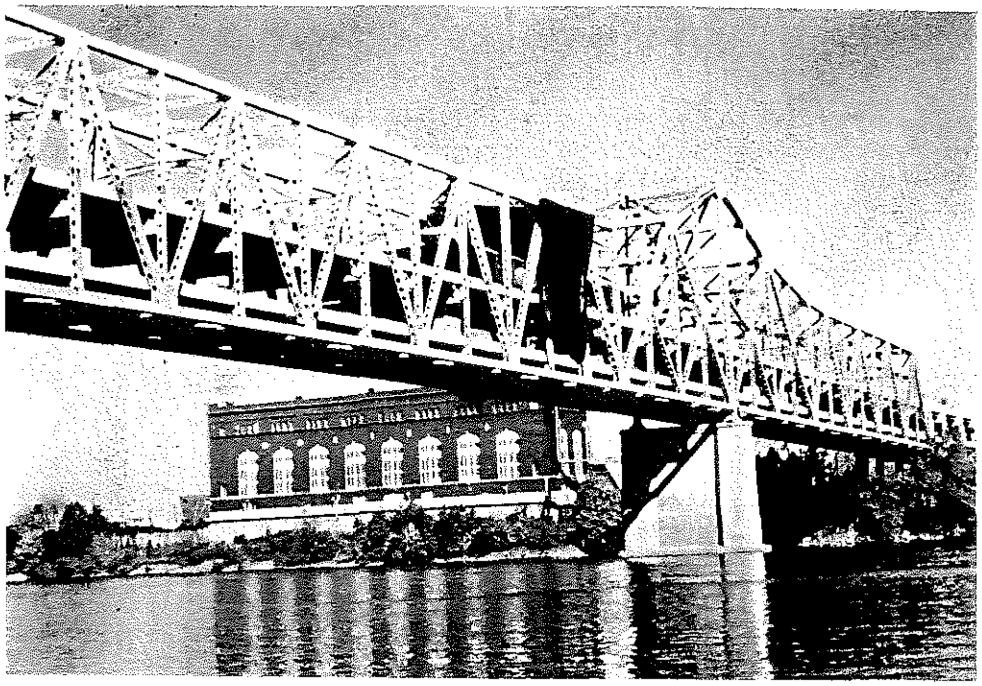

Figure 1. Containment Windscreens Employed on the I 75 Bridge at Covington (1990).

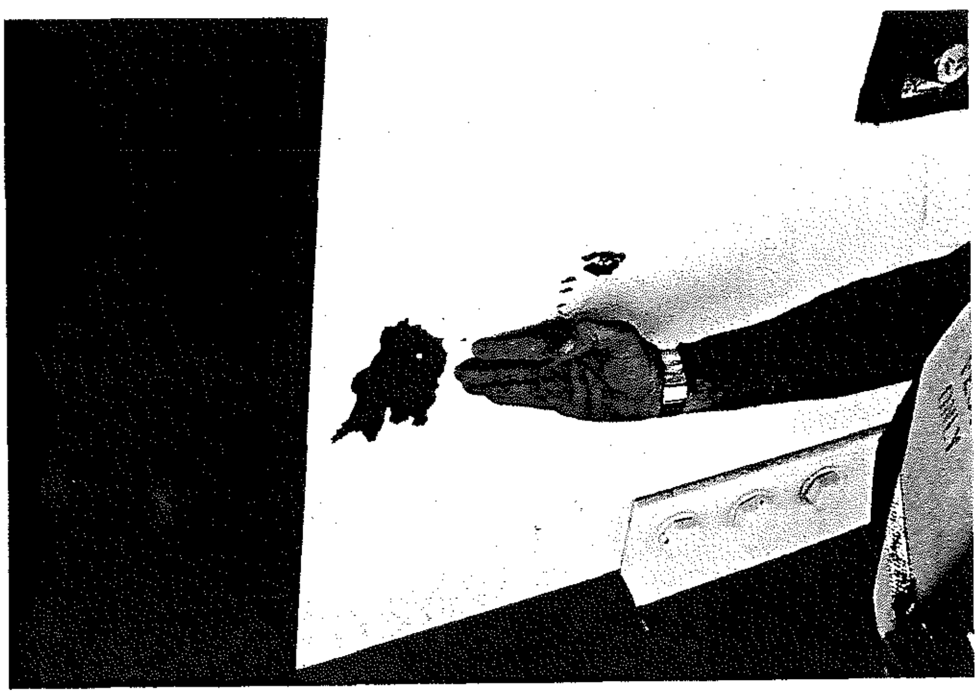

Figure 2. Coating Failure on New Construction Steel on the US 27 Bridge at Covington (1993).

