257

National Cooperative Highway Research Program

NCHRP Synthesis 257

Maintenance Issues and Alternate Corrosion Protection Methods for Exposed Bridge Steel

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Maintenance Issues and Alternate Corrosion Protection Methods for Exposed Bridge Steel

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to state DOT bridge maintenance engineers, coating specialists, chemists, and researchers. Manufacturers and suppliers of corrosion protection products and systems (other than lead-based paint) for exposed structural steel on existing bridges will also find it of interest. This synthesis describes current practice regarding maintenance and protection strategies for exposed structural steel on existing bridges. NCHRP Synthesis 251; *Lead-Based Paint Removal for Steel Highway Bridges*, provides a complementary and more in-depth treatment of maintenance issues involving lead-based paint removal.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board defines the maintenance management systems and decision making criteria used by transportation agencies for maintaining exposed bridge steel. Material selection criteria, surface preparation and application practices, quality control and quality assurance programs, and funding mechanisms are discussed in detail. The impact of recent and proposed environmental and worker protection regulations on current practice is reported. Information for the synthesis was collected by surveying state transportation agencies and by conducting a literature search. Responses to the survey, Appendix C to this document, are published on the Internet as NCHRP Web Document 11 at http.www2.nas.edu/trbcrp.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Shuang-Ling Chong, Ph.D., Research Chemist, Federal Highway Administration; Theodore Hopwood II, Transportation Research Engineer, Kentucky Transportation Center; Eric S. Kline, Manager, Technical Services, KTA-Tator, Inc.; Robert Kogler, Coatings Engineer, Federal Highway Administration, Frank N. Lisle, Engineer of Maintenance, Transportation Research Board; Eileen Phifer, Michigan Department of Transportation, Maintenance Division; Murl L. Sebring, Transportation Maintenance Engineer/ Resident Engineer, New York State Department of Transportation; Krishna K. Verma, Welding Engineer, Federal Highway Administration; and Raymond Warness, Senior Chemical Testing Engineer, California Department of Transportation, Office of Materials Engineering and Testing Services.

This study was managed by Stephen F. Maher, P.E., Senior Program Officer, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in Topic Panel selection and project scope development was provided by Sally D. Liff, Senior Program Officer. Linda S. Mason was responsible for editing and production.

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

MAINTENANCE ISSUES AND ALTERNATE CORROSION PROTECTION METHODS FOR EXPOSED BRIDGE STEEL

SUMMARY

Recent legislation regarding the removal and disposal of existing bridge steel coatings containing toxic materials, volatile organic compound (VOC) limits on the applied coatings, and worker health issues are impacting the alternatives and costs associated with bridge steel corrosion protection. Nowhere has the impact been greater than in the maintenance of existing bridges. Eighty to 90 percent of the existing painted steel bridges are coated with a lead or other toxic, heavy metal-based coating. The regulation issues are causing owners to rethink corrosion protection strategies. These strategies include: doing nothing to the paint and replacing the steel; painting over the existing hazardous paint (overcoating); and total removal of the existing coatings.

Current regulations govern the release of toxic materials into the air, into the water, and onto the ground. In addition, the disposal of solid and hazardous waste and worker protection during removal and handling of the toxic material are also governed. Furthermore, VOC limits are regulated or are proposed to be regulated for coatings being applied in fabricating shops as well as architecture and industrial maintenance coatings applied in the field. Yet to be resolved by the Environmental Protection Agency (EPA) are requirements for the certification of workers and contractors during a lead-based paint activity on structures, and what defines such an activity.

This synthesis summarizes the state of the practice and any recently completed or ongoing research on the preservation of exposed structural steel by state DOT's on existing bridge structures. (NCHRP Synthesis 251, published January 1998, addresses the issues and practice of removing lead-based paint from steel bridges.) The steel discussed includes: exposed bridge steel above the splash zone (including bearings); expansion dams; scuppers; and downspouts. The focus is to identify key issues during the management decision process and the logic behind existing and potential strategies. Issues discussed include materials selection criteria, environmental factors and conditions, type and extent of surface preparation, relative cost factors and their effect, application practices, worker safety, quality assurance and quality control issues (QA/QC), and funding mechanisms. The use of prioritization, routine, deferred, preventive, rehabilitation, and replacement strategies are considered as part of an overall bridge management decision. The use of weathering steel is also discussed.

Information for this synthesis was gathered by sending a questionnaire to U.S. and Canadian transportation agencies in addition to performing a Transportation Research Information Service literature search on the subject. Queries were also made to the Society for Protective Coatings (SSPC), the Federal Highway Administration (FHWA), the Basic Industrial Research Laboratory at Northwestern University, and the EPA.

Almost all of the lead-based paint on existing bridges is an oil or oil/alkyd formulation that is in varying states of deterioration. At present, no responding agency is painting with a lead-based paint. As the bridge industry moved from lead-based coatings, 80 percent of the agencies switched to using a zinc-rich primer system with varying numbers and types of topcoats. This use is primarily for new construction although it is increasingly being used

in maintenance painting for both total removals and surface-tolerant approaches. Galvanizing is the coating that the agencies indicate has the longest expected life. Metallizing, which has 50-year life expectancies and is mostly used in Europe, has yet to receive widespread use in the United States. There is increased use by the agencies of collaborative specifications and collaborative qualification testing by qualified independent consulting and testing firms. The use of a multiple type, cyclic accelerated test appears to be more predictive of field performance and its use is suggested for incorporation into performance-based specifications.

For maintenance painting, agencies are using a combination of approaches, including total removal of the existing paint, spot repair and spot topcoating of deteriorated areas, zone painting of designated areas, and overcoating. Overcoating of the existing lead-containing paint has become a popular choice because it least disturbs the existing leaded paint and, hence, lowers the costs. Overcoating is also increasingly being coupled with marginally prepared surfaces and the use of surface-tolerant materials in an attempt to lessen the cost even more. Coatings are selected for use depending on the type of surface preparation to be performed.

Performing surface preparation with vacuum-assisted power tools can lower a worker's exposure to lead. This is the one area that the engineer can use to lower costs. While hand and power tools can produce the smallest amount of waste for disposal (waste minimization is part of the EPA requirements), these methods are not good at removing embedded contaminants, such as salt, which can shorten the life expectancy of newly applied coatings. Of all the corrosion protection options being used, overcoating is expected to provide the shortest life expectancy. Suggestions are made for a national database to document the extent and number of approaches being used and the success of each. Also, alternative methods to increase the life expectancy of maintenance painting are discussed.

Agencies have various QC/QA plans in place and the FHWA has mandated a laboratory qualification plan for the acceptance of materials that can also be used by the supplier to provide acceptance test results. There is, however, no national quality assurance plan regarding the use of the materials once they have reached the job site. Suggestions have been made for the possible combination of two currently available approaches to produce a QC/QA system for agency use.

The cost of environmental and worker protection issues is easily equal to the cost of the total removal of the existing coating. On a per unit area cost, zone and spot painting operations can be as high as, if not higher in price than total removals. Meanwhile, overcoating procedures are about half the cost of total removal, depending mostly on the type of surface preparation required. Early preventive maintenance is encouraged to create less disturbance of the lead-based paint. Because of the significant cost benefits associated with preventive maintenance, a dedicated source that does not have to compete with other maintenance items seems merited.

There are lingering concerns as to whether all of the issues regarding the use of weathering steel have been identified. While some structures are reported to be performing unsatisfactorily, the majority of the structures are reported to be performing acceptably. There are, however, localized areas of concern on these structures, such as joints and bearings, where concentrated corrosion is occurring. Any remedial action adds to the need for maintenance funds. A synthesis is suggested to assess the effectiveness of the present guidelines for the use of weathering steel.

While environmental issues, worker protection issues, funding issues and uncertainty of action issues are of high concern to the maintenance engineer, the high cost of maintenance is the greatest concern because of the overall lack of maintenance funds. Pontis and BRIDGIT bridge management systems are available to assist in the maintenance decision-making process. These software products can rank structures by condition or need, prioritize by life-cycle costs, and optimize fund use. However, they have not been widely implemented due to a lack of staffing and funding. Decision making by transportation agencies is based primarily on ranking by condition, which is based on current condition assessments. Indeed, condition based maintenance is practiced by all of the agencies. Deferred maintenance, when practiced, is more likely to be based on lack of funding rather than life-cycle justification. Repair and rehabilitation of a structure is practiced more often than structure replacement.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Recent and forthcoming legislation dealing with the removal and disposal of existing coatings containing toxic materials, with volatile organic compound (VOC) limits on the applied coatings, and with worker health issues, impact the alternatives and costs associated with bridge steel corrosion protection. Nowhere has the impact been greater than in the maintenance of existing bridges. Eighty to 90 percent *(1,2)* of the existing steel bridges are coated with a lead or other toxic heavy metal-based coating. The regulation issues are causing owners to rethink corrosion protection strategies. These strategies include doing nothing to the coating and eventually replacing the steel, painting over the old coating (overcoating), and total removal of the existing coatings.

Current regulations govern the release of toxic materials into the air, into the water, and onto the ground. In addition, the disposal of solid and hazardous waste and worker protection during removal and handling of the toxic material are also governed. Furthermore, VOC limits are regulated or are proposed to be regulated for coatings applied in fabricating shops as well as architecture and industrial maintenance (AIM) coatings applied in the field. Yet to be resolved by the Environmental Protection Agency (EPA) are requirements for the certification of workers and contractors during a lead-based paint (LBP) activity on structures and what constitutes an LBP activity.

Until the 1970s and the advent of zinc-rich coatings, lead-based coatings were routinely and widely used, usually in an oil or oil/alkyd resin *(3)*. As lead issues have gained prominence, regulations involving its removal, disposal, and handling have been implemented. There is no requirement that a lead-based paint be removed just because it is on a structure, nor is there a ban on the reapplication of a lead-based coating in the industrial sector. There are regulations, however, on worker exposure during the application of such coatings and, of course, during its removal. For consumer use, however, there is a ban on the sale of lead-containing paint. Paint for consumer use is defined as lead-containing if the total lead content is more than 0.06 percent (16 Code of Federal Regulations{CFR} Part 1303). *The Residential Lead-based Paint Hazard Reduction Act of 1992* has defined a paint as being lead-based if it contains 1.0 mg/cm^2 or 0.5 percent by weight.

The cost of maintenance painting a structure with a lead-based coating increases significantly if the paint is disturbed. Cost increases are due primarily to containment requirements, disposal issues, and worker protection. The cost increases are not necessarily due to the cost of the coating to be applied, whether it is VOC compliant or not. In the past, not much attention was paid to the matter of containment and disposal of debris or to worker exposure issues during surface preparation. This is not the case in today's painting environment. The release of lead-based paint during uncontained open blasting, shown in Figure 1, is now unacceptable because it violates laws regarding collection and disposal of waste containing lead-based paint.

As the United States became more mobile with the use of the automobile, a demand was created for more roads. That demand led to a major expansion of the road systems, starting with the advent of the Interstate Highway System in the mid-1950s during the Eisenhower administration. The resultant bridges associated with this "boom" in highway construction are, in many instances, approaching the end of their design life. Also, the use of deicing salts to remove snow and ice from roadways and bridges increased during the same period. This has placed higher demands on the coating systems and has led to an escalation in corrosion. Painting has long been the corrosion protection method of choice and regarded as an item that could be deferred if other activities were given a higher funding priority. Unexpectedly rough winters or natural disasters create emergencies that may affect the scheduling of maintenance painting projects. These demands for maintenance are at a time of heightened environmental awareness and escalating costs.

For bridge painting, typical cost items include:

- the cost of paint and its application,
- surface preparation costs,
- containment costs, including erection and dismantling,
- disposal costs,
- worker safety costs, and
- maintenance of traffic costs.

Painting for new construction and maintenance painting share most of these cost categories, but generally the containment and disposal issues for the removed coating are primarily a maintenance painting cost item. The paint to be applied, in all cases, has its own worker protection issues, such as exposure limits on catalysts, hardeners or initiators, that are independent of the lead issues. Significant worker exposure costs for lead occur when existing lead-based or other heavy metal containing coatings are disturbed.

Principles of Corrosion

Steel does not occur naturally. The main component of steel is iron, which is present in nature as an ore that is usually the oxidized form of the metal, iron oxide. The ore is processed to produce iron metal by the addition of energy through chemical or metallurgical means. This energized or active state is not thermodynamically stable, in the sense that the metal tends to

FIGURE 1 Open blasting.

lose this added energy and return to the natural state *(4,5)*. Chemical oxidation is the reaction in which an element loses electrons when it reacts with a reactant molecule or atom. Oxygen is one of the most readily available reactants and metals lose electrons to form oxides in the presence of oxygen. Iron reacts with oxygen to form various iron oxides, commonly thought of as rust. This is the most typical reaction, although sulfur is another readily available reactant.

Corrosion of steel is the deterioration of the metal by its environmental exposure *(6)*. It is generally an electrochemical process. A galvanic corrosion cell requires four elements to work: 1) an anode to provide the electrons; 2) a cathode to receive the electrons; 3) electrolytes to serve as a conductor of ions, oxygen, water, or other conductive solution; and 4) a metallic pathway, usually the metal itself.

Corrosion occurs at the anode. The cathode is usually the source of hydrogen ions or dissolved oxygen and is protected from corrosion. The iron goes into solution at the anode and reacts at the cathode to produce hydrogen gas, water, or hydroxyl ions. The hydroxyl ions react with iron to produce iron hydroxide that will react with oxygen, usually dissolved in water, to produce rust. The removal of any of the elements of the galvanic cell will stop the flow of current and stop the corrosion *(7)*.

The collection of dirt and debris on steel members allows water to remain in contact longer with the surface, providing an oxygen source for future corrosion. This is concentration cell corrosion *(8)*. Washing a bridge is a good preventive maintenance option to help prevent this type of corrosion.

The amount and rate of oxide produced depends on various factors. These factors are pH, humidity, electrolyte composition, temperature, and metallurgical differences to name a few *(3,7)*. If the oxide film is not adherent, or cracks or spalls off, more corrosion occurs. It can exfoliate, trapping moisture and contaminants. The density of the oxide film affects the ability of ions to diffuse through it, affecting the rate of the corrosion process.

The production of the oxide of a metal is not necessarily bad. The formation of a thin aluminum oxide on the surface of aluminum protects the aluminum metal itself *(4)*. Chromium is added to produce stainless steel and will oxidize with oxygen to produce the chromate ion $CrO_3^{=}$. This ion is absorbed on to the surface to isolate the surface from further corrosive action (passivation) *(4)*. The formation of an appropriate, dense iron oxide is the principle on which weathering steel is based *(6)*.

Coatings have long been used to stop or mitigate the corrosion of exposed steel by breaking the path in the corrosion cell. Coating systems generally fall into three types: barrier, inhibitive, and galvanic. Barrier systems, such as epoxy mastics, work by blocking the access of the moisture to the metal surface. This removes the oxygen supply from the corrosion cell. For inhibitive systems, such as those containing lead and chromates, the inhibitive ions from the coating are carried through the film to the metal surface to passivate the steel. Galvanic systems, such as zinc rich systems, act as a sacrificial anode, preferentially sacrificing itself instead of the metal it is coating *(1,3,7,8)*.

PURPOSE OF THE SYNTHESIS

Scope

This synthesis reviews the current state of the practice regarding the maintenance and protection strategies for exposed structural bridge steel in light of the recent and proposed environmental and worker protection regulations. Maintenance management systems being used by transportation agencies are identified and the factors that influence decision making are outlined. The synthesis details material selection criteria, surface preparation and application practices, quality control and quality assurance programs, and funding mechanisms.

Organization of the Synthesis

Chapter 2 provides a review of the environmental and worker protection regulations, particularly as they deal with the removal of toxic heavy metal-containing coatings from existing structures. Chapter 3 discusses the various materials that are used by agencies to provide corrosion protection for exposed bridge steel. In chapter 4, surface preparation is discussed in regard to the level of cleanliness that can be achieved. Chapter 5 highlights various design criteria for new structures that can assist in corrosion protection efforts. For maintenance, the discussion focuses on approaches to providing protection. In chapter 6, various aspects of quality control and quality assurance are discussed, from how materials are qualified and accepted to what approaches are available to assure the quality of the work being performed. Chapter 7 explains how agencies determine what to do to provide corrosion protection and what issues are important to them in their maintenance decision-making process. Chapter 8 reports on the agencies' expectations for the various corrosion protection approaches and whether the approaches are meeting their expectations. Chapter 9 discusses ongoing research by the responding agencies and chapter 10 presents conclusions drawn from information gathered by the questionnaire and the literature search.

Sources of Information

A rather lengthy and comprehensive questionnaire was developed and sent to the transportation agencies in the United States, Canada, the District of Columbia, and Puerto Rico. The questions dealt with various aspects of what is used to provide corrosion protection and the logic used in arriving at the maintenance decision. A copy of the questionnaire is in Appendix A.

Fifty-three responses were received for a response rate of 85 percent. Several states provided reports on the issues along with their responses to the questionnaire. Appendix B is a copy of FHWA's Technical Advisory on Weathering Steel. Appendix C, a tabulation of the agency responses to the questionnaire, is available on the Internet through TRB's home page at http.www2.nas.edu/trbcrp. It is listed as NCHRP Web Document 11. A glossary of terms and a list of acronyms used in the synthesis follow Appendix B.

A key word search for various topics dealing with corrosion protection and maintenance of existing steel bridge structures was conducted using the Transportation Research Information Service (TRIS) computerized information file. The Society for Protective Coatings (SSPC), formerly the Steel Structures Painting Council, FHWA, EPA, and the Basic Industrial Research Laboratory at Northwestern University were queried and information was obtained from professional journals and other publications, which are named in the reference list.

CHAPTER TWO

REGULATIONS

Although lead poisoning has been known as a danger for years, most of the attention directed to lead was in the housing sector. With the advent of waste disposal regulations in the 1970s, the removal of lead-based coatings helped to shift that emphasis to the industrial sector. A consequence of the resulting requirement to contain removed material created high lead levels in the worker's environment. This caused an increase in the number of workers being overexposed to the hazardous or toxic materials present. The increase of reported overexposures to workers caused an increase in the emphasis on worker protection issues, in addition to the emphasis on waste issues. In turn, the focus of the steel protection industry on lead related issues has led to a heightened awareness of and emphasis on other toxic or hazardous materials in the work place.