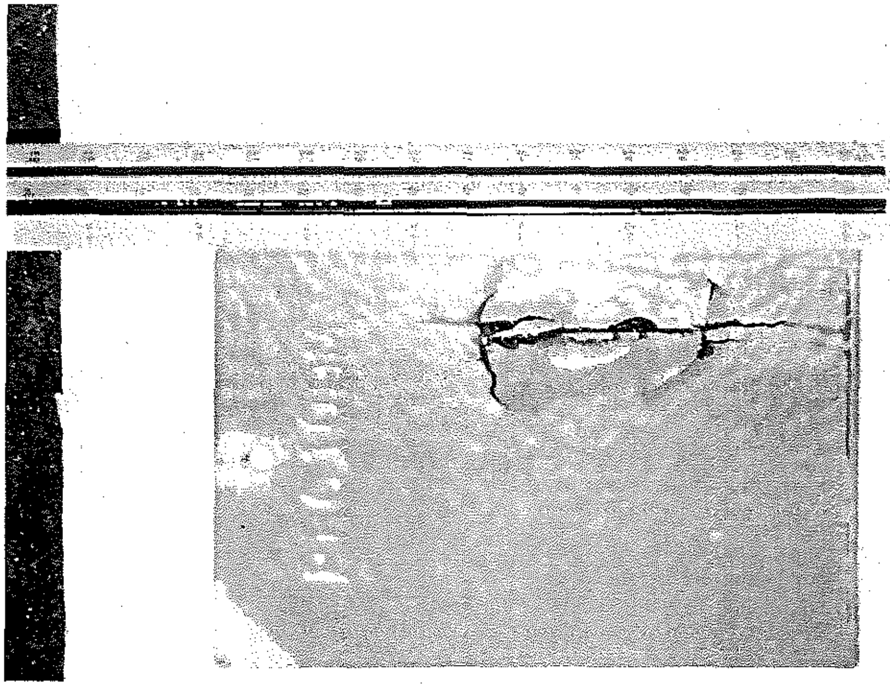

Figure 3. Accelerated Corrosion/Weathering Overcoating Specimen that Failed by Undercutting at the Scribe (1996).

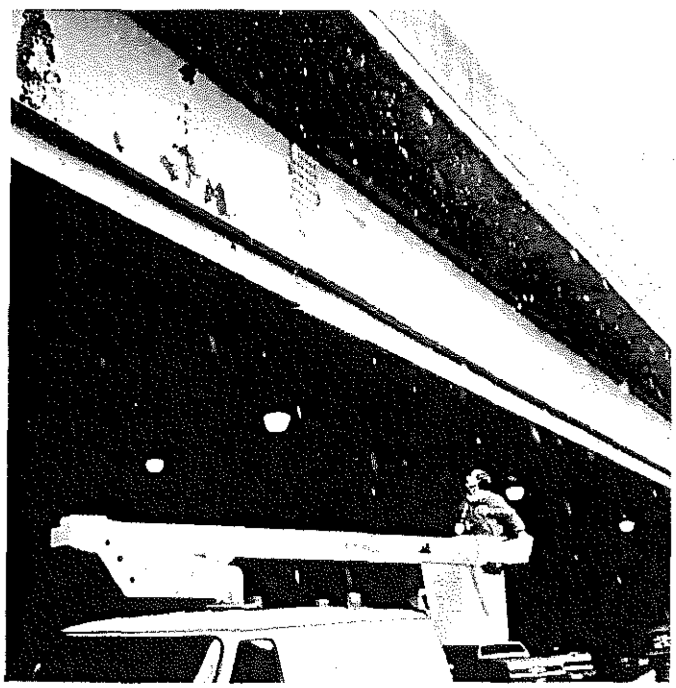

Figure 4. Completed Field Exposure Test Patches on the I-65 Expressway at Preston Street in Louisville (1992).

Figure 5. Initial Condition of the KY 177 Bridge Showing Severe Weathering of the Alkyd Topcoat (1992).

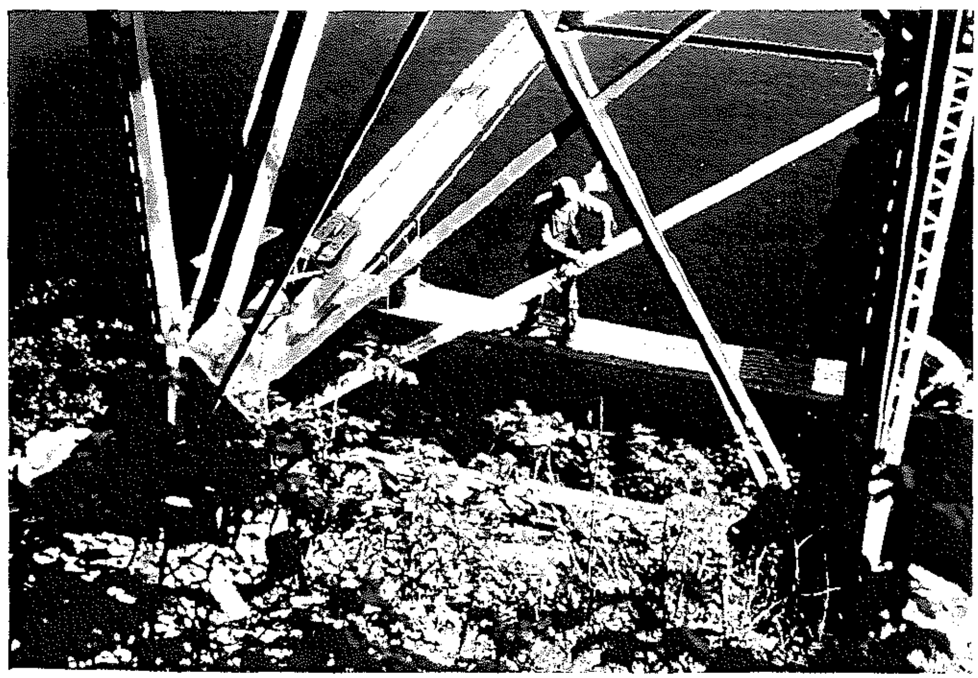

Figure 6. Application of Overcoating System on the KY 152 Bridge by Rolling (1992).

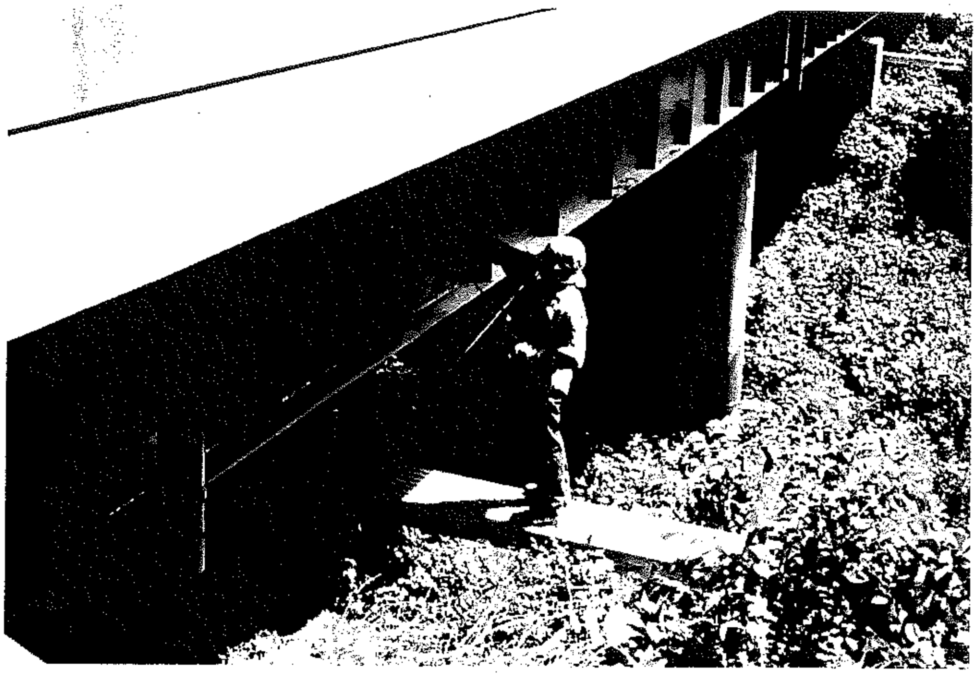

Figure 7. Application of Overcoating System on the KY 728 Bridge by Spraying (1992).

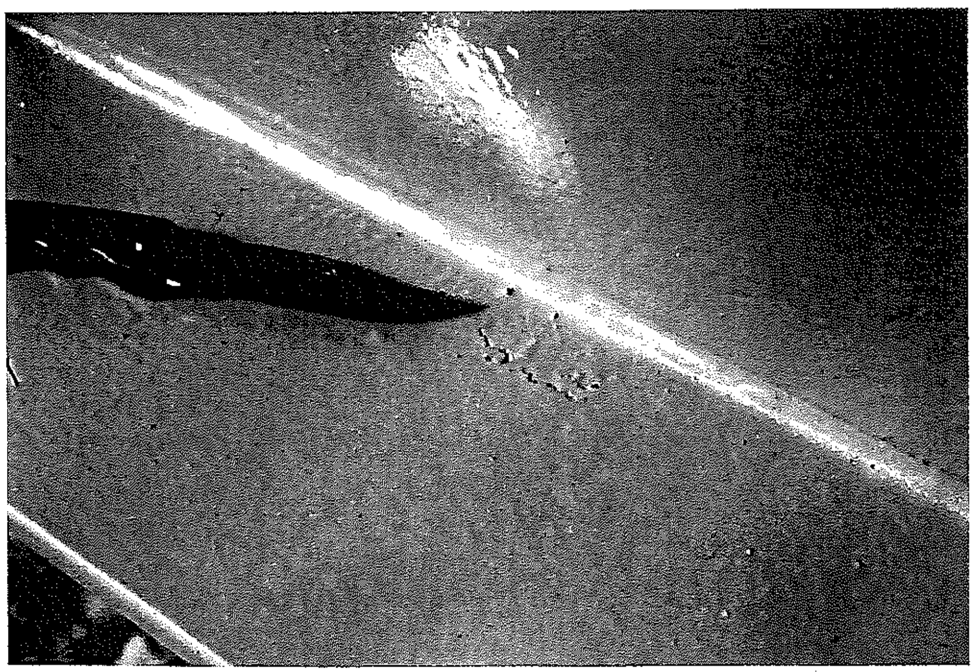

Figure 8. Lifting Tear Reflected Through Successive Coats of Paint on the KY 728 Bridge (1992).