How these concerns ultimately come back as regulations to the industry is a matter of Congressional action. After an act is passed by Congress, the particular federal agency that has regulatory oversight for that legislation will propose rules in the *Federal Register* based on the provisions of the act. After a public comment period, the comments are considered by the agency in formulating the final rule, which is published in the *Federal Register* and becomes part of the Code of Federal Regulations (CFR). The control and enforcement of the regulations may be delegated to a state agency if the federal regulatory agency determines that the state plan is equal to or more stringent than the federal plan. Twenty-five states have been given control in worker protection programs by the Occupational, Safety and Health Administration (OSHA) while control for the other 25 has remained at the federal level (29CFR1926.62).

WASTE ISSUES

Resource Conservation Recovery Act

The Resource Conservation Recovery Act (RCRA) [40CFR Parts 260–268] was passed by Congress in 1976 and was followed by a strengthening of the act with the Hazardous and Solid Waste Amendment (HSWA) in 1984. These acts define the management of waste from the time it is generated to its final disposal. The regulations identify and classify waste; establish the test methods for determining the classification; define generator; and deal with the transportation, storage, treatment, and disposal of the waste. Solid waste by definition includes liquid waste and sludges. The regulations do not define any type of containment to be used.

A waste is determined to be hazardous if it contains any amount of a listed material (component) or if it exhibits one of the listed characteristics. These characteristics are ignitability, reactivity, corrosivity, and toxicity. Table 1 lists the metal contaminants subject to the toxicity characteristic criteria; the waste identification number that has to be given to the waste for disposal purposes; and the toxicity level above which the waste is considered to be a hazardous waste. If below this level, the waste is a solid waste containing a toxic or hazardous material.

TABLE 1

MAXIMUM CONCENTRATION OF CONTAMINANTS FOR THE TOXICITY CHARACTERISTIC

EPA Hazardous Waste No.	Contaminant	Regulatory Level (mg/L)
D004	Arsenic	5.0
D005	Barium	100.0
D006	Cadmium	1.0
D007	Chromium	5.0
D008	Lead	5.0
D009	Mercury	0.2
D010	Selenium	1.0
D011	Silver	5.0

The toxicity value is a modeled value based on the drinking water standard. It is intended to be a measure of the likelihood that the waste constituent will leach out of a landfill into the groundwater supply, causing the drinking water standard for a particular constituent to be exceeded. The extraction liquid is designed to be representative of the liquids that will exist in a landfill based on decomposition in the landfill *(1)*. This test is based strictly on the ability of the element to leach, not the total amount of the element present.

Individual states may impose stricter limits than those set forth in the federal regulations. California and Michigan regulate zinc *(9)* in solid waste. Zinc is not a listed material under RCRA nor is it a characteristic contaminant under RCRA. California is in the process of reconsidering its requirements (*Status report, Zinc Rich Main Committee, SSPC Symposium, November 1996)*.

Hazardous wastes are regulated under the Subtitle C section of the regulations. Whenever a waste disposal site is referenced as a Subtitle C landfill, it is a site that can accept waste identified as a hazardous waste. Subtitle D landfills can only accept solid waste identified as nonhazardous waste. In 1990, the oddly named Third Third Land Ban amended RCRA, which effectively banned the land disposal of hazardous waste *(10)*.

The initial test procedure for identifying and classifying the toxicity of the characteristic elements was the Extraction Procedure Toxicity Test (EP-TOX) [EPA Test Method 1310]. This test was very operator dependent and test results could be influenced by the technique of the operator. In 1990, the EPA changed the toxicity characteristic identification test from the

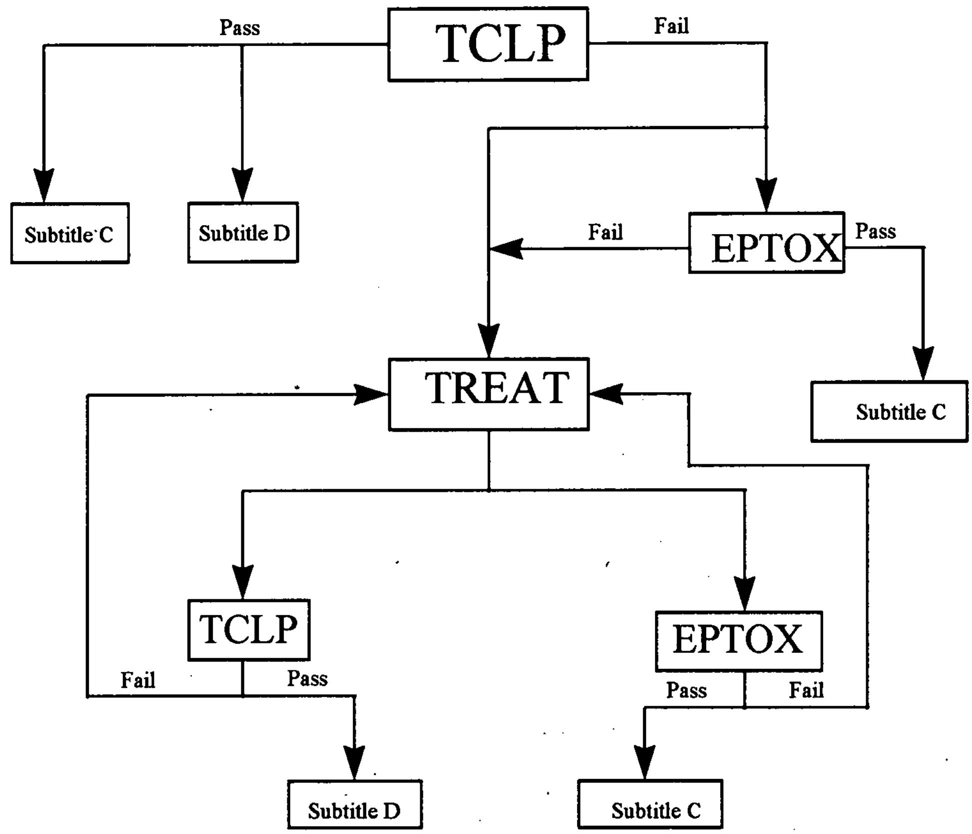

FIGURE 2 Contaminant testing hierarchy *(Courtesy of Lloyd Smith).*

EP-TOX to the Toxic Characteristic Leaching Procedure (TCLP) [EPA Test Method 1311]. All hazardous waste is now to be treated and stabilized, that is rendered nonhazardous, prior to disposal using the TCLP. Lead- and arsenic-containing waste, however, are two exceptions. Although arsenic is not typically used in structural steel coatings, it sometimes shows up in coal slags that are used for blasting purposes.

Waste identified as hazardous for these two contaminants by TCLP can be retested using EP-TOX. If the waste passes the EP-TOX, it can be land disposed in a Subtitle C landfill with no stabilization or further treatment. No waste can fail both tests and be land disposed without treatment. The present testing hierarchy is illustrated in Figure 2. This dual aspect has been confusing. In August 1995, the EPA proposed in the *Federal Register* that EP-TOX be disallowed for determining land disposal for arsenic and lead. The final rule was scheduled for the summer of 1997.

Present EPA requirements are that the waste be treated, that is, stabilized, to below the present toxicity level. For lead this value is 5 mg/L, that is, 5 ppm. In 1995, the EPA proposed that the treatment standard for lead be lowered to 0.37 mg/L *(11)*. However, on May 12, 1997, the EPA reproposed in the *Federal Register* that the treatment level be 0.75 mg/L. A lead-containing waste that leaches less than 5 mg/L by the TCLP test would not need to be treated. A waste that leaches more than 5 mg/L would be treated to below this new value.

Subtitle D sites have to be permitted by the state regulatory agency to accept particular types of contaminant waste. States may impose stricter restrictions than the federal ones. Waste disposal sites are site-specific in their permits for the type of contaminants that can be accepted. Thus, not all Subtitle D landfills may be permitted to accept a particular contaminant, even if it is nonhazardous.

Two approaches to obtaining a nonhazardous waste have evolved. There is the pre-addition approach of adding material to the blasting abrasive prior to use and the post treatment approach, which adds material to the collected waste. The pre-addition of steel filings to expendable abrasives or the use of steel abrasives can produce a waste that is identified as nonhazardous. The waste may become hazardous if the steel that is present in the waste is allowed to rust. Although nonhazardous, further treatment may be necessary to achieve long-term stability *(2)*. As a nonhazardous waste, a treatment permit to further stabilize the waste is not necessary.

Indeed, in the *Federal Register* in March 1995, the EPA proposed to ban the addition of steel filings to an expendable abrasive as an effective means of stabilization. This ban would apply whether as a pre-addition or post addition. However, the pre-addition of certain proprietary products to the abrasives appears to be a good method for producing a stable nonhazardous waste *(12,13)*. Post-treatment with portland cement for lead-containing hazardous waste seems to be the best method for stabilizing the waste *(2)*. However, the post addition of cement or other stabilizers after a hazardous waste has been generated is considered treatment and requires a treatment permit. While the RCRA regulations will allow generators to treat their hazardous waste on-site, each bridge is usually considered a site and regulatory agencies are reluctant to go through the public hearing process for each bridge. It is an illegal activity to treat a hazardous waste unless a permit has been issued by the regulatory agency. Violation is considered treatment to avoid disposal.

All solid waste is regulated, even if it tests to be nonhazardous. It requires proper disposal and cannot be left lying on the ground.

Waste Reduction

RCRA encourages waste minimization. The annual report that hazardous waste generators submit to the EPA requires identification of waste reduction measures to be used. The amount of waste generated by various surface preparation methods will be discussed in the section on surface preparation.

Comprehensive Environmental Response, Compensation and Liability Act

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) [40CFR Parts 300-373] of 1980 addresses the cleanup of hazardous waste sites in addition to releases or spills of hazardous substances. This act is better known as "Superfund." Coupled with CERCLA is the Superfund Amendments and Re-Authorization ACT (SARA) of 1986, which extended CERCLA's timeframe. It also created provisions for community right-to-know, public education, emergency planning, and notification of public authorities if releases of certain substances occur. These are hazardous substances and pollutants or contaminants that may present an imminent and substantial danger to public health or welfare. A reportable quantity (RQ) [40CFR 302] for releases of these substances has been established. They are substances that have been

- Identified by the Clean Water Act (CWA) and CERCLA as hazardous substances,
- Identified as hazardous waste under the Solid Waste Disposal Act,
- Listed as hazardous air pollutants by the Clean Air Act (CAA) and its amendments, or
- Listed as imminently hazardous chemical substances or mixtures by the Toxic Substances Control Act (TSCA).

The RQ for lead is presently 4.5 kg (10 pounds) in a 24-hour period. Releases of antimony, arsenic, beryllium, cadmium, chromium, copper, nickel, selenium, thallium, and zinc are to be reported as well. There is an exception to the reporting requirements if released particles are larger than 100 microns (0.004 in.) in size. Power tool and abrasive blast cleaning procedures will pulverize the lead-based coating, making it likely that the lead particles will be smaller than 100 microns (0.004 in.). The RQ is the actual amount of lead released if the lead content is known or the total amount of the lead-containing waste released if the actual lead content is not known. Whenever the RQ is exceeded, the National Response Center is to be notified.

WATER ISSUES

Clean Water Act

The Clean Water Act (CWA)[40CFR Parts 100–149] addresses Storm Water Discharge (SWD) and National Pollutant Discharge Elimination System (NPDES) criteria. The NPDES addresses discharges to water from point sources, whereas storm water is viewed as runoff. Bridges are not generally identified as point sources, but tunnels under either water or land will have to have a discharge permit if water from the tunnel is discharged. Typically, the types of lead-based paint that have been used on bridges are not those listed in this act as hazardous substances. These are compounds such as lead acetate, lead arsenate, lead halides, lead nitrate, lead phosphate, lead sulfate, lead stearate, lead sulfide, and lead thiocyanate. Even if none of the above compounds is present, this does not mean that a lead-based paint debris is exempt. The purpose of the NPDES permit is to regulate intentions to discharge into the water. All discharges, other than storm water runoff or fire fighting water, are considered illicit. If lead is present and allowed to be discharged, a citation for no permit to discharge under the NPDES would probably be issued since discharge permits are unlikely to be issued *(10)*. This act deals with the total contaminant present in the water.

AIR ISSUES

Clean Air Act Amendments

As part of the CAAA (40CFR 50), the National Ambient Air Quality Standards (NAAQS) establish standards for sulfur dioxide, particulate matter, carbon monoxide, ozone, nitrogen oxide, and lead. Some agencies are applying the standards for particulate matter and lead to bridge work involving the removal of lead-based coatings. The ozone standard may affect bridge work in the sense that the VOC level of the coating may be limited in areas not in attainment with the ozone standard for that area.

Particulate Matter

The PM 10 particulate standard is for dust particles that are under 10 microns (0.0004 in.) in size and is independent of the lead issue. Dust of this size is considered to be respirable. The sample is taken using a sampling device (see Figure 3) that pulls air over a filter. The test is not a measure of lead but of the amount of particulate below 10 microns (0.0004 in.). PM 10 dust cannot be used to measure respirable lead. There is no direct correlation between the PM-10 samples and the personal pump samples required by OSHA *(14)*. The standard is

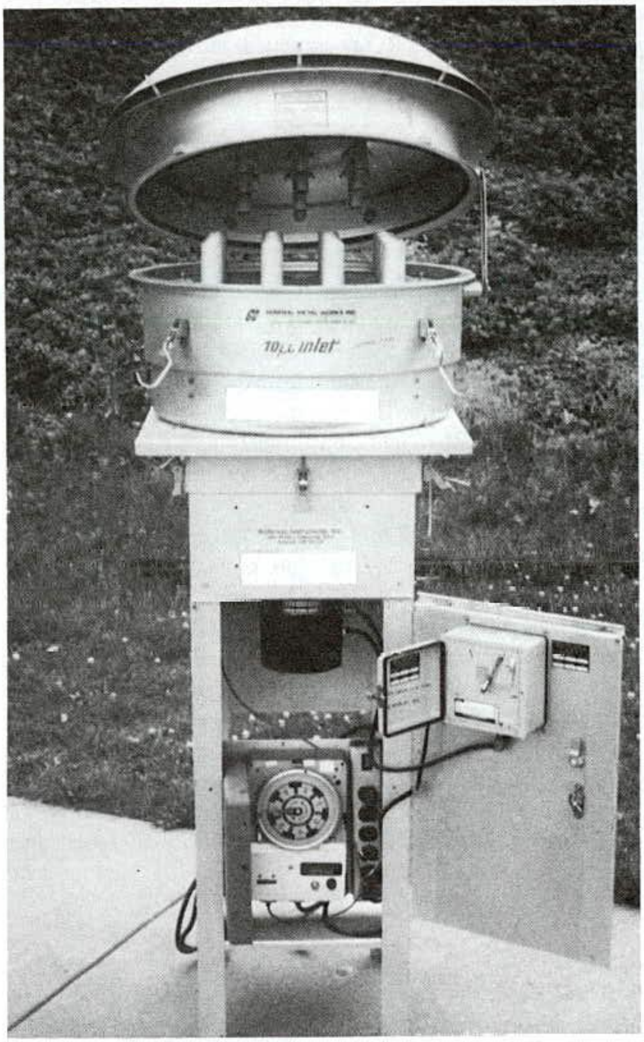

FIGURE 3 PM 10 air sampler *(Courtesy of KTA/SET Environmental).*

150 mg/m^3 of air averaged over 24 hours. An annual arithmetic mean of 50 mg/m^3 of air is also part of the standard.

Lead

Lead, as an air pollutant, is measured as a constituent of the total suspended particulate (TSP). Air is pulled through a high-volume sampler, as shown in Figure 4, and the collected material is analyzed. The measurement is total lead present in the collected sample, not a leach value. The standard is 1.5 mg/m^3 of air. The values are averaged on a calendar quarter.

Visible Emissions

Visible emissions, other than lead and particulate matter, may also be regulated. These emissions are usually based on visible opacity ratings over a stated period of time. The emission is called fugitive dust when the source is soil disturbance. It is called a fugitive emission if the emission is uncontrolled and not soil-related, for example, a leak through an unsealed joint between two tarpaulins. If the emission does not contain any material for which there is an NAAQS, then this type of emission is referred to as a "nuisance dust or emission." The visible opacity ratings are not a measure of escaping airborne lead particles.

FIGURE 4 TSP air sampler *(Courtesy of KTA/SET Environmental).*

Ozone

The current ozone standard is 0.12 ppm maximum hourly average. The standard is attained for a region when it is determined that the number of days per calendar year with the maximum hourly average concentration is less than or equal to one. Nonattainment occurs when the number of days that the standard is exceeded is more than one. Prior to the CAAA of 1990, the emission of VOC from paint materials was generally not regulated in the field except for isolated parts of the country that have a particularly severe air pollution problem.

Manufacturing is regulated because it is a fixed site for emissions and, therefore, tends to concentrate the quantity of emissions. The argument is that fixed sites can more easily be equipped with collectors, such as condensing towers, to collect or trap the VOC given off from paint. Fabricating shops are regulated under a section of the regulations called *Painting of Miscellaneous Metal Parts Rule* (PMMP) [40CFR Part 50].

Under this rule, the amount of VOC being emitted is limited. This is accomplished by restricting the amount of VOC in the paint being applied and the total amount of VOC that can be emitted from the facility. Since this rule is not a national rule, it is generally applied in regional nonattainment areas. States are allowed some leeway in how they implement the rule to achieve the reductions. Ozone itself is not emitted from paint. Precursors to ozone, that is, hydrocarbon materials that react with nitrogen to produce ozone, are emitted. To limit the amount of ozone being formed, the precursors are limited. The more serious the ozone problem the more severe or more restrictive the emission limits. For this reason, there are different requirements at the various fabricating shops around the country. These requirements are meant to cover the total amount of VOC that can be emitted, and not so much the composition of a VOC-containing material.