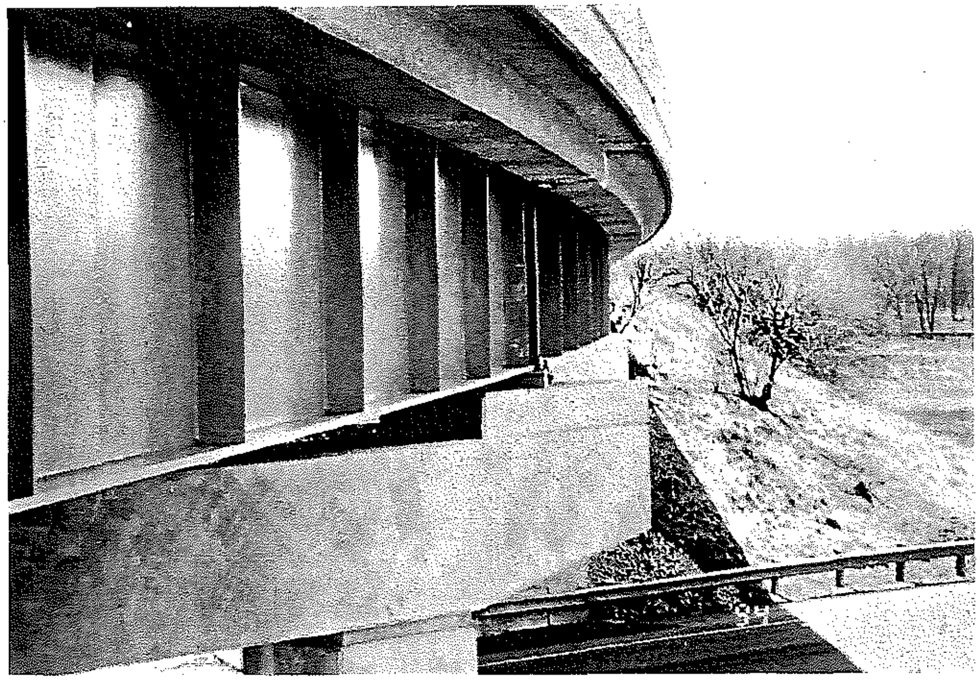

Figure 9. High-Gloss Polyurethane Topcoat on the Overcoated Bluegrass Parkway Bridge over US 60 (1994).

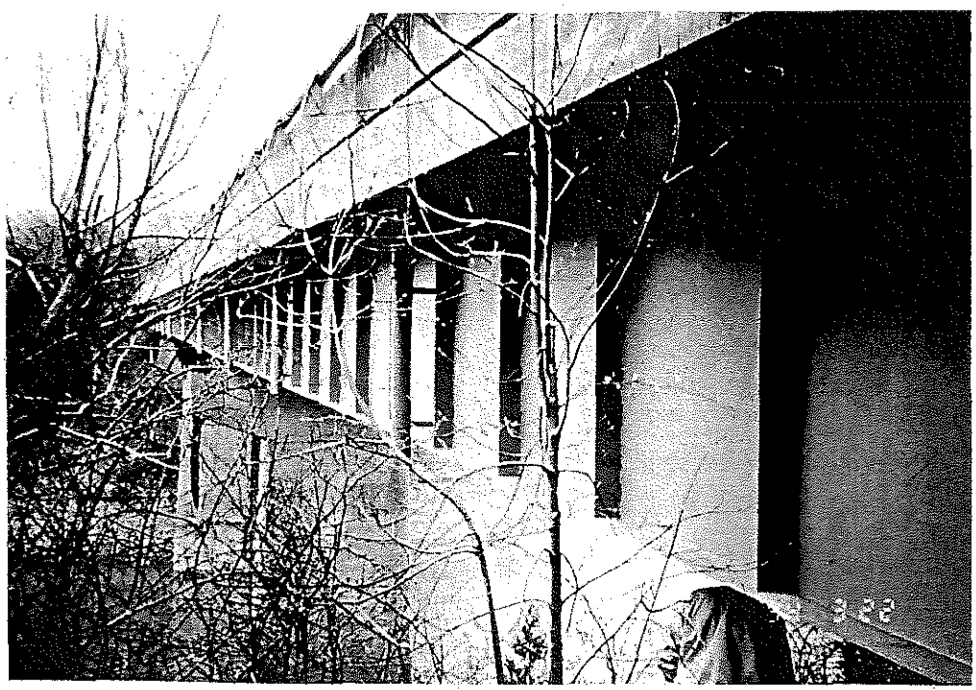

Figure 10. KY 1015 Bridge after Overcoating (1994).

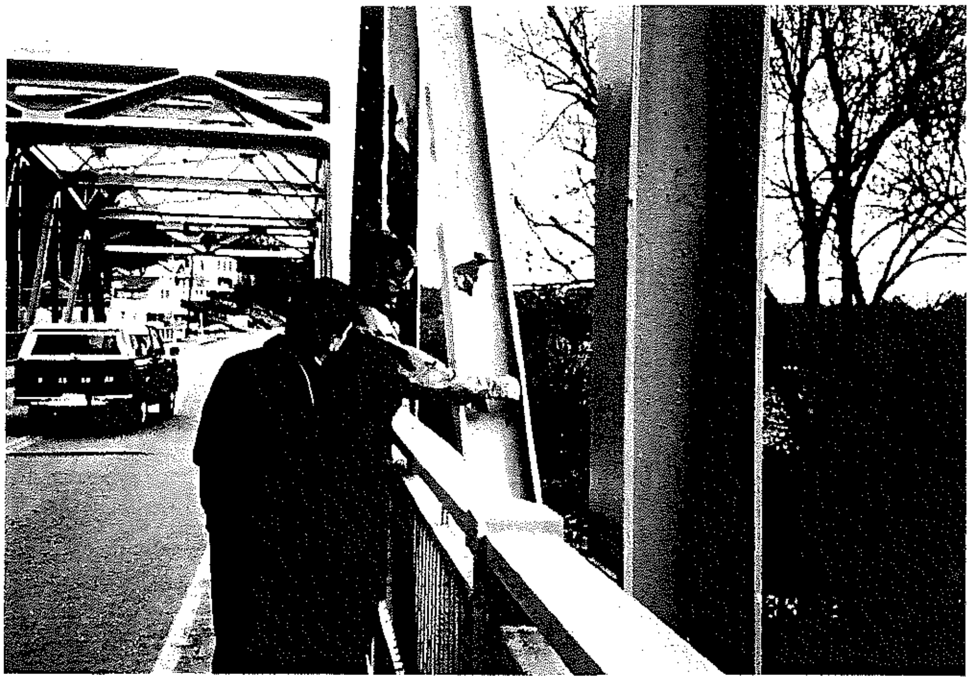

Figure 11. Disbonding Failure of Overcoating System on the KY 177 Bridge (1994).

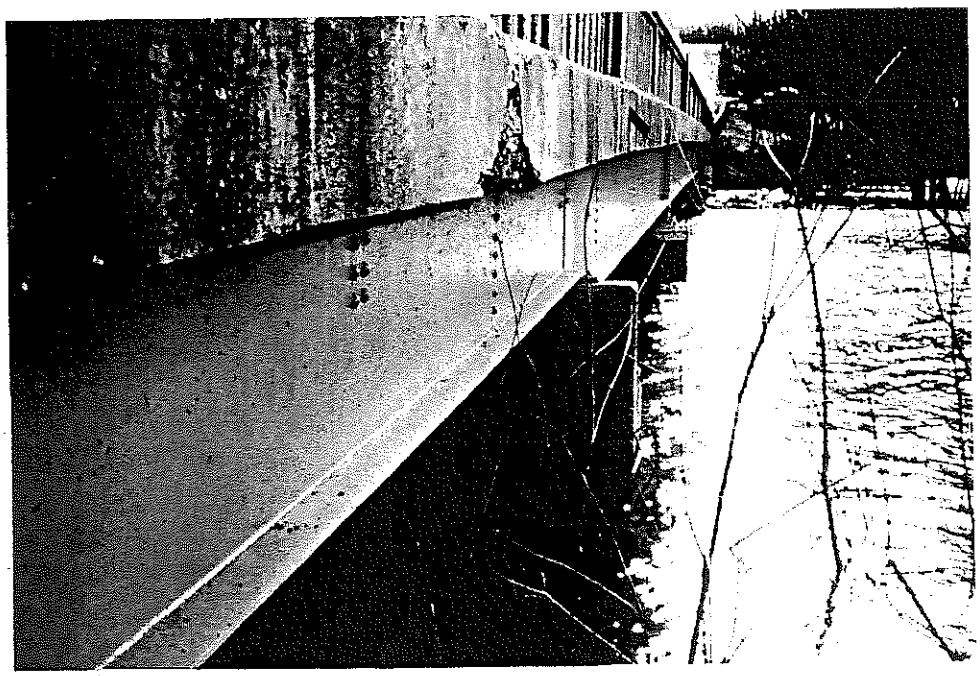

Figure 12. KY 20 Bridge after Overcoating (1994).