For PMMP, the federal requirement of 420 g/L (3.5 lb/gal) is used as the standard. Local and/or state regulatory agencies establish limits for daily, weekly, or yearly emissions at a site. These limits require that a VOC-compliant material be used after any one of the trigger amounts of emission is obtained. What differs from state to state or even region to region, is the level at which a compliant material has to be used.

For example, at a large fabrication plant in Lancaster, Pennsylvania, the PMMP limits are 1.36 kg (3 pounds) per hour, 6.8 kg (15 pounds) per day or 2.4 Mg (2.7 tons) per year. Lancaster is in a moderate nonattainment area. If the plant were located in Philadelphia, a severe nonattainment area, the allowable limits would be different, and there would be a cap on the total that could be emitted *(Personal conversation with Dale Aulthouse, High Steel Structures, August 1996).* The statewide PMMP limits in Virginia are 3.6 kg (8 pounds) per hour, 18.1 kg (40 pounds) per day or 6.3 Mg (7 tons) per year *(15).* As with all such rules, the regulatory agencies always retain the option of issuing variances that may be more or less strict, depending on regional conditions.

With the passage of the 1990 CAAA, the EPA proposed to limit the VOC level of AIM coatings that are applied outside of a fabricating shop at the actual bridge site. This limit will apply even in attainment areas. The PMMP limits are not proposed for change.

Although the states have the responsibility for the enforcement of the standard, the EPA has the choice of how the enforcement is to be carried out. It can select to control the amount of emissions for the AIM coatings through a control technology guideline, such as the PMMP rule that is region specific, or it can develop a national rule that would apply to all of the states. The EPA attempted to set the VOC levels for AIM coatings through a regulation/negotiation (reg/neg) process hoping to develop a national rule. This was a process where the EPA called together manufacturers, users, and state regulators in an attempt to negotiate national VOC levels. After 2 years of negotiating, the reg/neg process failed to reach a consensus.

During the initial negotiations, the proposed VOC level for industrial maintenance was 350 g/L (2.9 lb/gal). In anticipation of this limit, the FHWA investigated new zinc rich coating systems based on this value. Performance was not compromised in meeting this limit *(16,17).*

In August 1996, the EPA published its proposed limits in the *Federal Register.* The proposed limit for AIM coatings is 450 g/L (3.75 lb/gal). This is the limit based on the maximum thinning recommended by the manufacturer. The proposed limit is higher than the PMMP limit of 420 g/L (3.5 lb/gal). For an agency that requires all the coats of the painting system to be applied in the shop, it means that the intermediate and topcoats will have to meet the PMMP limits, not the AIM limits. Except for this area, the bridge corrosion protection industry should see little impact from this proposed limit. However, on November 27, 1996, the EPA published a new proposal to lower the ozone standard to 0.08 ppm. It is yet unclear how the industrial coatings industry will be affected.

WORKER SAFETY ISSUES

Occupational Health and Safety Act

The Occupational Health & Safety Act requires OSHA to regulate the exposure of workers to all types of hazardous conditions to assure safe and healthful working conditions. Because of the large number of bridge structures painted with coatings containing lead, the OSHA lead exposure regulations have received a lot of attention. This attention has also brought attention to other regulated toxics.

Lead is regulated by OSHA under two standards, the General Industry Standard (29CFR 1910) and the Construction Industry Standard (29CFR 1926). The Construction Industry Standard applies to both construction and maintenance activities, although most transportation agencies consider them separate activities.

Since the early 1970s, the Construction Standard for the permissible exposure level (PEL) for lead was 200 mg/m^3 of air. The General Industry Standard was 50 mg/m^3 of air. The PEL is a time weight averaged (TWA) over 8 hours and is measured in the air in the breathing zone. The PEL is the maximum level of exposure to which an employee can be exposed regularly. Figure 5 depicts a worker during personal pump testing to assess exposure. Because of the need to contain blast debris in order to meet RCRA requirements, this, in effect, concentrates the lead in the air and increases the number of workers being exposed or overexposed to lead.

In the Residential Lead-Based Paint Reduction Act of 1992 (better known as Title X), Congress required that OSHA develop a stricter lead standard for the construction industry. The new construction standard for lead (29CFR 1926.62) went into effect in May 1993. It lowered the PEL to 50 mg/m^3 of air. The presence of any lead triggers the regulation requirements for lead consideration. For certain activities, it is assumed that there is an exposure. These activities include the application of lead-based paint; the removal of lead-based paint by grinding or blasting; and the cutting, burning or dismantling of structures with a lead-based paint. This means that programs have to be in place for protective clothing, respirators, hygiene,

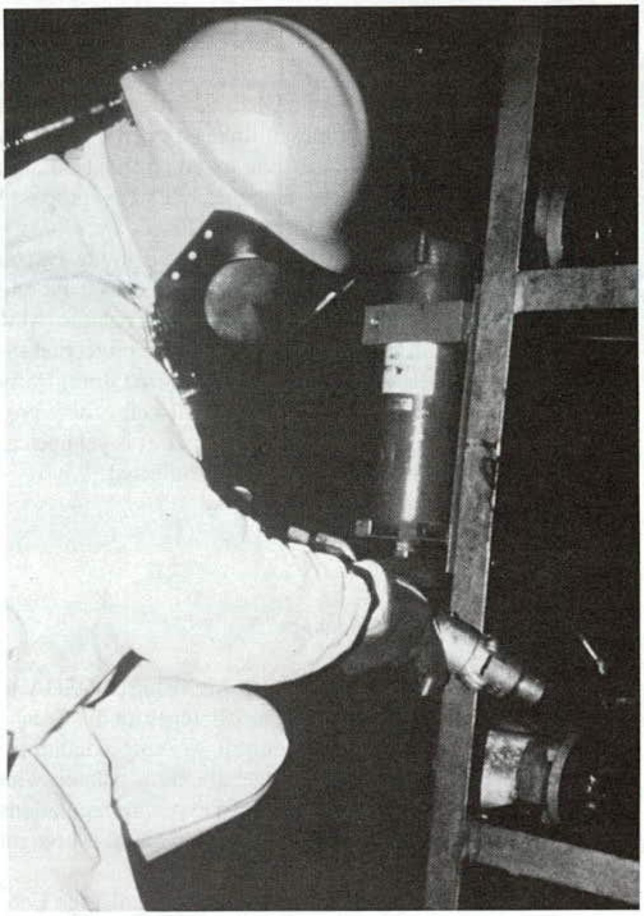

FIGURE 5 Testing using personal pump *(Courtesy of KTA/ SET Environmental).*

medical surveillance, and training just to determine if there is a lead exposure problem. The worker has to be protected until monitoring shows that the exposure for the activity is below the action level (AL). An AL is usually half of the PEL and is the level that triggers certain actions such as medical surveillance, hygiene measures, etc. This assumption is a significant change from both the previous construction standard and the general industry standard. Two different personal protective approaches for abrasive blasters, which are needed depending on the exposure, are illustrated in Figure 6.

OSHA also has standards for the amount of lead in the blood stream. Lead primarily enters the body through either inhalation or breathing. Medical removal of the employee is required if the blood lead level reaches 50 mg/dL of blood. The OSHA rules deal with total concentration of lead present whether it is in the air stream (breathing zone) or in the blood stream.

Although much of the discussion has been centered around lead, there are other metal contaminants in the bridge painting arena for which there are established PEL that cannot be overlooked. These contaminants can be in either the existing paint or in the abrasives that are used to remove the paint. OSHA would expect that these hazards be recognized and that appropriate training be provided to the employees on site. These are listed in Table 2 with their PEL.

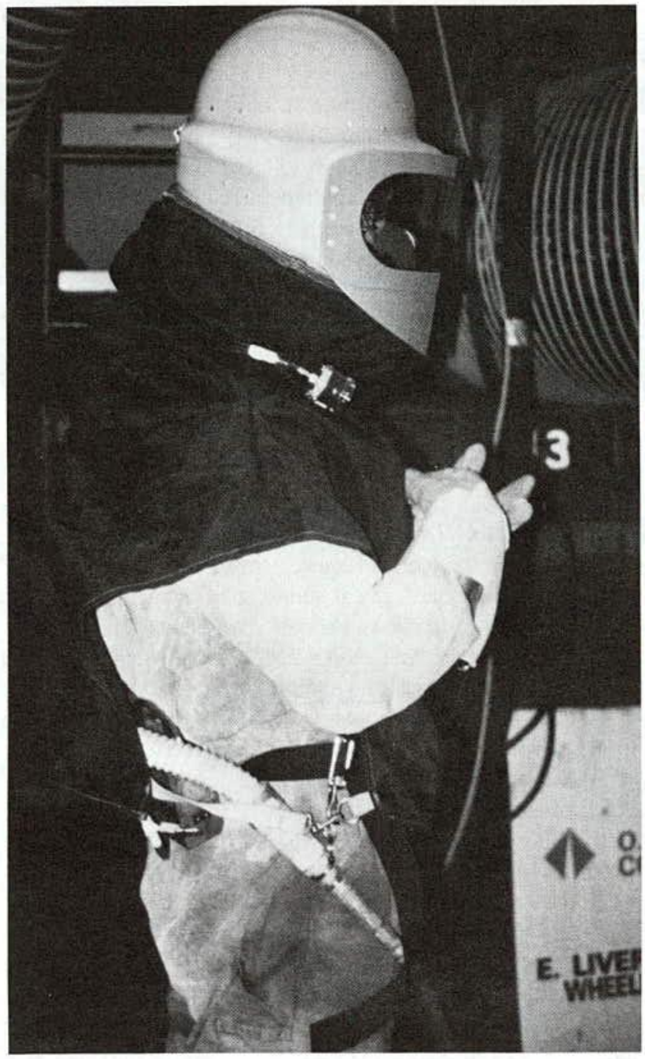

FIGURE 6*a* Well dressed blaster *(Courtesy of KTA/Set Environmental).*

Hazard Communication

29CFR 1910.1200 requires that the hazards of all chemicals produced or imported are transmitted to employers and employees. This is done primarily through warning labels, material safety data sheets (MSDS), and employee training. The primary method that employees have of obtaining information is by reading and understanding the MSDS, which must be made available to all employees. Since the implementation date of the standard, there is not a supplied material that does not have an MSDS. The MSDS unfortunately does not provide information about the paint being removed unless it was a paint that was applied after the implementation of the standard and the MSDS is in the project records.

Basically, manufacturers are required to list the ingredients by name and amount and to provide exposure data. PEL exposure levels have been established by OSHA. Threshold limit values (TLV) are exposure levels that have been established by the American Conference of Governmental Industrial Hygienists (ACGIH). Both measurements are made in the breathing

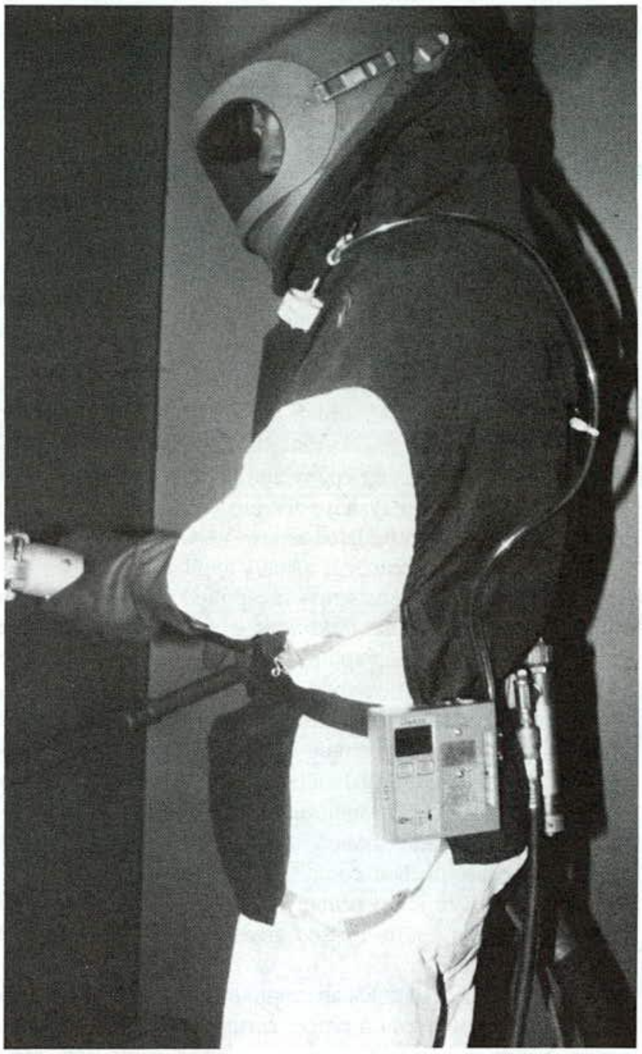

FIGURE 6*b* Well dressed blaster *(Courtesy of KTA/SET Environmental).*

TABLE 2

PERMISSIBLE EXPOSURE LIMITS FOR LIKELY CONTAMINANTS (Courtesy of KTA-Tator)

Contaminants	Permissible Exposure Level (μ/m^3 of air) TWA	Likely Source of Contaminant
Arsenic	10	Coal slag abrasive
Beryllium	2.0 5.0 ceiling limit	Coal slag abrasive
Cadmium	5.0	Paint
Chromium	500	Paint
Cobalt	100	Paint
Copper	1,000	Paint, Copper slag abrasives
Iron	50	Paint
Iron Oxide	5,000	Paint, Iron or Steel abrasives
Iron Salts	1,000	
Lead	50	Paint
Mercury	25	Paint
Nickel	1,000	Nickel Slag abrasives
Silica	100	Sand abrasives
Zinc	5,000	Paint

zone, are time weighted for an 8-hour period, and indicate the maximum exposure that is deemed safe. The MSDS may show either value.

All ingredients that have been determined to be health hazards have to be listed if their content is greater than 1 percent or 0.1 percent, if carcinogenic. Information to be listed includes, but is not limited to, flash point; vapor pressure; reactivity; potential for fire and explosion; hazards for each type of chemical, such as solvents, pigments, and reactive elements, such as catalysts or hardeners; first aid; route of entry; and hygiene and protective measures needed. One of the problems with MSDS's is that they inform users of what is present, but not what they may actually be exposed to upon use of the product. This is because the amounts listed are based on what is in the product as a whole, whereas exposure is based on how much is dispersed into the air in the breathing zone. Only personal pump monitoring during the actual work activity will indicate exposure levels.

Contractor Certification and Training

The OSHA rules for lead require that the contractor have a competent person on the job site at all time during lead work. This person is not to be confused with the proposed EPA certified worker requirement, although they may be the same person.

In addition to including bridges and commercial buildings in its requirements for regulations and directing OSHA to develop a new standard for lead in construction, the Title X legislation of 1992 requires that a laboratory certification program be established to test for lead in paint, soil, and dust; that the EPA develop regulations that assure that workers are trained and that contractors are certified; that a model lead training program be developed for use by the states; and that an LBP activity be defined for bridges. Above this LBP activity or level, the certification program would be required. For housing, this value is defined as 0.5 percent lead per cm^2. This can be compared to a level of 0.06 percent (600 ppm) under which a consumer product is considered to be lead free. This LBP activity standard has not yet been established for steel structures.

Due to public comments about overlap with OSHA, the EPA suspended implementation of its proposed regulations regarding training and certifications for LBP activities relating to bridges. It was postponed for 18 months *(18).* On August 29, 1996, it was delayed again. This delay will also give the EPA an opportunity to clarify the definition of deleading and to assess overlap with OSHA requirements 29CFR 1926.62 *(19).* However, several states have already implemented or are in some process of implementing contractor accreditation and certification requirements for bridge structures. These are New Jersey, Oklahoma, Vermont, Louisiana, Maryland, Nebraska, Missouri, Virginia, Arkansas, California, Connecticut, Georgia, Illinois, Maine, Massachusetts, Minnesota, New Hampshire, Ohio, and Rhode Island *(20,21,22).* While it is likely that a licensing fee will have to be paid to each state under their program, it is not clear that each state will accept the training from another state in lieu of its own training program. The EPA model training and accreditation program is also on hold.

CHAPTER THREE

MATERIALS

Various types of materials are used to provide corrosion protection for exposed steel structures. The materials may vary depending on whether they are used for new structures, maintenance replacement structures, or maintenance painting of existing structures. Paint is the corrosion protection material that has been used longest and most often.

PAINT

The SSPC defines paint as "any pigmented liquid, liquefiable, or mastic composition designed for application to a substrate in a thin layer that is converted to an opaque solid film after application. Used for protection, decoration or identification, or to serve some functional purpose" *(23)*. Coating is defined as a "liquid, liquefiable or mastic composition that has been converted to a solid protective, decorative or functional adherent film after application as a thin layer" *(24)*. In other words, a coating can be a dried or cured paint. The terms are generally used interchangeably.

For many years, the primary system of choice for bridge steel was a lead pigment in an oil or oil/alkyd resin. Red lead and basic lead were the primary lead pigments of choice *(3)*.

As agencies moved away from lead-based paints for use on steel, inorganic and organic zinc rich paints were the principal replacements *(3)*. Inorganic zinc rich paint (IOZ) has been used more widely in the fabricating shops than organic zinc rich paint (OZ) because of its ability to be used on the mating or faying surfaces of slip critical or friction connections. Rather than welding two sections of steel together, the sections are bolted together using splice plates. Bolts are torqued to the required tension. The connection depends on the friction developed between the mating surfaces to prevent slipping into shear when the connection is loaded. IOZ can provide a higher slip value than bare blasted steel. In order to be used on a slip critical connection, the primer has to be tested for its slip and creep values *(25)*. The results have to equal or exceed the slip design requirements.