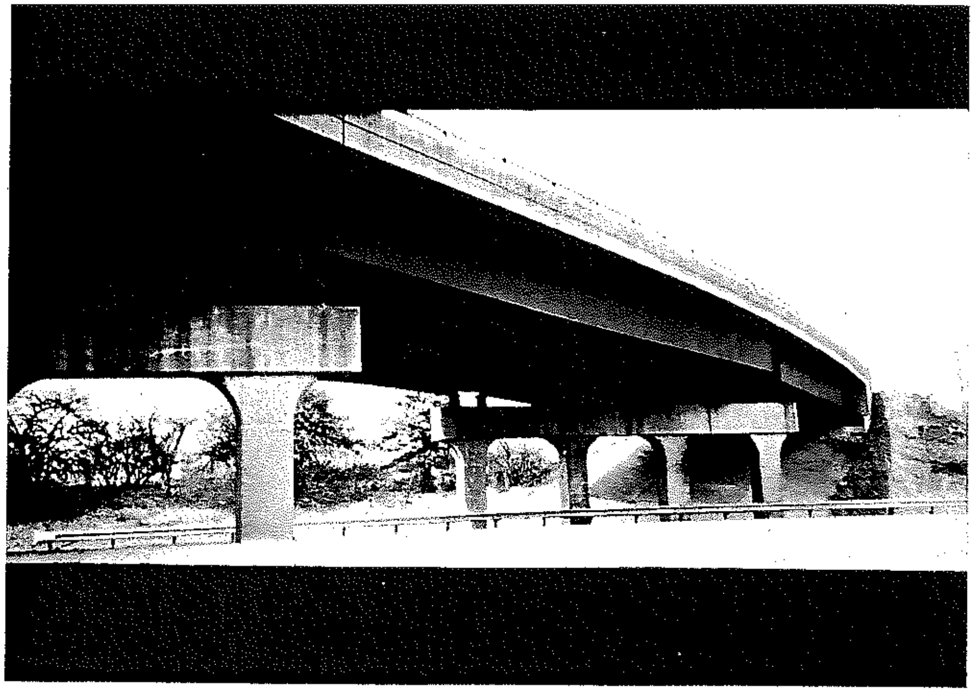

Figure 13. US 25 Bridge after Overcoating (1994).

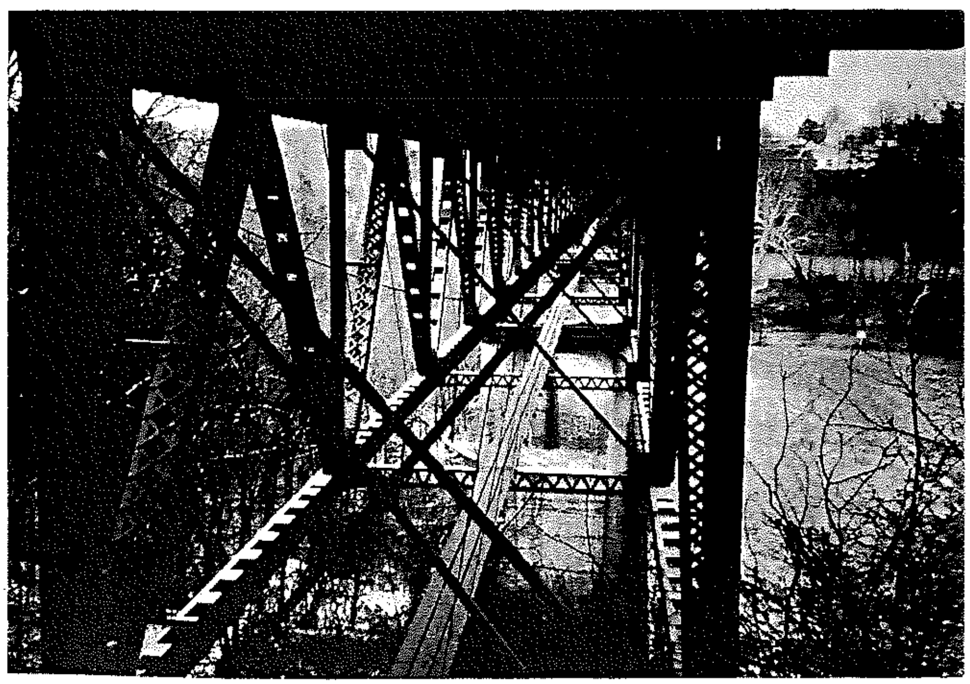

Figure 14. US 31W Bridge after Overcoating (1995).

TABLES

Table 1. Summary of First-Phase KyTC Experimental Bridge Overcoating Projects (1992-1994)

Bridge No.	Location// Identification No.	County// District No.	Bridge Description	Tons of Steel-Metric (Short)	Existing Paint// Condition	Surface Preparation	Overcoating System//Method of Application	Project Cost	Completion Month/Year
1.	KY 804 over the Southern R.R.// SRS-100-0804 -002.330(B91)	Pulaski// 8	1-27.8 m (90 ft.) and 2-18 m (59 ft.) rigid steel frame spans	72 (80)	gray alky topcoat over red lead primer//topcoat wheathered on legs: some corrosion at bearing areas	2,500 psi pressure washing: hand tool cleaning	polyamide epoxy spot prime// brush: polyamide epoxy int. coat//brush: acrylic polyurethane topcoat//roll	$20,000	9/92
2.	KY 728 over Bacon Creek// SRS-050-0728 -008.367(B21)	Hart// 4	2-27.8 m (90 ft.) continuous steel girder spans	180 (198)	aluminum alkyd topcoat over red lead primer//very good: little corrosion at bearing areas and deck joints	2,500 psi pressure washing: hand tool cleaning	ceramic acrylic full prime//brush: epoxy mastic int. coat//spray: acrylic polyurethane topcoat//spray	$34,000	6/92
3.	KY 177 over Licking River at Butler// SRS-096-0177 -004.852(B1)	Pendleton// 6	2-25.9 m (84 ft.) steel deck girder spans and 3-46.4 m (150.5 ft) steel thru truss spans	493 (542)	previously overcoated: four alkyd coats//severely weathered topcoat: some corrosion on lower chord	2,500 psi pressure washing: hand tool cleaning	amido-amine epoxy spot prime//brush: amido-amine epoxy int. coat//brush: acrylic polyurethane topcoat//roll	$132,000	7/92
4.	KY 143 over Vaughn Ditch// SRS-117-0143 -009.462(B43)	Webster// 2	1-24.7 m (80 ft.) steel pony truss span	7.2 (8)	previously overcoated: multiple alkyd coats//severely depleted coating: extensive corrosion[1]	2,500 psi pressure washing: hand tool cleaning	calcium-sulfonate alkyd full prime//spray: calcium sulfonate alkyd topcoat//spray	$15,500	4/92
5.	KY 595 over West Fork Silver Creek// SRS-076-595 -000.483	Madison// 7	1-13.3 m (43 ft.) steel I-beam span	9.1 (10)	unknown: not inspected prior or during painting	2,500 psi pressure washing: power tool cleaning	water-borne acrylic spot prime//brush: water-borne acrylic int. coat//brush: water-borne acrylic topcoat//spray	$7,500	5/94
6.	KY 1015 over Dog Creek// SRS-050-1015 -000.793(B19)	Hart// 4	1-41.4 m (134.5 ft.) and 2-33.2 m (107.7 ft.) steel continous girder spans	349 (385)	aluminum alkyd topcoat over red lead primer//coating in fair condition - spot corrosion	2,500 psi pressure washing: hand tool cleaning	MIO m.c. polyurethane spot prime//brush: MIO m.c. polyurethane int. coat//brush: MIO m.c. polyurethane topcoat//spray	$72,000	7/92
7.	Blue Grass Pkwy over US 60// MP120-9002 -071-110	Woodford// 7	1-15.2 m (50 ft.), 1-33.5 m (110 ft.) and 1-19.8 m (65 ft.) steel continuous girder spans	180 (198)	aluminum alkyd int. and topcoats over red lead primer// paint in fair conditon - weathered and some spot corrosion at some locations	2,500 psi pressure washing: hand tool cleaning	aluminum m.c. polyurethane spot prime//roll: acrylic polyurethane int. coat//roll: acrylic polyurethane topcoat//roll	$34,000	4/93
8.	KY 152 over Harrington Lake//	Garrard// 7	1-13.7 m (45 ft.) and 1-14 m (46 ft.) steel cantilever deck truss spans and 1-18.3 m (60 ft.) and 3-64 m (210 ft.) steel deck truss spans	437 (481)	previously overcoated - multiple alkyd coats//peeling coating: extensive corrosion	2,500 psi pressure washing: hand tool cleaning	aluminum epoxy mastic spot prime//brush: aluminum epoxy mastic int. coat//roll: acrylic polyurethane topcoat//roll	N/A (includes renovation)	6/92
9.	KY 1812 over North Fork of KY River// SRS-013-5300 -C00039	Breathitt// 10	1-27.8 m (90 ft.) steel pony truss, 1-51.2 m (166 ft.) steel thru truss and 1-18.5 m (60 ft.) steel I-beam spans	136.5 (150)	previously overcoated - multiiple alkyd coats//extensive corrosion	1,500 psi pressure washing: power tool cleaning	epoxy mastic spot prime//brush: epoxy mastic int. coat//roll: acrylic polyurethane topcoat//roll	$61,300	4/93
10.	KY 30 over the South Fork of KY River// MP-095-0030 -011.478(B2)	Owsley// 10	2-43.3 m (142 ft. steel thru truss spans and 1-12.1 m (40 ft.) steel I-beam span	N/A	inorganic zinc/vynil//chalked with some corrosion a bearings	1,500 psi pressure washing: hand tool cleaning	epoxy mastic full prime//spray; acrylic polyurethane topcoat//spray	$694,000 (includes renovation)	11/93