There are three classes of slip values: 0.33 (Class A); 0.5 (Class B); and 0.4 (Class C) *(25)*. Class A surfaces are typically millscale or rust bearing steel. Class B is typically a blasted surface and Class C is typically used for galvanized surfaces. The higher the slip value, the lower the number of bolts needed to prevent slippage. If the faying surfaces are to be painted, the coating needs to have been tested and approved for that particular slip value design. If the faying surface is painted in the shop, there will be no need to reblast the surface before installation in the field. Rust will occur on unpainted faying surfaces and may need to be removed depending on the design criteria. The design criteria determines the type of preparation necessary, with higher designs being more critical *(6)*.

Early on, the topcoat of choice for a zinc rich primer was a vinyl coating. It was relatively easy to apply and fast drying with excellent dry fall characteristics, decreasing the likelihood of painting passing vehicles. Unfortunately, vinyl paints are usually high in VOC, which often limits their use under today's environmental regulations. In general, the bridge industry has moved to using epoxy and polyurethanes or waterborne acrylics as resin systems for topcoat materials because of their ability to be formulated as low-VOC coatings.

For new steel, the primer is usually applied in the shop and the intermediate or topcoats may be applied either in the shop before shipment or in the field after erection. Because of the ease of accessibility, shop application can lower the cost of the overall painting system; provide for better application conditions; and expedite construction with only erection damage and splice plates to be painted in the field. The use of precoated fasteners, such as galvanized, instead of "black" or uncoated fasteners, helps to minimize the amount of field preparation. Painting these bolted areas always requires extra attention because of their complexity, but it is even more important when there is no primer protection present. Figure 7 illustrates rusting due to missed areas when painting around bolted areas.

However, when all coats are applied in the shop, more emphasis has to be placed on proper curing of the newly applied primer before subsequent coats are applied. Extra care must also be taken to minimize erection damage. VOC levels are concentrated when the topcoats are shop applied, and may cause problems for the fabricating shops depending on their regulatory restrictions.

For maintenance painting of existing structures, the approach is not as straightforward. Accessibility is not as good and there is no centrifugal blaster to perform surface preparation. Cure times between coats is important as well as having to deal with compatibility and surface contamination issues.

Specifications that are used by states fall into several category types, compositional, such as SSPC Paint 25; combination, such as AASHTO M300, which has both compositional and performance characteristics; total performance by class, such as Michigan's and Virginia's zinc rich specifications; or formula based, such as those used in Louisiana and California. North Carolina is using a four-coat waterborne acrylic system that has inhibitive pigments in all four coats. This is similar to the 'defense in depth' approach that used a basic lead silico chromate/alkyd system for the primer, intermediate, and topcoats *(3)*. This approach allows subsequent intermediate and topcoats to have inhibitive properties as well, as opposed to being a barrier or cosmetic coat.

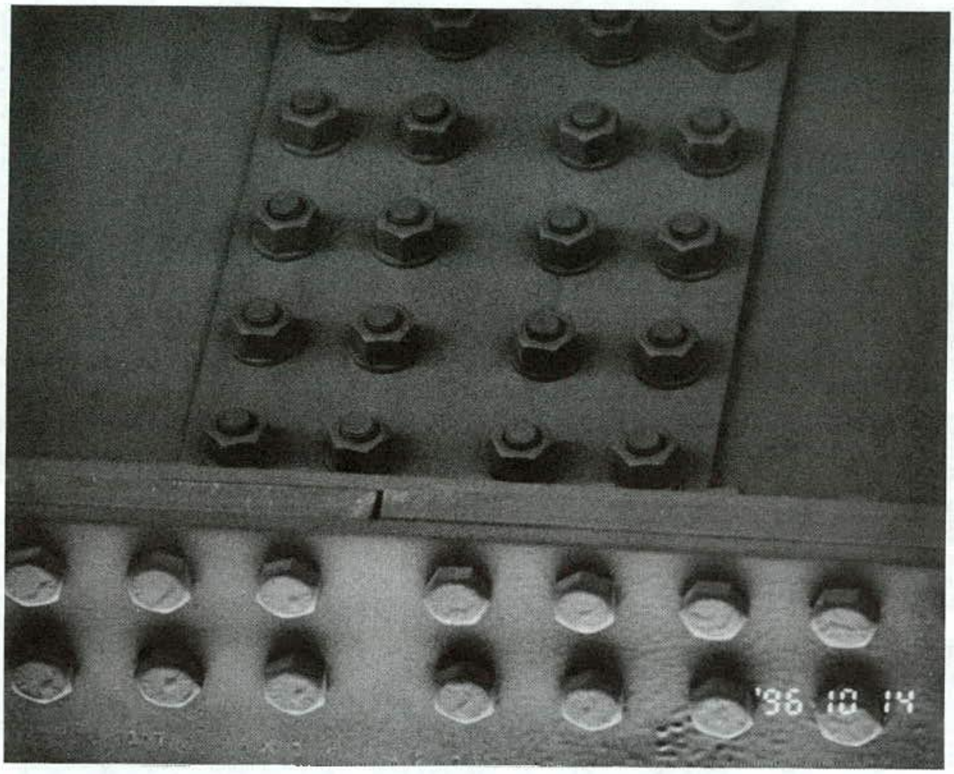

FIGURE 7 Poorly painted splice area.

Certain regions of the country have joined together to develop collaborative specifications. The most notable are the Structural Committee for Economical Fabrication (SCEF) of FHWA Region III (which consists of the MidAtlantic states) and the Northeast Protective Coating Committee (NEPCOAT). The Materials section of AASHTO balloted a system specification based on these regional approaches in the summer of 1995. If and when approved, it will be the first time that AASHTO will have a coating system specification based on performance. The specification has provisions for both IOZ and OZ primers, and details the accelerated test results that have to be submitted to the states for their acceptance. The qualification testing is to be performed by approved consultant laboratories *(26)* or other recognized testing agencies, such as state DOT and university laboratories.

Usage

Ninety percent of the agencies responding to the survey use a zinc rich system to paint new steel when the requirement is to paint. Both IOZ and OZ formulations are used. The type and number of intermediate and/or topcoats used over the zinc rich primers differ, varying from none, to one, to two coats. The most widely used intermediate and topcoat system is an epoxy polyamide and polyurethane system. Half of the agencies responding require that the intermediate and topcoats be applied in the shop.

For maintenance painting, agencies indicate that a variety of coating materials are being used depending on what type of surface preparation is specified. Twenty-five percent of the agencies report the use of a zinc rich system when a total removal is specified. Nonleaded alkyd systems as well as waterborne acrylic, epoxy mastic, and polyurethane resin systems are also being used. In addition to zinc, other protective pigments being used include aluminum, red iron oxide/zinc oxide, calcium sulfonate and zinc hydroxy phosphite. No agency reported the use of any lead-based coating.

In Europe, micaceous iron oxide (MIO) is used extensively as a pigment *(27,28)*; but only Virginia has reported any long-term use in the United States. MIO, which has a lamellar or platey crystalline structure, is now making inroads into paint systems in the United States, particularly in the moisture cured urethanes, as a barrier pigment (see Appendix C).

Approximately 80 percent of the agencies indicate the use of coatings with VOC levels less than 420 g/L (3.5 lb/gal), whereas 25 percent report using materials with 350 g/L (2.9 lb/gal) or less.

METALLIZING

Metallizing, a form of thermal spraying, is the spray application of a coat or layer of molten metal onto a prepared surface (usually blasted steel). The metal is melted by passing it through a flame or electric arc gun and is sprayed onto the surface with a jet of compressed air. Upon deposition, it cools and interlocks into the angular profile *(29)*. Because this is a mechanical bond, the angularity of the profile is very important. It is usually obtained by grit abrasive blasting or by using

FIGURE 8 Electric arc metallizing in shop.

a higher blend of grit versus shot in a centrifugal blaster. Flame-cut edges generally have to be ground to remove carburized steel so that the necessary profile can be imparted. The American Welding Society (ANSI AWS C2.18-93) *(30)* as well as SSPC have published guides on metallizing *(31)*.

The surface preparation usually required for metallizing is a white-metal blast (SSPC SP 5/NACE No. 1). Zinc (Zn) or zinc/aluminum (Zn/Al) alloy has been used in the bridge painting area whereas the Navy has primarily used aluminum (Al) *(32)*. High-deposition electric arc guns are faster than flame guns but may result in a rougher surface. Advances in electric gun technology have made metallizing almost as fast as painting. For work that is completed in fabricating shops, erection and handling damage can be corrected in the field by the metallizing process after proper surface preparation has been performed. Figure 8 shows electric arc spray being used in a fabricating shop as well as nondestructive testing for coating thickness.

Metallized surfaces have traditionally been sealed or painted. Figure 9 shows a sealed metallized pot bearing. In a recently completed FHWA study of VOC compliant materials (metallizing is zero VOC), sealed and unsealed metallized surfaces were compared. The results show that the unsealed metallized surfaces performed well in outdoor exposure studies. Indeed, the metallized samples performed best of the systems evaluated *(17)*. However, if used in an unsealed condition, corrosion byproducts will invariably form, filling the natural porosity of the coating. They may not be removable at a later date without damaging the metallizing if it is decided to remove these by products before topcoating the surface. Sealing the surface initially will prevent the formation of these corrosion products from occurring *(Personal conversation with Dr. Tom Bernecki, BIRL, Northwestern University, Fall 1995)*.

The surface behavior of untopcoated zinc metallizing is no different than untopcoated IOZ primers or galvanizing *(33)*. Zinc reacts preferentially to iron because it has a lower oxidation potential. Zinc reacts with oxygen, carbon dioxide, and moisture to form insoluble byproducts. If aluminum metallizing is used, it does much the same in that the aluminum reacts with oxygen to form an aluminum oxide that is insoluble and thus protects the steel *(6)*. Once the reaction products are formed to fill the pores, these materials now function in a barrier capacity *(33)*.

The two oldest metallized structures in the United States are the Kaw River Bridge in Kansas (1936) and the Ridge Avenue overpass in Philadelphia (1936). In both cases, the metallized surfaces were topcoated. They have not been repainted since the initial application in the mid-1930s *(34)*. (Present limited efforts to determine the type of topcoats used proved fruitless.) The number of metallized bridge structures in the United States is small. As a comparison, in the United Kingdom (UK) approximately 80 to 90 percent of shop fabricated bridge steel is metallized. The British use mostly aluminum (Al) as the primer and their approach is different from that typically used in the United States. In the UK, a thin film, usually less than 100 microns (4 mils), is used followed by the application of subsequent coats that also contain inhibitive pigments. This is contrasted to the United States, where thicker metallizing, approximately 200-300 microns (8-12 mils) is used, with topcoats being primarily applied for aesthetic purposes *(28)*.

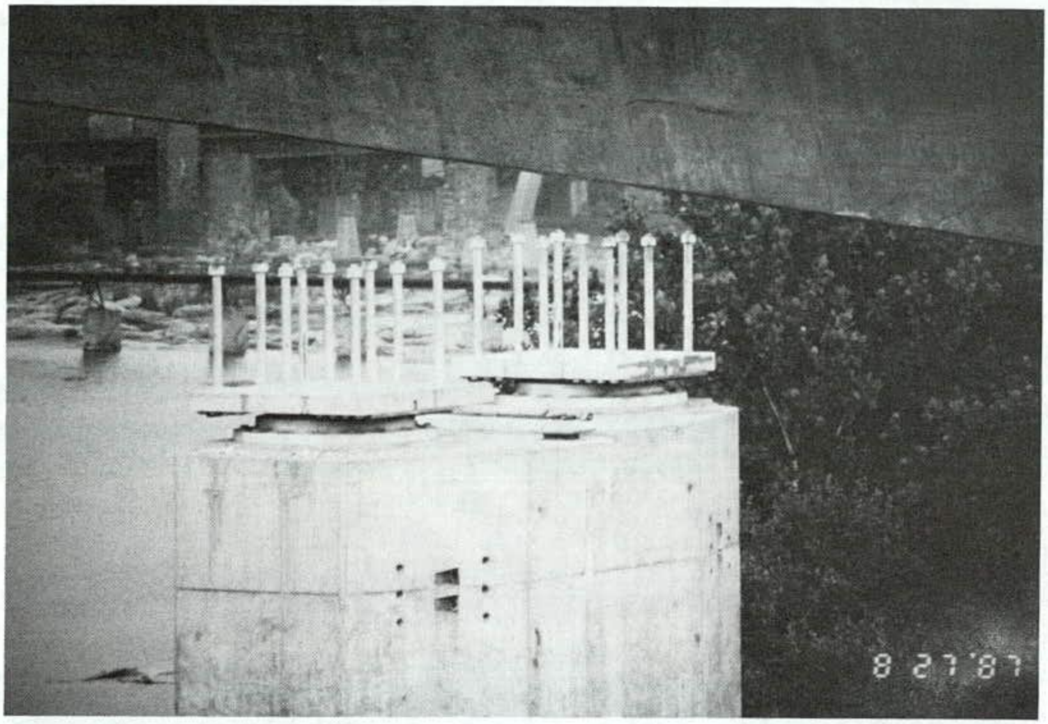

FIGURE 9 Metallized pot bearing.

Usage

Responses to the questionnaire indicate that seven agencies report the use of metallizing for beams and girders for a total of 36 structures, whereas 16 agencies report the use of metallized bearings and expansion devices. Connecticut, Indiana, Ohio, New Jersey, and Pennsylvania have metallized structures in the field. Ohio has a 10-year history of field metallizing and has metallized six structures. Connecticut has metallized 10 structures with the oldest being about 10 years old. In both states, 85:15 Zn/Al alloy was used. Virginia reports a 10-year history of shop applied metallizing using Zn and has done five structures. One structure has a 3-year history of no sealer or topcoat. Numerous applications of metallized bearings have been reported.

Costs

Metallizing costs vary, depending to a large extent on where the work is performed. In the fabricating shop, the cost of metallizing is about \$47.30 per m^2 (\$4.40 per ft^2) *(35)*. In comparison, recent field application costs in Connecticut average about \$182.25 per m^2 (\$16.95 per ft^2) (this price also includes the cost of lead-based paint removal). It is also more difficult and costly to obtain a white metal blast on a corroded, possibly pitted, contaminated surface in the field.

HOT DIPPED GALVANIZING

Galvanizing is the dipping of properly prepared steel into a molten tank of zinc metal *(8,36)*. The molten zinc forms a metallurgical bond with the metal. As is the case with all zinc metal coatings, the zinc acts as a galvanic coating, preferentially sacrificing itself at the anode.

A major limiting factor in the use of hot dipped galvanizing is the size of the tank that contains the molten zinc. Figure 10 shows beams being lowered into a tank. Smaller items, such as the bearings shown in Figure 11, are easily galvanized. Since the tanks are not portable, the steel has to be taken to the galvanizer. Accordingly, if galvanizing is to be used on existing bridges, the bridges have to be dismantled and transported to the galvanizing site.

The typical galvanizing process involves several steps, beginning with a caustic cleaning and followed by a rinse. Then comes an acid or pickling step, which is also followed by a rinse. After this rinse, the steel is fluxed by dipping into a tank of zinc ammonium chloride solution prior to its immersion into the molten zinc bath. Alternatively, the ammonium chloride may be floating on the surface of the molten zinc. After an appropriate immersion time, the steel is removed, quenched, and cleaned up; any damage is repaired and excess material removed.

The galvanizer can use the caustic and acid tanks to strip lead-based paint. The painted steel is first immersed in the caustic bath. If this does not remove all of the coating, the steel is then immersed in the acid or pickling bath. The steel is rotated between these baths until the coating is removed, and then follows the normal galvanizing process. The removed paint is incorporated with other cleaning waste, which is taken to a treatment, storage, and disposal (TSD) site for treatment and disposal under RCRA regulations. These wastes are already hazardous due to their pH levels. Care is taken to prevent this waste from becoming a part of the dross zinc, a zinc

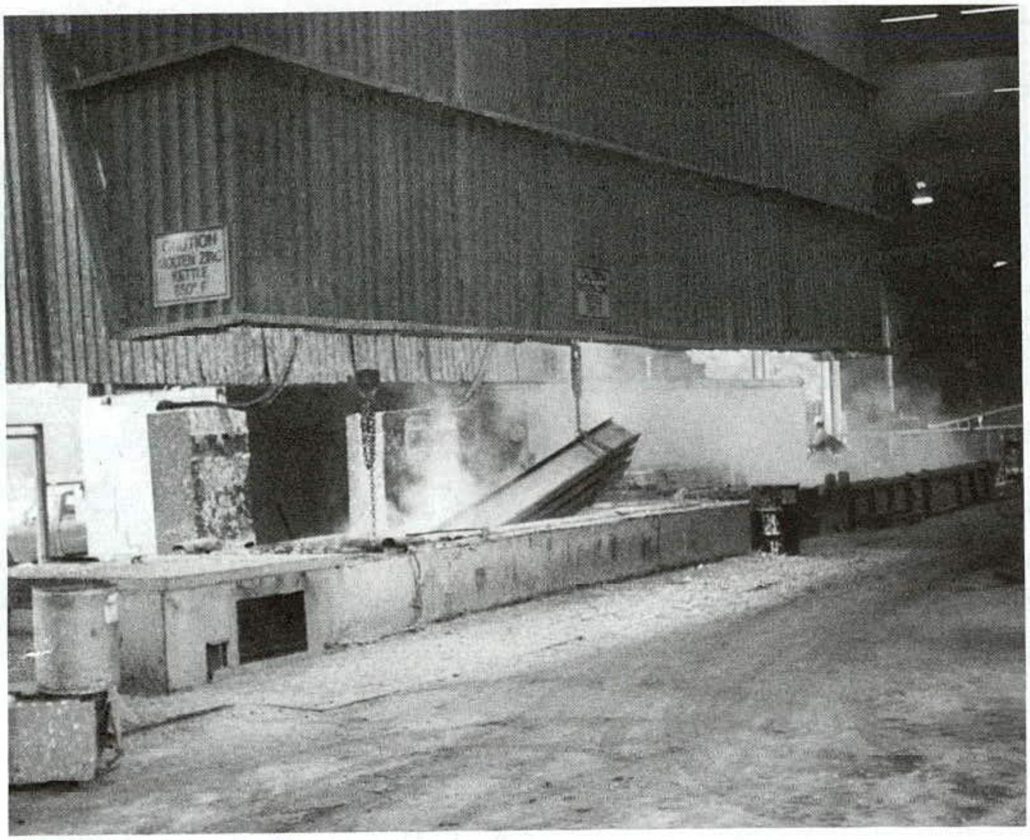

FIGURE 10 Galvanizing dip tank.

FIGURE 11 Installed galvanized bearing.

byproduct that forms on the surface of the molten zinc dip tank. This byproduct is sold to reclaimers *(Personal conversation, Ron Bryce, VA Galvanizing, October 1993).*

Unless it is to be topcoated, galvanizing is a finished job when it leaves the galvanizer. Erection damage to the galvanizing can be repaired in the field by either metallizing or other recommended repairs in accordance with procedures established by ASTM A780-93A.

Galvanized surfaces can also be topcoated *(37,38).* However, newly galvanized surfaces are often difficult to topcoat without first performing some type of surface preparation. The process usually involves a procedure to remove any oils or grease and zinc salts followed by the use of a surface preparer that acts as a tie coat. Vinyl butyral wash primer, DOD-P-15328, has been used extensively for this purpose. Unfortunately, it contains zinc chromate, which has environmental implications, and, in addition, is high in VOC. Just as an oil or oil/alkyd paint is not suitable for application to a zinc rich primer, an oil/alkyd is not a good choice for galvanized surfaces either. Most coating manufacturers have specific recommendations on how to prepare the surface based on their products.

Costs

When used on dismantled bridge parts to strip lead-based paint and coat the members, the galvanizing process is estimated to cost $0.88 per kg ($0.40 per pound) after delivery to the galvanizing plant *(Private conversation with Ron Bryce, VA Galvanizing, October 1993).* Respondents to the survey report costs between $0.33 and $0.70 per kg ($0.15 and $0.32 per pound) for new steel with the price for bearings, insert plates, and cross frames being $0.33 to $2.42 per kg ($0.15 to $1.10 per pound). At 9.3 m^2 (100 ft^2) per 900 Kg (1 ton), this would equate to $32 to $69 per m^2 ($3 to $6.40 per ft^2).

Usage

Nine agencies report that approximately 178 structures have been totally galvanized. Twenty-one agencies report the use of galvanizing on bearings for regular and weathering steel, insert plates for prestress concrete beams and cross frames for both steel and prestressed concrete beams. The longest length reported to have been dipped is 30 m (100 ft), but most are between 12 m and 18 m (40 ft and 60 ft). The length that is able to be galvanized is strictly a function of the size of the dipping tanks. Canada reports the largest use of galvanized steel in terms of number of structures.

POWDER COATING

Powder coating is the process of a applying a fine, dry powder to a substrate that is heated to make the powder form a continuous film. Electrostatic spray, fluidized bed immersion, and thermal spraying are the three methods of application. With the electrostatic method, charged powder particles are sprayed onto an electrically grounded metal. The coated metal is cured in an oven. With the fluidized bed method, the heated metal is immersed into a chamber where air and powder particles have been used to create a fluidized environment, which in turn creates the coating. Oven size and immersion bed size limit the size of the metal part that can be powder coated. The third method involves the thermal spraying of heated material onto a preheated surface. The powder is fed through an application gun that melts the powder prior to its being projected onto the preheated metal surface *(39,40).* This particular form of thermal spraying is capable of being used in the field but is limited by the ability to preheat the metal to be coated. The powder coating is usually a barrier-type coating, and, as such, has a tendency to undercut badly when damaged and exposed to chloride environments. Powder coatings are not known to be able to provide a slip value that will allow them to be used on slip critical or friction connections.

Usage

Only Indiana and Maryland report the use of powder coatings for beams and girders. Five agencies report the use of powder coatings for cross frames or diaphragms. Virginia and Maryland have used powder-coated tunnel ceiling panels, whereas Oregon has used the product for soundwall posts.

Although not within the scope of this synthesis, the largest use of this material has been to coat rebar that is placed in concrete. The FHWA powder-coated rebar study found that the failure mechanism was indeed undercutting when no primer element was in the powder coating. It confirmed that the primary reasons for failure were underfilm corrosion due to low film build and handling and installation damage. The addition of zinc dust to the epoxy powder or the use of a zinc rich coating under the powder coating improved the performance *(40).* This occurs because the coating system now has galvanic properties instead of just barrier properties.

WEATHERING STEEL

With regular carbon steel, a protective coating is applied to the constructed steel item. With weathering steel, the iron is alloyed at the steel mill with copper, chromium, silicon, vanadium, titanium, and zirconium, which will react in the atmosphere to produce a protective oxide coating. The ions of these added metals tend to form compounds that are larger in diameter and smaller in diffusion velocity. They plug the pores in the iron oxide that is formed by the weathering of the steel, thus blocking the transmission of electrolytes and breaking the corrosion cell. Salt contamination and prolonged wetting *(6)* are the primary causes of interference with the formation of the protective iron oxide.

In the late 1970s, Michigan first noted problems with severe corrosion of weathering steel because the protective iron oxide was not developing. As a result of Michigan's study and other work, it was determined that indiscriminate use of weathering steel can lead to problems *(41).* For weathering steel to produce a protective film, several conditions have to exist:

- No prolonged wetting, a wet/dry cycle required,
- No heavy concentrations of corrosive pollutants, especially deicing salts,

• Exposed surfaces must be periodically washed by rain water, and

• Good design detailing so that corrosion producing dirt, debris, and moisture are not trapped.

Early in the use of the material, the effect of inattention to the above listed conditions was not known. Joints leaked runoff water containing deicing salts onto the steel. Salt spray from traffic was sprayed up onto the steel from the roadways beneath the bridges, contaminating the steel surfaces. Dirt, debris, flaking rust, millscale, bird droppings, bird nests, etc. were allowed to accumulate on flanges. Low clearances with poor airflow did not allow the structures to dry out. All of these conditions prevented the protective oxide from being produced.

As a result of the investigation into the matter, the FHWA issued a technical advisory on the subject *(42)* in 1989. It contained comments about environmental exposure, location and design details, and maintenance actions and guidelines for use. This advisory is included in Appendix B.

The technical advisory advocates the painting of weathering steel expansion joint areas such as the one shown in Figure 12. IOZ paint systems or Zn metallizing have been shown to be the best systems to use when remedially painting weathering steel and salt contamination is present. Although the zinc rich systems can tolerate residual salt better than most coatings, there is a limit *(43,44)*. IOZ paint can tolerate up to 50 mg/cm^2 and OZ has been shown to be able to tolerate up to 20 mg/cm^2. Other types of coatings do not provide as high a tolerance. The salt level needs to be kept below 20 mg/cm^2 to optimize performance *(43)*.

Unpainted weathering steel can cause an aesthetics problem due to the staining of concrete from drainage. The application of a sealer or other coat to protect against staining, the wrapping of piers and abutments during construction to minimize staining during rainfall, and removal of the staining are recommended options *(6)*. The use of a proprietary non-mineral acid cleaner has been shown to be effective in the removal of the stains without affecting the concrete *(45)*. Figure 13 illustrates the hand spray application of this cleaner.

The American Iron and Steel Institute (AISI) has tracked the performance of 52 weathering steel bridges since the Michigan problem surfaced. The report recognizes that there are some concerns, such as leaking expansion joints. However, outside of these localized areas of concern, the 52 monitored structures are reported to be performing well. The report concludes that, when used properly, weathering steel can be a cost-effective option when based on life-cycle costs *(46)*.

Usage

Forty-eight agencies report that 4,301 weathering steel bridges are in use. Twenty-five agencies report that the steel is rusting too much, has pack rust formation, or is rusting too much at expansion joints, although no indication was provided of the number of structures exhibiting these conditions. Except for problems associated with tunnel effects, most of the reported problems can be contributed to localized areas, such

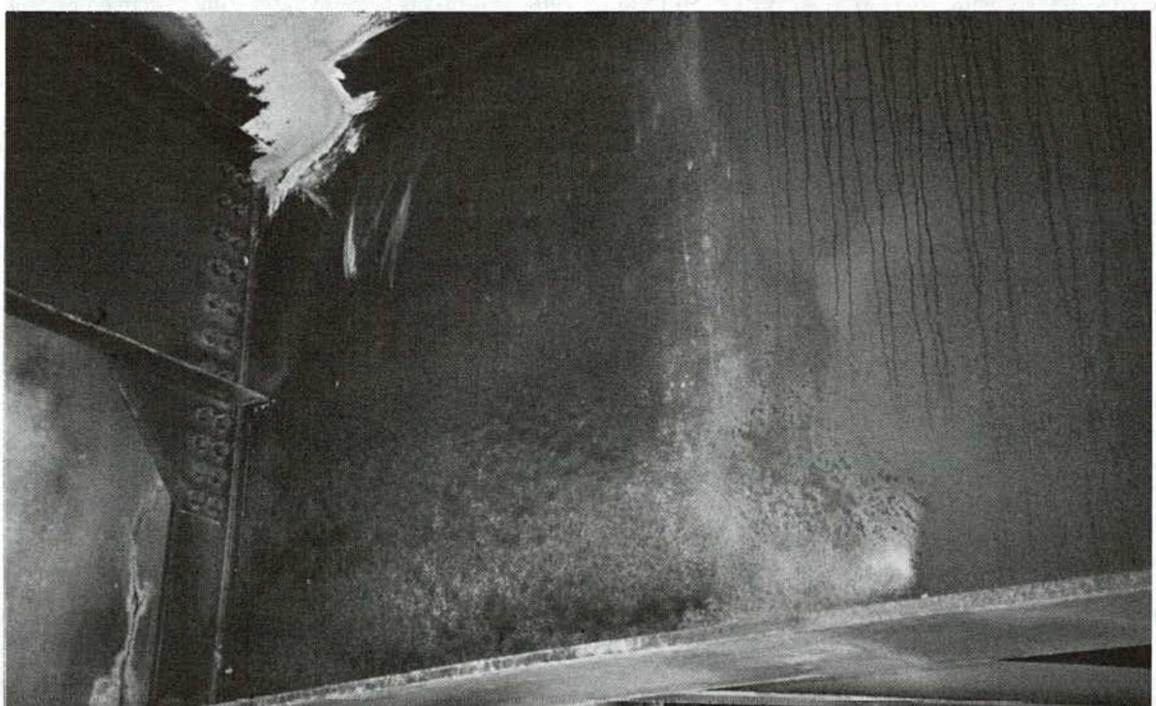

FIGURE 12 Weathering steel with painted ends.

FIGURE 13 Cleaning rust stains.

as leaking joints and site-specific problems. Both of these conditions create maintenance problems. These localized areas of concern are consistent with the AISI report. Agencies reported 692 structures to be performing unsatisfactorily. The states reporting the greatest number of structures performing unsatisfactorily are Alaska, Illinois, Louisiana, Ohio, Utah, Virginia, and Michigan. Except for Utah, which has used a membrane to seal the decks and water blasted the steel to remove salt, the other states have used a zinc rich paint system to remedially paint the structures. In addition, Missouri recently collected information by questionnaire about the use of weathering steel. This survey also reported a mixed history of use and performance *(47)*.

OTHER MATERIALS

Other materials or combinations of materials are being used for bridge construction. Stainless steel has been used for pin-and-hanger assemblies in conjunction with steel members *(48)*. AASHTO has design criteria for the use of aluminum *(49)* and timber bridges *(50)*. Steel diaphragms with precast concrete beams *(51)* as well as timber decks on steel and concrete beams are also used. Figures 14, 15, and 16 illustrate some of these combination uses.

Steel structures comprise about 40 percent of the U.S. inventory over 6 m (20 ft) long whereas timber comprises about 10 percent. Concrete, be it prestressed stringers, slabs, boxes, etc., comprises about 50 percent of the inventory *(52)*. Timber has been used mostly for short span, rural bridges *(53)*. Concrete is used primarily for spans of a 100 ft or less when used (See Appendix C, Survey Responses, NCHRP Web Document 11, accessible from TRB's homepage). For steel and concrete superstructures, the deck is usually steel-reinforced concrete.

Fiber-reinforced plastic is being studied experimentally for use as a composite with timber, concrete, and steel members as well as with cables *(54,55,56)*.

Usage

All of the responding agencies use concrete and/or steel structures with 46 percent of the agencies preferring concrete where its use is applicable. This is mainly for short spans

FIGURE 14 Weathering steel diaphragms with prestressed beams.

generally less than 30 m (100 ft) in length. Thirty-eight percent of the agencies report a combination use of prestressed concrete and steel for either beams or cross frames. There was no reporting of a design/build structure.

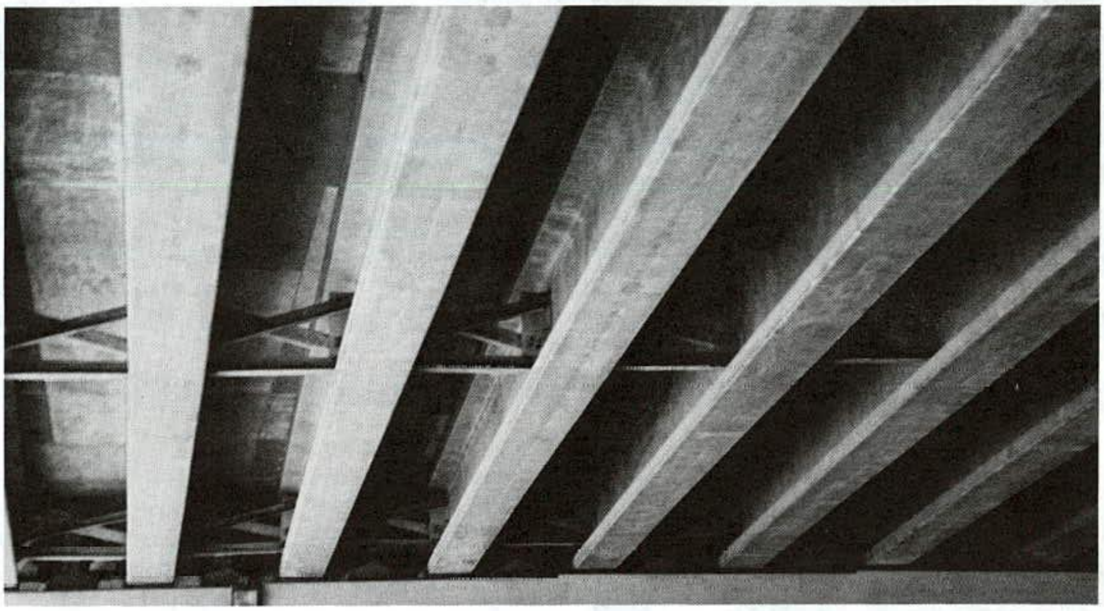

FIGURE 15 Galvanized steel diaphragms with prestressed beams.

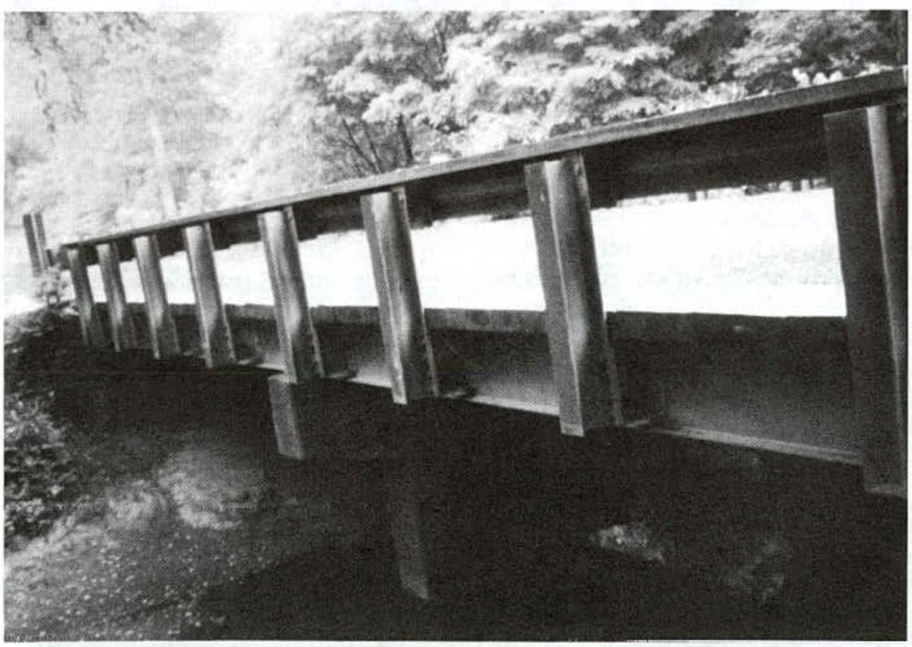

FIGURE 16 Galvanized members with wood deck.

CHAPTER FOUR

SURFACE PREPARATION

Surface preparation is work that is done to prepare a surface for painting. The preparation applies to painted and unpainted surfaces and it may involve washing, scraping, blasting, or doing nothing to the surface to remove various contaminants such as rust, paint, oil, grease, dust, dirt, and mill scale. It may also provide the surface with the proper profile, or anchor pattern, for the coating to be applied. Two sources of surface preparation cleanliness standards are the SSPC and the National Association of Corrosion Engineers (NACE). Standards are written to cover varying degrees of surface cleanliness.

CLEANLINESS

Standards *(57)*

SSPC-SP 1 Solvent Cleaning—This specification covers the method for removing visible oil, grease, cutting compounds, and soluble contaminants on the surface. It uses a combination of solvents, alkaline cleaners, and steam/detergent cleaning. Contaminants include water soluble chloride salts from either deicing salts or marine exposure, sulfate salts from chemical or atmospheric exposure or other soluble iron salts. This method does not remove salts embedded in rust or pits of pitted steel. This standard is the first step required in all the subsequent surface preparation standards.

SSPC-SP 2 Hand Tool Cleaning—This standard covers the use of hand tools (nonpowered) to remove loose mill scale, loose rust, loose paint, and other loose detrimental matter. Loose is defined as that which can be removed by lifting with a dull putty knife. This method does not remove salt that is embedded in adherent rust or the pits of pitted steel.