Legend:

N/A - Not available

Notes:

1. Evaluation of initial conditon obtained from photographs and KyTC sources.

Table 2. Summary of Initial Second-Phase KyTC Experimental Bridge Overcoating Projects (1993-1995)

Bridge No.	Location// Identification No.	County// District No.	Bridge Description	Tons of Steel-Metric (Short)	Existing Paint// Condition	Surface Preparation	Overcoating System//Method of Application	Project Cost	Completion Month/Year
1.	KY 20 over Woolper Creek// FE02-008-0020 -002.802(B18)	Boone// 8	1-24 m (78 ft.), 2-16.2 m (52.5 ft.) and 2-12.6 m (40.8 ft.) steel continuous I beam spans	N/A	previously overcoated - multiple alkyd coats//existing paint poor: extensive blistering, spot corrosion	50 psi washing with detergent	aluminum epoxy mastic full prime//spray: acrylic polyurethane topcoat//brush	$55,200 (includes renovation)	11/93
2.	KY 974 over Upper Howard Creek// CB06-025-0974 -010.537	Clark// 7	1-24.7 m (80 ft.) steel pony truss span	13.7 (15)	unknown: not inspected prior or during painting	50 psi washing with detergent	acrylic polyurethane topcoat//brush	$9,500	6/94
3.	US 431 over Green River// BHO 431-2(12), FD28 -075-0431-005-006	McLean// 2	10-16.8 m (55 ft.) steel I-beams, 1-91.44 m steel continuous plate girder span and 3-45 m (148 ft.) steel deck truss spans	662 (729)	previously overcoated - multiple alkyd coats//existing paint poor: extensive peeling, extensive corrosion	50 psi washing with detergent	aluminum epoxy mastic full prime//spray: acrylic polyurethane topcoat//spray	$1,976,400 (include renovation)	8/95
4.	US 31E over Beech Fork River// FE02-090-031E -012.815(B45)	Nelson// 4	3-43.2 m (140 ft.) steel thru truss spans	268 (295)	previously overcoated - multiple alkyd coats//existing paint poor: extensive peeling, extensive corrosion	50 psi washing with detergent	acrylic polyurethane topcoat//spray	$74,000	11/95

Legend:

N/A - Not available

Table 3. Summary of Follow-on Second-Phase KyTC Experimental Bridge Overcoating Projects (1994-1995)

Bridge No.	Location// Identification No.	County// District No.	Bridge Description	Tons of Steel-Metric (Short)	Existing Paint// Condition	Surface Preparation	Overcoating System//Method of Application	Project Cost	Completion Month/Year
1.	US 42 over Kentucky River at Carrollton// FE02-021-0042 -043.948(B43)	Carroll// 6	6-18.5 m (60 ft.), 3-21.5 m (70 ft.) steel continuous girder spans, 2-62 m (201 ft.) and 1-92.5 m (300 ft.) steel truss spans	1,091 (1,199)	previously overcoated - multiple alkyd coats//existing paint poor: extensive peeling, spot corrosion	150 psi washing* with detergent (* variable pressure permitted)	MIO m.c. polyurethane penetrating sealer full primer//brush: MIO m.c. polyurethane topcoat//brush	$186,600	10/94
2.	KY 52 over Beech Fork River// FE02-090-0052 -000.838	Nelson// 6	2-27 m (87.5 ft.) and 1-38.6 m (125 ft.) steel continuous girder spans	268 (295)	alkyd topcoat over red lead primer// paint in good condition: spot corrosion	150 psi washing* with detergent (* variable pressure permitted)	calcium sulfonate alkyd topcoat//brush	$47,400	9/94
3.	US 25 over I 75// FE02-034-0025 -020.250(B1)	Fayette// 7	1-24.7 m (80 ft.), 1-38.6 m (125 ft.) and 1-26.2 m (85 ft.) steel girder spans	248 (273)	sulfonated wax//existing coating poor on fascia surfaces: corrosion on fascia girers and at bearings	alkaline paint remover on side spans: 1,500 power washing: power tool cleaning with detergent	calcium sulfonate alkyd spot prime//brush: calcium sulfonate alkyd topcoat//spray:	$74,000	9/94
4.	US 31W over Green River// FE02-050-031W -010.045	Hart// 4	4-16 m (52 ft,) steel I-beam spans, 1-61.7 (200 ft.) and 7-45.6 m (148 ft.) steel deck truss spans	1,062 (1,168)	previously overcoated - multiple alkyd coats//existing paint poor: extensive peeling, spot corrosion	150 psi washing* with detergent (* variable pressure permitted)	aluminum m.c. polyurethane penetrating sealer spot prime//brush: MIO m.c. polyurethane int. coat//brush: MIO m.c. polyurethane topcoat//spray	$322,000	10/94