SSPC-SP 3 Power Tool Cleaning—This standard covers the use of power-assisted hand tools to remove loose mill scale, loose rust, loose paint, and other loose detrimental matter. Loose is defined as that which can be removed by lifting with a dull putty knife. This method does not remove salt that is embedded in adherent rust or pits of pitted steel.

SSPC-SP 5/NACE No. 1 White-Metal Blast Cleaning—This standard covers the use of abrasives to provide a surface that, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products and other foreign matter. This method may not remove all the salt that is embedded in the pits of pitted steel. This method is capable of imparting a profile to the steel surface which is an independent requirement from the standard.

SSPC-SP 6/NACE No. 3 Commercial Blast Cleaning—This standard covers the use of abrasives to provide a surface that, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter except for random staining, which is limited to no more than 33 percent of each unit area of approximately 6400 mm^2 (9 in^2). This method may not remove all the salt that is embedded in the pits of pitted steel. This method is capable of imparting a profile to the steel surface, which is a requirement independent of the standard.

SSPC-SP 7/NACE No. 4 Brush-off Blast Cleaning—This standard covers the use of abrasives to provide a surface that, when viewed without magnification, shall be free of all oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Loose is defined as that which can be removed with a dull putty knife. Tightly adherent mill scale, rust, and coating may remain on the surface. This method does not remove salt that is embedded in adherent rust or the pits of pitted steel.

SSPC-SP 8 Pickling—This standard covers the use of chemical reaction, electrolysis, or both to remove all visible rust and mill scale. The steel is dipped into the pickling tanks for the reaction to take place. This method will remove salt that is embedded in the pits of pitted steel.

SSPC-SP 10/NACE No. 2 Near-White Blast Cleaning—This standard covers the use of abrasives to provide a surface that, when viewed with magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products and other foreign matter except for random staining, which is limited to no more than 5 percent of each unit area of approximately 6400 mm^2 (9 in^2). This method may not remove all the salt that is in the pits of pitted steel. This method is capable of imparting a profile to the steel surface that is a requirement independent of the standard.

SSPC-SP 11 Power Tool Cleaning to Bare Metal—This standard covers the use of power-assisted tools to provide a surface that, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, rust, mill scale, coating, oxides, and corrosion products. It shall provide a profile of at least 25 microns (0.001 in). This method does not remove the salt that is embedded in the pits nor does it require the removal of slight residues of rust and paint in the lower portion of the pits of pitted steel. This method is required to impart a profile to the steel surface which is not an independent requirement from the standard.

SSPC-SP 12/NACE No. 5 High and Ultrahigh-Pressure Water Jetting *(58)*—This standard covers the use of water jetting (WJ) to provide a surface which can be free of visible, when viewed without magnification and nonvisible, when tested, oil, grease, rust, paint, mill scale and residues of salt contaminants to the level specified. Oil and grease may be removed by the use of ultrahigh pressure water jetting (UHPWJ) or steam cleaning with detergent in accordance with SP 1 or other approved methods. Under this specification, WJ is cleaning at pressures of 70 MPa (10,000 psi) or higher with high pressure (HP) being between 70 and 170 MPa (10,000 and 25,000 psi) and ultrahigh pressure (UHP) being above 170 MPa (25,000 psi). Below 70 MPa (10,000 psi), the process is referred to as water cleaning (WC) with low pressure WC being less than 34 MPa (5,000 psi) and high pressure WC being between 34 and 70 MPa (5,000 and 10,000 psi). Included in the standard are four definitions for the visual surface preparation and three definitions for nonvisual surface preparation. UHPWJ will remove salt contaminants from pitted steel. This method does not impart any profile to the steel.

Chemical Strippers

There is no standard for the use of chemical strippers nor the degree of cleanliness to be expected. The type of stripper to be used depends on the type of paint present. The strippers are typically solvent based or alkali based. Certain pigments can present a problem. For example, alkaline stripper will have problems with aluminum pigmented paints, retarding the process. As a final step, the structure has to be washed to neutralize the surface and to remove any traces of solvent. The wash water will, in all likelihood, need to be contained *(59)*. The strippers do not remove rust or millscale or salt embedded in pitted steel, nor do they provide any profile.

While the strippers have some negatives, such as handling and disposal issues, they have an advantage also. Airborne lead particles are generally not an issue. Hence, exposure above the action level is unlikely. Chemical strippers, when used prior to other surface preparation methods, may provide an opportunity to lessen worker exposure issues regarding lead.

Profile

Surface profile can be determined by the use of replica tape in accordance with ASTM D-4417, Method C, "Field Measurement of Surface Profile of Blast Cleaned Steel."

Methods

Surface preparation in a fabricating shop is much easier than in the field if for no other reason than the steel is readily accessible from the ground or floor. In addition, the use of centrifugal blasting devices greatly speeds up the blasting process. A centrifugal blasting device is a cabinet through which steel members are passed on a conveyor belt. While inside the cabinet, centrifugal force is used to fling abrasive, usually a mixture of steel shot and grit, onto the steel as it passes through. While the size of the girder affects how the blaster is set up, it only takes about 30 minutes to pass a girder through the blaster regardless of size and can easily produce a white metal surface. Vacuum hoods are attached to the cabinet for collecting dust that is generated during the blasting process and abrasive falls into bins for reuse. Unless it becomes contaminated, the abrasive is continuously reused, and, as the abrasive degrades and diminishes, the cabinet is recharged with new abrasive.

Blasting in the field requires the use of a compressor, a blasting pot, hoses, nozzles, access to the structure, and containment. Various types of abrasives can be used, either recyclable or expendable. For a near-white blast, blasting at a rate of 6.4 m^2 (100 ft^2) per worker hour is a good production rate in the field.

Steel members have been removed from bridge structures in Virginia *(Personal knowledge)* and Pennsylvania *(Personal conversation, Dave Kuniega, Pennsylvania Department of Transportation, March 1996)*, transported to fabricating shops, blasted to remove lead-based paint, repainted and re-erected. When centrifugal blasters are used, this process achieves some economy because of blasting rates and ease of containment. It is still no better than field blasting for contaminant removal unless special attention is paid to the process.

Hand tools, as the name implies, are tools that depend on muscle power to operate. They include wire brushes, scrapers, and putty knives.

Power tools, as the name implies, use a power source, usually air, to run the tool. They include grinders, sanders, rotopeens, and chipping hammers. They may be fitted with vacuum attachments for containment. A problem for power tools is the inability to access the nooks and crannies of complicated areas, such as bearings.

Contaminants

An assessment needs to be made to determine whether the method of surface preparation will remove surface contaminants to a level that the coating being applied can tolerate. Failure to do so will result in early rust back.

Abrasive blasting does not remove oil and grease contaminants. Blasting just spreads it around, contaminating a large area. The best approaches to remove rust and salt contaminants are wet abrasive blasting and UHPWJ *(60)*. Dry abrasive blasting's ability to remove embedded salt depends on the size of the abrasive. Finer abrasives can enter pits and scour them better *(61)*. The blast standards do not specify a size range for the blast abrasive.

Flash rusting is a thin layer of corrosion that is attributed to ambient moisture and contaminants. It usually occurs when too much time has lapsed between surface preparation and painting. It is usually reddish brown in color as shown in Figure 17. Rust that results from insufficient removal of chlorides is blackish in color. While it is possible to demonstrate whether all of the salt has been removed from the surface just by wetting it and letting it rust, attempting to quantify the amount of salt in the field is not easy *(62)*. The known methods for field use are a relative indication at best, of the salt level.

Because rust is usually one of the main reasons for maintenance painting, a coating that can be applied over rust has the potential to reduce the overall cost of the painting job. The problem is that rust usually contains contaminants. Thus, the

FIGURE 17 Flash rust *(Courtesy of Ultra-High Pressure Projects).*

coating has to be capable of being applied successfully over the rusted surface as well as being able to tolerate the contaminants in the rust. Residual salt contaminants greatly affect coating life *(3,63,64,65,66).*

PAY ITEMS

Pay items are contract administration terms used to define the type of surface preparation and painting that is going to be done to a specific area or section of a bridge. This area might be the whole structure, a zone, or a spot. Some typical pay items used in specifying the amount of surface preparation to be done are:

Repainting—sometimes called "Total Removal and Repaint Existing Structure," this pay item requires complete removal of all the existing paint and corrosion using the appropriate required cleaning methods to the cleanliness degree specified. The whole structure is then coated with the specified coating system.

Overcoating—sometimes called "Prepare and Paint Existing Structure," this pay item requires that damaged, deficient, or deteriorated coating and corrosion be repaired using the appropriate required cleaning methods to the cleanliness degree specified. These areas are then spot primed and the whole structure is coated using the specified coating system.

Spot Painting—sometimes called "Prepare and Spot Paint Existing Structure," this pay item requires that isolated areas of corrosion and damaged, deficient, or deteriorated coatings be repaired using the appropriate required cleaning methods to the cleanliness degree specified. Then only the repaired, isolated areas are coated with the specified coating system.

Zone Painting—this pay item requires that a specified area of corrosion and damaged, deficient, or deteriorated paint be repaired using the appropriate required cleaning methods to the cleanliness degree specified followed by coating of the repaired areas only with the system specified. It is used frequently in conjunction with the other pay items to obtain different degrees of cleanliness on the same structure.

Overcoating

A term that has been used a lot is encapsulation. "Encapsulation is a process that makes lead-based paint inaccessible by providing a barrier between the lead-based paint and the environment, with this barrier being formed using a liquid applied coating or an adhesively bonded material" (40CFR Part 745). While the application of a coating over a lead-based paint may act as a barrier, it does not render the lead-based paint inaccessible because the system is now only as good as the adherence of the lead-based paint to the substrate or the newly applied barrier to the lead-based paint. In the bridge industry, the term "overcoating" generally describes painting over lead-based paint instead of encapsulation because of the potential lack of permanence of the newly applied paint.

Overcoating, which technically has to do with applying paint over an existing paint, is increasingly being coupled with a surface-tolerant spot repair approach. The primary driving force is the cost of performing work in connection with a lead-based paint. The less that the lead-based paint is disturbed, the lower the cost of preparation.

A surface-tolerant approach involves not cleaning an area to the best available condition as expected under a good painting practice, but rather to some intermediate condition. Then a coating material is used that has been formulated to be tolerant of this intermediate surface condition and existing paint. This provides the least disturbance to the existing paint. The service life of the system is determined by how well the surface preparation and the surface coating are matched. In most cases, the higher the degree of surface preparation, the higher the cost; however, it is more likely that the coating will perform for a longer period of time with the higher degree of surface preparation. The lower the degree of surface preparation, the lower the cost, but it is less likely that the coating will perform for a long period of time. Typically, for the same type of coating, the weathered abrasive blasted surface is four to five times more durable than one that is hand cleaned *(63)*.

Adherence of Existing Coating

Not only is the ability to tolerate residual contaminants an issue, the adherence of the existing paint and the compatibility of the newly applied paint are also issues. The presence of millscale may affect adhesion. Poor adherence of the existing paint or incompatibility can cause a catastrophic failure, usually a delamination of the paint system. With incompatibility, the newly applied coating attacks the coating, whereas with poor adhesion, the existing paint cannot tolerate the adhesive, cohesive, or internal stress applied to it *(67)*. Figure 18 shows the delamination of the existing paint from the mill scale surface after one winter due to poor initial adhesion.

SSPC Guide No. 9 "Guide for the Atmospheric Testing of Coatings in the Field" discusses ways to assess coating compatibility. It is also helpful in determining whether the surface cleaning to be specified is adequate to achieve adhesion of the newly applied paint. ASTM D-3359, "Standard Methods for Measuring Adhesion by Tape Test" and ASTM D-4541, "Standard Method for Determining Pull-off Strength of Coatings using Portable Adhesion Testers" are typically used to assess the adhesion of the existing coating.

ASTM D-3359 has two methods of assessing adhesion, the X-cut method (Method A) and the cross-hatch method (Method B), which is limited to coatings no thicker than 125 microns (0.005 in.) dry film thickness. After scribing through the coating system (down to the substrate), tape is used to pull off any broken paint. The amount of delamination is estimated and rated on a scale of zero to five in accordance with the appropriate grading tables. A rating of five is perfect with no loss of adhesion; a rating of zero denotes a loss greater than 65 percent. Depending on the experience of the agency, a limit can be selected below which the paint is determined to be too poorly adhered for overcoating. Values of 2A and 2B (or less) are marginal values and generally considered to have a high risk for delamination when overcoated *(68,69)*.

ASTM D-4541 uses a dolly (metal stub) that is glued to the surface. After the glue has cured (usually 24 hours), the dolly is pulled off with a tester that measures the force necessary to remove the dolly. A value of 0.7 MPa (100 psi) or less is considered too poorly adhered for overcoating. The risk factor for delamination is large *(70)*. The tape test is the easier of the two to use since the results are immediate.

Costs

Table 3 compares the cost of preparing the steel and painting it in the fabricating shop and in the field. It costs about \$15 per m^2 (\$1.40 per ft^2) to apply a three-coat paint system in a fabricating shop *(Personal correspondence, Dale Aulthouse, High Steel Industries, May 1996)*. This is independent of any painting in the field for untopcoated areas, such as splice plates and damage repair.

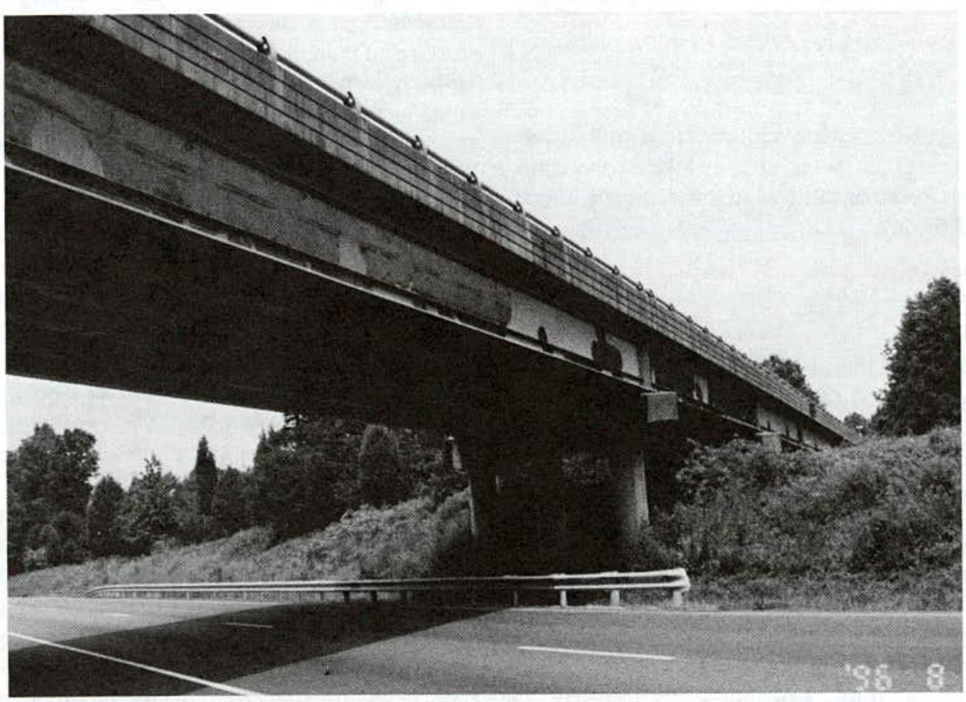

FIGURE 18 Delamination failure.

TABLE 3
SHOP VERSUS FIELD PAINTING COSTS

	Shop ($/ft^2)	Field ($/ft^2)
Paint	0.39	0.35
Application	0.78	0.90
Surface preparation	0.23	1.00
Total	1.40	2.25

Contrast this with total paint removal in the field and application of a similar three-coat paint system. Smith, Tinklenberg and Peart *(71)* report that the cost of paint removal to a near-white blast is $24 per m^2 ($2.25 per ft^2). The difference in cost between the shop and the field reflects the greater ease of painting in the shop and the method of blast cleaning for surface preparation in the field. The difference in paint costs are insignificant and may be due to slightly different paint, regional or time factors between sources, or the need for touchup in the field for shop painted steel. When a degree of difficulty of $21 to $43 per m^2 ($2 to $4 per ft^2) is added, in addition to costs for containment, collection and disposal of debris, and worker protection, they report that the average costs for total removal of a lead-based paint provides an average cost of $80 per m^2 ($7.50 per ft^2). For a total lead-based paint removal, costs can vary significantly due to such items as local requirements for containment, amount of enforcement, neighborhood concerns, paint system used, and others.

Compare the published prices with the responses in Appendix C, NCHRP Web Document 11. Painting of new structures is about $24 per m^2 ($2.25 per ft^2). This price would include any field touchup, plus any price inflation since the other costs were reported. Responses indicate a wide range of costs for maintenance painting depending on the type of surface preparation required. Kentucky reports the lowest cost, $15 per m^2 ($1.40 per ft^2), for its overcoating approach, which is using chipping hammers to remove rust scale and then water cleaning the structure with 34 MPa (5,000 psi) water. At the other end of the scale, total removal of the leaded paint from a structure using abrasive blasting, Connecticut reports an approximate cost of $124 per m^2 ($11.50 per ft^2). The respondents indicate that total removal is about $75 to $85 per m^2 ($7 to $8 per ft^2) for zone painting, and spot painting costs are equal or slightly higher. The cost for overcoating is about half that of the price of total removal.

Usage

There was no report by the respondents that any methods of paint application are being used other than the usual brush, roll, or spray as recommended by the manufacturer. None of the respondents reported the regular use of water jetting or abrasive injected water blasting.

Eighty percent of the respondents to the survey require a near-white blast or better as surface preparation for new structures. For existing structures, the responses vary a great deal depending on the end result required. Repainting and zone painting use either SP 6, SP 10, or SP 11. Overcoating and spot repair use a variety of preparation methods, from power washing to spot blasting.

For those agencies reporting the use of steel box construction (Appendix C), 65 percent of the respondents indicate that the interiors are required to be painted. The remainder either do not use box girders or do not require them to be painted. All of the respondents indicate that painting is done for corrosion protection. Twenty-five percent indicate that the painting is done for ease of inspection and 25 percent of the agencies indicate that white topcoats are used to aid in inspection and visibility inside the box.

WASTE PRODUCTION

Different methods of surface preparation produce different amounts of debris to be disposed, requiring differing amounts and types of containment and different worker protection. Waste is generated for all surface preparation methods. SP 1 generates solvent wipe waste as well as wash water waste. These waste streams are separate from those for the removed debris, except for UHPWJ where the SP 1 cleaning is combined with the surface preparation itself.

The amount of waste generated by hand tools and power tools is limited to just the actual paint and rust being removed or disturbed. The most waste to be generated by power tools is when all the paint is removed under an SP 11 preparation. For a red lead primer with an aluminum topcoat that is about 125 microns (0.005 in.) thick, the total coating material is about 0.9 kg (2 pounds) per 9.3 m^2 (100 ft^2) *(72)*. Generally less extensive containment is needed if vacuum-assisted power tools can be used.

Abrasive blasting with expendable abrasives produces the most debris because it includes the paint, corrosion debris, and any expended abrasive. A surface area of 9.3 m^2 (100 ft^2) will yield about one barrel of waste. If recyclable steel abrasives are used, the amount of debris is reduced to about one-tenth of that of expendable abrasives *(73)*. Abrasive blasting requires the most extensive containment devices.

Wet abrasive blasting (WAB) will wet the dust particles. This has the potential to reduce the amount of airborne dust and thus a lesser containment device may be acceptable. Worker exposure may also be lower *(13)*. The quantity of waste produced will be large because the waste stream will be about the same as that with an expendable abrasive in addition to the water.

For the UHPWJ shown in Figure 19, the water, removed paint, and debris will also have to be contained and collected. If the water is filtered and cleaned for re-use by an ion exchange filtering device, about 2.7 Kg (6 pounds) of waste/sludge is generated per 9.3 m^2 (100 ft^2) *(Personal conversation, Robert Ashworth, UHPP, October 1996)*.

Vacuum abrasive blasting (VAB) is a process using a tube-within-a-tube approach. The abrasives are propelled down the inner tube, through the nozzle head, which is surrounded by brushes. The abrasive strikes the steel surface and is sucked back, along with any removed material, through the outer tube to the collector. This process will reduce the amount of

FIGURE 19 Ultrahigh pressure water jetting.

containment required as long as the blasting head is held against the surface of the steel. Otherwise it is open blasting. It has the same problems as power tools in terms of accessing complicated areas. VAB can reduce worker exposure if used properly but it has the same waste generating characteristics as regular blasting.

SSPC-Guide 6, "Guide for Containing Debris Generated During Paint Removal Operations," provides information about various types of containments, airflows, and ventilation requirements. SSPC-Guide 7, "Guide for the Disposal of Lead-Contaminated Surface Preparation Debris," provides information about the handling, testing, and disposal of debris generated during the removal of lead-based paint.

EDGE PREPARATION

Edge preparation for cut steel is a labor intensive effort in the fabricating shops. Specifications may require that edges be ground or rounded to a certain radius. It is generally accepted that liquid coatings tend to pull away from sharp edges, leaving exposed steel *(73)*. Sandor, in his research for the National Shipbuilding Research Program, has shown that, to perform the same as flat surfaces, the edges need to have a minimum radius of 0.003 m (1/8 in.) R; that coating thickness decreased with decreasing edge radius; and that the sharper the edge the shorter the life expectancy. His work also showed that the inorganic zinc typically used in fabricating shops is a poor performer on sharp edges and that an epoxy polyamide does well *(74,75)*. Typically, flat panel qualification testing for paint does not evaluate edges for rusting. The edges of panels quite frequently are treated in such a manner that corrosion at the edges will not affect the assessment. If edges are not rounded and if a coating system is used that does not protect the edges, then the likelihood of having poor edge performance is high.

Grinding edges to remove carburized steel in order to impart an acceptable profile for a particular type of coating is a separate issue. For steel to be metallized, an angular profile is necessary. It can be achieved with grit abrasives. Fabricating shops are hesitant to put all grit in their centrifugal blasters because grit wears out the blasters faster. Most fabricating shops used steel shot abrasives, which are round and add a certain percentage of grit that becomes round with multiple reuse. The shot produces a more peened surface. Grinding the edges first allows the use of a shot/grit mixture to prepare the surface.

Usage

A majority of the respondents require some type of edge preparation. The responding agencies are about equally divided between radiusing and grinding to breaking or beveling the edges for painted structures. Three agencies do not require any special preparation. There is no one significant reason for preparing the edges, the responses being divided about equally between always being done this way, imparting profile for adhesion, and nonground edges rusting first.

CHAPTER FIVE

DESIGN CRITERIA

NEW CONSTRUCTION AND REPLACEMENT

Design details can affect the performance of a protective system, and more design options are available when a new or replacement structure is being designed. Depending on site conditions, it could be a simple, continuous, or jointless span design. Joints can and do leak. Obviously, the fewer joints there are to leak, the fewer problems that can be associated with the leak *(51)*. In areas of the country that use deicing salts, leaking joints allow the deterioration of not only the superstructure, but the deck and the substructure as well. The same comments apply to deck drains that allow the discharge to come in contact with the superstructure. Figures 20 and 21 illustrate no-joint designs for painted and weathering steel.

Many design details are known to contribute to corrosion. Back-to-back angles, particularly those with spacers, as shown in Figure 22; fillet welds instead of continuous welds; inaccessible areas after construction; complicated bearing details; and flat surfaces that trap dirt and debris are just a few. Problems with these types of details have been well documented *(74,76)*.

The impact of some details is not so obvious. From a painting and corrosion standpoint, C-section diaphragms, as shown in Figure 23, are a better choice than angled cross-bracing, shown in Figure 24. C-sections have larger flat surfaces, fewer welds, edges, and inside angles and are easier to paint than angle bracing. Areas that are difficult to paint, such as in Figure 25, result in overspray, extra thickness, mudcracking, and waste of paint product. Wasting paint is not only uneconomical, it adds to environmental emissions. The easier to paint the higher the likelihood of a quality paint job.

The use of galvanized diaphragms and galvanized fasteners places even less emphasis on the painter's technique. Figure 26 shows galvanized fasteners. Figure 23 illustrates another design positive from a corrosion protection aspect. If angled steel is used, the use of bolted galvanized angles instead of welded angles assures that there is coating on the faying or mating surfaces and helps to reduce the likelihood of crevice corrosion.

If sole plates for steel bearings for prestressed concrete beams are screwed instead of welded to the insert plate, field welds and welding damage are eliminated *(Personal observation, Meisner Marine, I-664 Project, Newport News, Virginia, fall 1988)*. If carried one step further and galvanized or metallized, then only installation damage has to be addressed in the field.

Higher strength, thinner section steel is often used to reduce initial weight. This reduction is intended to reduce initial

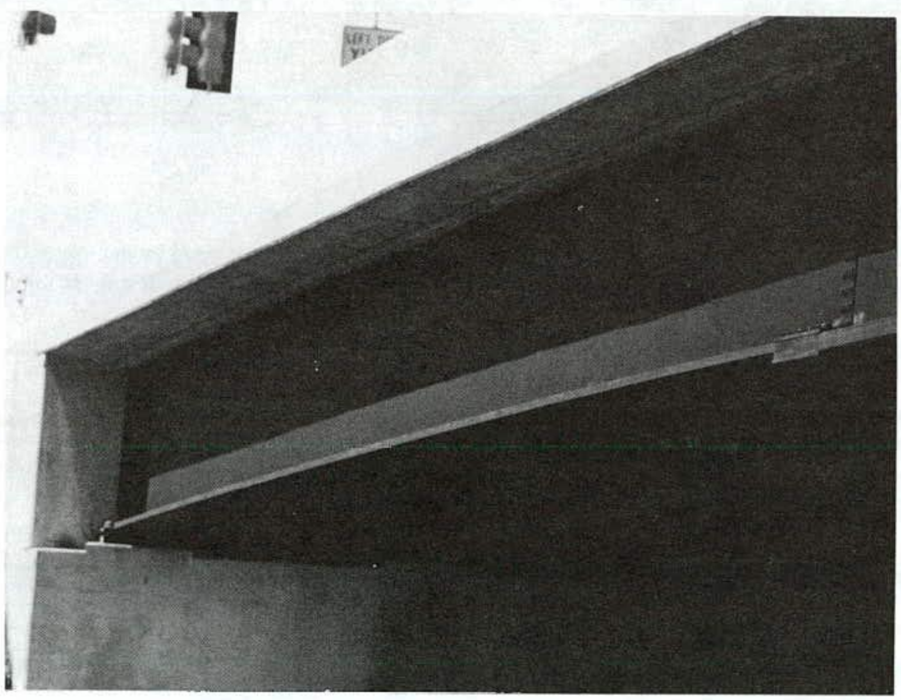

FIGURE 20 No-joint weathering steel design.

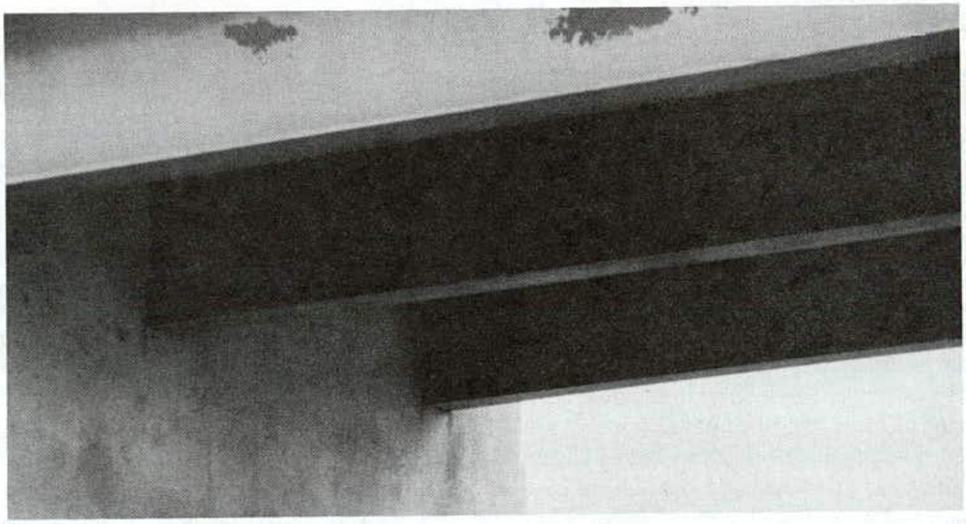

FIGURE 21 No-joint painted steel design.

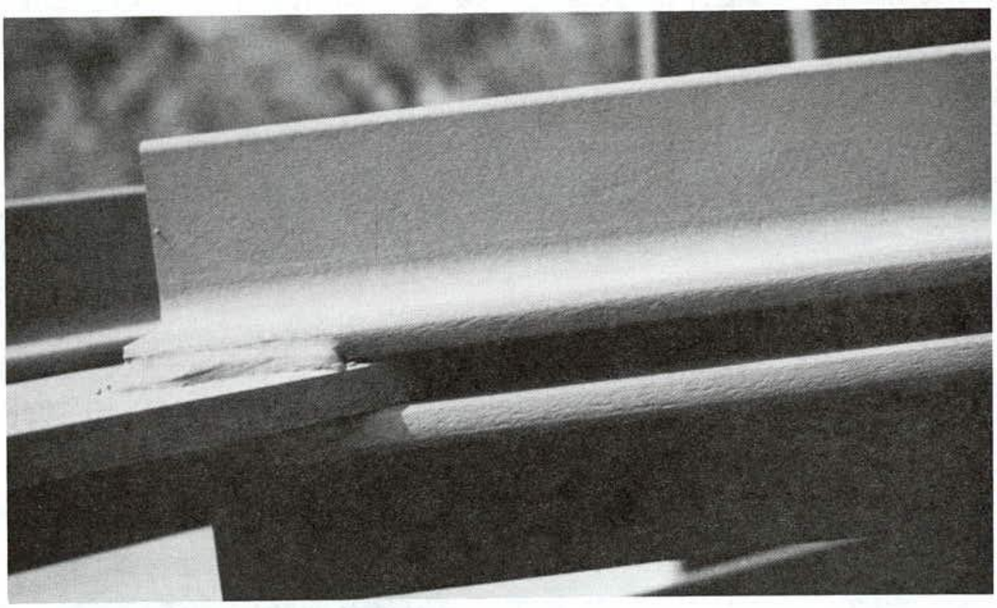

FIGURE 22 Back-to-back angles.

cost. However, more stiffeners and bracing may be needed, which are harder to paint. Changes in flange thickness and width to reduce weight may be even more expensive due to extra labor for welds and resultant inspections. Thinner sections may be a good concept from an initial cost aspect. They may not be good from the maintenance side *(77)*. Thinner sections place more emphasis on the performance of the corrosion protection system and more emphasis on the timely maintenance of that system. There is simply less section that can be lost to corrosion.

Beams and girders have flat flanges providing a convenient spot for debris to collect. The use of no-joint structures helps to eliminate the collection of debris on the flange through leaking joints. If weathering steel is used, the mill scale should be removed on all of the members before erection to assist in reducing the likelihood of pitting corrosion *(6)*. Mill scale is easily removed by the use of the centrifugal blasters in most fabricating shops. If not, as the mill scale weathers and falls off, it can collect on the top of the bottom flanges and create a possible corrosion cell. Weathering steel members are quite often partially blasted for splice connections and as a precondition for welding. This is evidenced in Figure 27 where the webs have been blasted but the flanges have not. To remove the mill scale with centrifugal blasters in this situation incurs almost no cost. If the structure is designed for a Class-B slip value, then it is necessary that unpainted splice connection faying surfaces be reblasted in the field prior to assembly to assure the proper friction.

A recent construction project in Virginia illustrates the potential problems that can occur from not recognizing all the facts and costs involved. The project design was to re-use steel from an overpass that contained lead-based paint as the steel

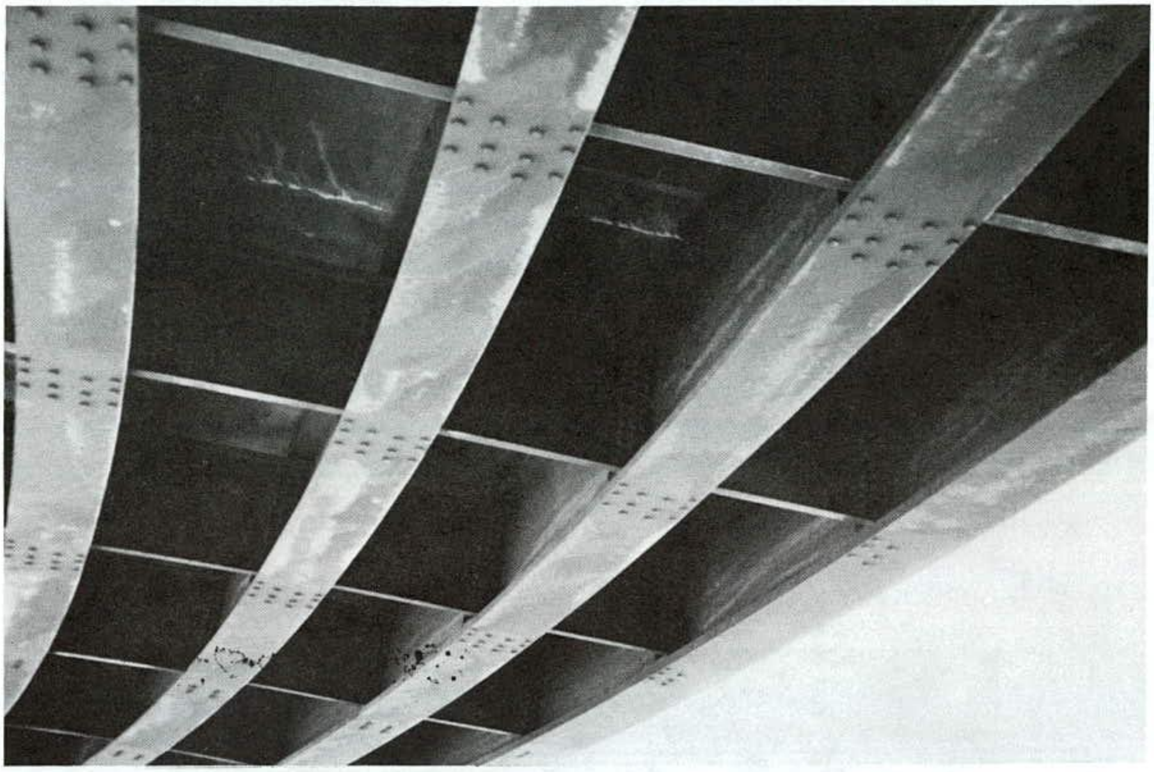

FIGURE 23 C-channel diaphragms.

FIGURE 24 Cross-bracing diaphragms.

for a new bridge. The contract required that the existing steel be dismantled, deleaded, retrofitted in a fabricating shop, primed, and returned to the project site. The price to recondition the steel was $13,000 more than new steel on the same project *(Personal knowledge, I-95 HOV, Northern Virginia, Summer 1995)*. In this particular instance, new steel was cheaper and, more importantly, is more likely to provide a cleaner surface to be painted with an expected longer life to first maintenance (especially in this case because there was no requirement to specifically remediate any salt contamination).

Timely payment for material can be worth money to both the agency and the contractor. If nonperishable materials, such as steel, are paid for on delivery to the fabricator, instead of when the steel is erected, the cost of operating capital for the fabricator should be lower and should reflect itself in the overall cost of the project. A partnership involving the deleading of the cables on the Williamsburg bridge in New York used a sunk-fund approach to pay the contractor for the completion of various stages of the work *(78)* to provide for more timely payment.

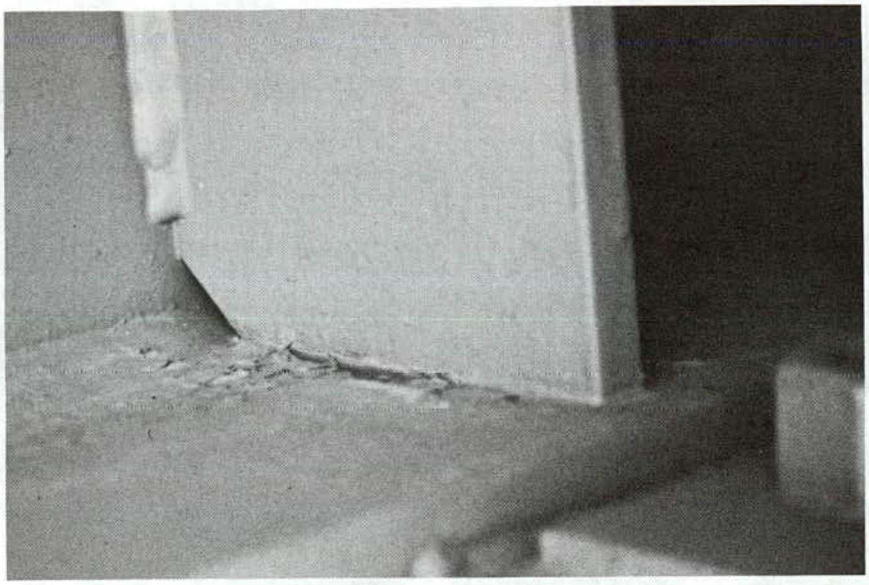

FIGURE 25 Poor paint application due to complexity.

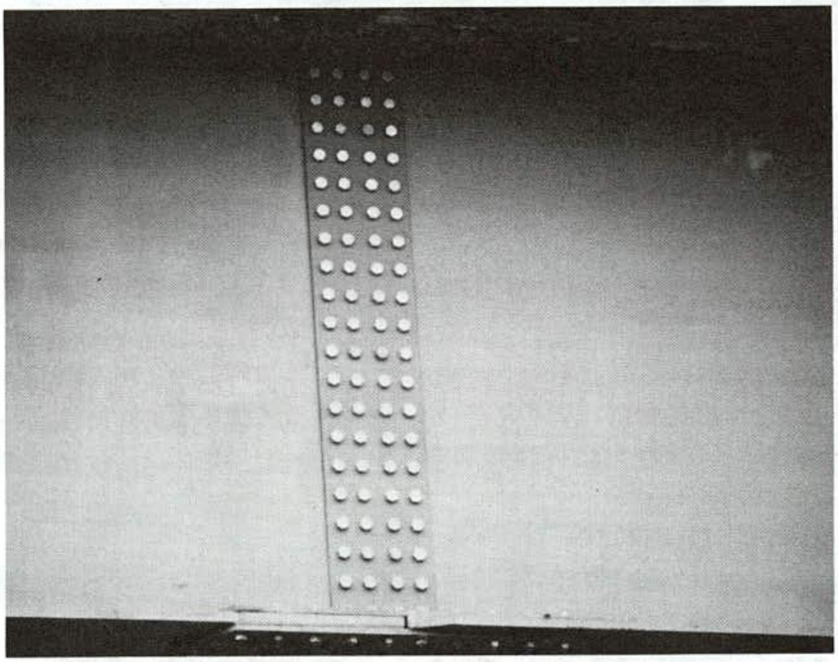

FIGURE 26 Galvanized fasteners.

MAINTENANCE

Unless a structure is being replaced, the design options for corrosion protection on an existing structure are not as plentiful for the maintenance engineer. An existing structure will have its existing coating system and likely a corroded surface contaminated with deicing salts and other debris. The maintenance engineer is quite often designing strategies to combat corrosion rather than structural details. After assessing the condition of the structural steel, the cost of the maintenance has to be considered along with the maintenance of the other elements of the bridge, namely the deck and substructure. The maintenance engineer has to balance the remaining life expectancy of the structure versus the cost of a repair option. The replacement of deteriorated bearings, the repair of leaking joints or the retrofitting of expansion joints with dams or funnels to redirect leaks or runoff are costly. These costs and the cost of painting of the structure, when coupled with a possible need for deck replacement, may lead to the decision to replace the steel. Waste issues as well as limits on emissions can possibly preclude the use of certain surface preparation techniques. This limit may affect the service life and raise the cost of repair of the coating system. Life-cycle costs need to be determined to select the best repair option.

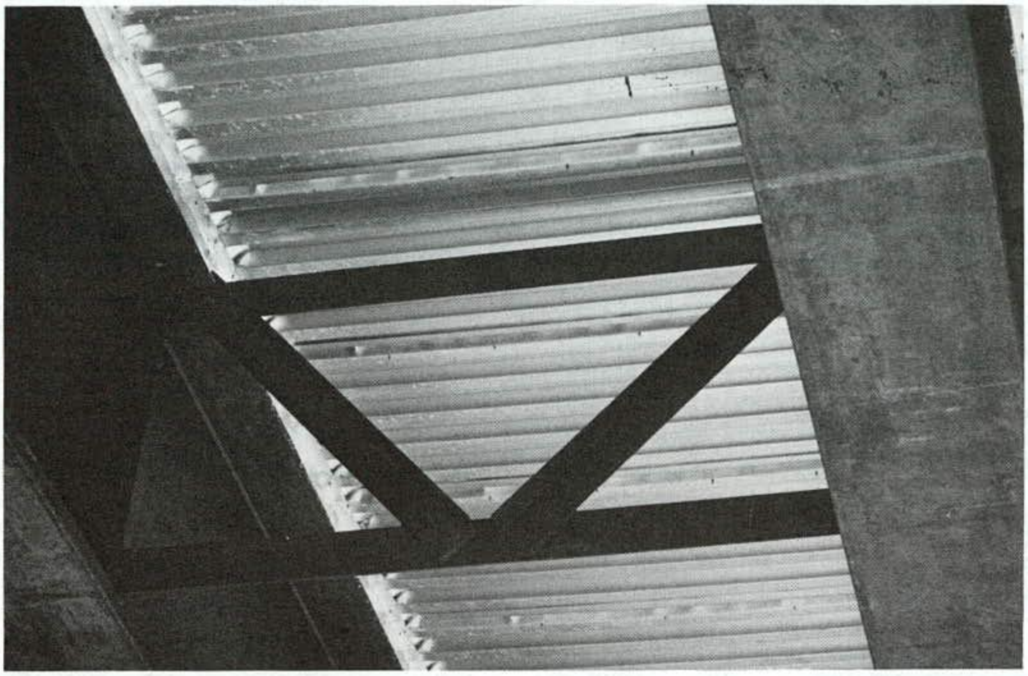

FIGURE 27 Mill scale on weathering steel.

Fund availability may also dictate which repair option is selected.

The bridge maintenance engineer's design approach can be very schedule oriented. His timetable may be shortened because of an emergency such as section loss or damage. If the structure cannot be taken out of service while maintenance is being performed, maintaining traffic can be problematic and costly. Not being able to take the structure out of service can also limit the choices for repair. Alternative materials to expedite the work process have to be considered in cooperation with the cost of traffic control measures. Alternative surface preparation approaches as well as the use of products, such as moisture-cured urethanes, that are more tolerant of moisture and dew points, allow night painting with less concern for ambient conditions. It is necessary to be aware that traffic control and mobilization issues can easily approach the cost of some repair options.

The demand for construction funds for a particular structure stops once it is constructed. With maintenance, its funding needs start at end of construction and continue for the life of the structure. Being able to intervene in the corrosion cycle in a timely manner reduces the cost of maintenance. Demand for construction or other funds may dictate deferral of maintenance, which may result in higher costs when the repair is performed.

WARRANTIES

Warranties are an option that is available for both new construction and maintenance work. The use of warranties was recognized by the FHWA on August 25, 1995, in the *Federal Register*. The fact that extended warranties were not accepted on federal-aid projects had been an obstacle and limited their use *(79)*. The FHWA has never objected to manufacturer's warranties that were supplied as part of the material itself. Its objection was requiring the warranty for federal-aid projects. A state, such as Michigan, which had required warranties in the past, had to do so on projects that involved state funds only. It should be noted that 5-year warranties are commonplace in Europe *(28)*.

There is a big difference between warranting performance as opposed to materials. A materials warranty is a warranty against defects in the material for the stated period of time. A performance warranty gets not only the manufacturer of the material involved in the process but the contractor who is applying the material as well. Several approaches are available to the agency when it is structuring its contract.

The agency can require that a performance warranty be supplied using prequalified products. The contract can also be totally end-result oriented, in that the contractor can provide whatever product he wants as long as the stated performance goals are met. This second process can allow for more innovation by the contractor. It also requires more trust on the part of the agency that is specifying or allowing the use of warranties. Warranties are, therefore, basically a type of partnering.

The length of the warranty period and the actual warranty provider are issues as well. Is the warranty to be provided by the contractor or by the manufacturer of the material? If by the manufacturer, then it is incumbent on the manufacturer to select capable contractors and to oversee their effort. The longer the warranty period the more intense the scrutiny should be by the responsible party. The agency will have to predetermine what deterioration criteria will invoke the provisions of the warranty.

Another issue is how to indemnify the agency. Is the agency going to depend on the good faith and reputation of the contractor or the supplier? Are bonds or an insurance policy to be used to assure that a responsible party is available if the warranty is invoked? The surety or performance bond may be for the life of the expected warranty or for a shorter period of time. The Province of Alberta selects a job for a warranty expecting to obtain a 20-year performance (See Appendix C). However, the performance bond is only for a 2-year reinspection/repair period at which time repairs for any deteriorated areas are performed. This is not dissimilar to an approach the Maryland State Highway Administration has used. The concept is that, if problems are corrected early, it will significantly increase life expectancy. Also, most errors show up early, if they are to show up at all.

With warranties, the agency becomes a manager of a service provider. This is the concept on a Canadian project. Canada's Ontario province is using a "Total Project Management Concept" on a major project in Toronto *(80)*. This project involves not only the use of warranties but aspects of both partnering and privatization. Managing service providers through the use of warranties is intended to be a means of achieving quality corrosion protection in a reduced manpower situation.

There is a decided advantage to warranties, particularly in regard to painting existing bridges. If a warranty contract is totally end-result for a stated period of performance with all the choices left up to the contractor, claims may be reduced. Whether to overcoat or totally remove the paint is not an agency decision. The agency would only need to have in place the conditions that would trigger warranty repair. Maryland is in the process of bidding such a contract.

The agency must determine what is being obtained with a warranty. The coating that the manufacturer would select and the surface preparation that the manufacturer would require probably would not be much different from what the agency might specify. The contractor will have to pay more attention to quality control issues. This should involve more checks or inspections on his part. In essence, the agency is paying extra money to assure that the work is done properly and to lessen the likelihood of premature failure.

The owner may, however, be able to lower his overall cost and increase the likelihood of successful performance of a paint job by sharing some of the responsibility. A commitment to full-time, knowledgeable inspection, either with agency personnel or independent inspectors, with defined hold points during the application process, may be less costly than the cost increase due to the warranty. A full time inspector's cost is about four to nine percent of the job cost *(3) (Personal conversation with Ken Trimber, KTA-Tator, December 1996)*. This can be compared to the projected cost for a warranty.

CHAPTER SIX

QUALITY CONTROL AND QUALITY ASSURANCE

Quality affects both performance and cost *(81)*. The best made material, improperly installed, reduces performance. Desire, attitude, and expectations can affect quality, which can be different things at different times, taking on different roles depending on the processes being used and the requirements of the job. Inspection alone will not produce a quality job, but lax inspection may well result in work that will not perform properly. For example, a specified near-white surface preparation requires a different approach to its inspection if it is bid as a lump sum versus a time and material bid. The final surface preparation is the same in both instances, but the level at which the inspector is needed to participate in the process is greater for the time and material job. The inspector will need to verify hours worked and efficiency and capability of blasting and painting equipment to lessen overcharges as well as the surface preparation.

Proper materials, equipment, application conditions, worker and environmental compliance, specification requirements, and oversight form the basis for a quality corrosion protection process. A successful paint job is typically thought to combine four items: surface coating, surface preparation, application, and oversight to assure that the required work is achieved. A breakdown in any of these four areas will result in a nonquality job *(82)*. The additional needs in today's environment make a quality job even more complex.

A plan to obtain quality ideally contains both a quality control (QC) side and a quality assurance (QA) side. Both of these aspects need to be incorporated into the materials qualification and acceptance process, the contractor qualification process, the worker and environmental protection process, and the specification writing process.

MATERIALS QUALIFICATION AND ACCEPTANCE PROCESS

Quality assurance programs have been widely used by agencies. The manufacturer or contractor normally performs various quality control aspects, whereas the agency usually performs the acceptance aspects. An integral part of the quality program is the decision on the type of material to be used, how it is qualified, how its production is controlled, and how it is accepted by the agency.

Agencies use various methods to accept materials. These programs generally fall into one of five methodologies:

Testing—the agency may accept materials by taking a sample of each batch of the material being used and testing it or having an independent laboratory do the testing. The sampling may be done either at the point of manufacture or at the job site. Taking the sample at the point of manufacture speeds up the construction process. If the material arrives on the job site with an agency stamp or tag indicating that testing has been performed and the material is approved for use, the contractor does not have to wait for the material to be tested.

Certification—the agency may use a certification process to accept, and the manufacturer certifies under a sworn statement, that the material being supplied meets the particular specification that is referenced. The agency has the option of taking samples for testing purposes.

Certified test results—the agency may use a certification process in which test results are certified and sworn as being the actual test results for the batch being used. The agency has the option of taking samples for testing purposes.

Visual acceptance—the agency may use a visual acceptance or visual comparison process. It may be as simple as a comparison against an approved list or comparison against a visual standard.

Approved lists—the agency may use an approved list process to accept materials. This process is used by an agency when a particular material has been evaluated, found to meet the performance or specification requirements of the agency, and is preapproved for use. This method is particularly useful where there is a lengthy test period for evaluation, such as a 6-month salt fog test. When a material is on such a list, it implies that the product is approved for use but still may be sampled and tested, and accepted by certification, certified test results, or visual comparison.

There is a distinction between testing that is done for qualification of materials and the testing that is done for the acceptance of materials. While independent test results are quite often used by states for qualification, contractor/supplier test results could not, in the past, be used by an agency for acceptance on federal-aid projects.

On June 29, 1995, this changed when the FHWA published in the *Federal Register* its rule to allow contractor supplied acceptance test results. Contractors and independent test laboratories may submit actual test results for acceptance to the state provided the results are from a qualified laboratory. The qualification process has yet to be established. State laboratories will also have to be qualified under the same process. The Asphalt Materials Reference Lab (AMRL) and the Concrete Cement Reference Lab (CCRL) certification programs are already in place through AASHTO, and will likely be models since AASHTO is charged with developing the qualification program.

The FHWA qualified testing applies to all materials, whether steel, paint, asphalt, or cement. Just as AASHTO already has a proficiency test program for asphalt and cement, it now has one for paint. Participating in proficiency testing is an integral part of the AMRL and CCRL certification programs and will likely be the first step in the development of any other qualification program. A written quality assurance testing plan is mandatory under the AMRL and CCRL programs.

The new laboratory qualification program, when used by the agencies to permit supplier- provided testing results for the acceptance of materials, has the potential to solidify the QC aspects with the supplier. The agency will be able to perform its QA role. The new process should lead to an expansion of trust between the agency and the supplier because there will now be a standardized testing program. A lack of trust between agency and supplier has been a detriment to the use of certifications in the past *(83)*. Ideally, the manufacturer's process should be identifying material that does not meet specifications. The monitoring samples taken by the agencies should just be a verification of the supplier's testing procedures, not the test results.

An advantage for the new testing program is that now a supplier may either get his laboratory qualified or use a qualified independent laboratory to test a batch of his product. These test results could then be supplied to all of the states that would use this product without each state having to take samples for testing. States that use just a certification process now can require certified test results. This should raise the level of quality of the acceptance program and the product being supplied because of intensified scrutiny. For agencies, it will provide a strengthened testing program. The use of certifications and certified test results is considered to be cost effective when properly used *(83)*. Money is saved because of less duplicative testing.

Although the FHWA requirement is only for acceptance of materials, there is no reason why this same concept cannot apply to the qualification process. A national approach to the concept of qualification laboratories has the potential to reduce testing costs for the agencies and to provide the basis for a QC/QA program. In fact, such an effort may have already begun. AASHTO is in the initial stages of setting up a qualified laboratory concept through its National Testing and Performance Evaluation Program (NTPEP), which is considering the use of the NEPCOAT approach of qualified laboratories for the evaluation of materials. Collaborative testing under NTPEP will mesh well with the proposed performance approach.

The new, proposed AASHTO performance system approach will use accelerated testing to determine performance. Recent work done by the FHWA indicates that the use of ASTM B-117, "Standard Method for Salt Spray (Fog) Testing," an accelerated weathering test, does not provide as good a correlation with field performance as the use of a multiple exposure, cyclic accelerated laboratory test *(84)*. To improve the quality of the performance tests and, therefore, the quality of the performance, the results of the testing should be as indicative of the actual performance as possible. Because the surface conditions for new steel versus existing steel are not the same, different qualifying conditions are likely to be needed. Qualification testing using new steel panels will probably not provide the same results that a rusted, contaminated panel would. Although SSPC has developed a process for preparing a rusted panel *(85)*, to date, no contaminated rusted panel procedure has been developed in an attempt to duplicate the existing steel condition.

Collaborative qualification testing passes the cost of qualifying to the manufacturer. It is recognized that this cost will be recouped in the sales price. However, because the manufacturer will be paying for the testing up front, he has an incentive to submit materials for qualification that have the potential to meet the requirements. In addition, a collaborative qualification program affords the supplier a greater basis for recovery of his expenses. Supplier-furnished qualification and acceptance results would be privatization at its ultimate.

The FHWA qualification program also extends to the independent assurance testing program that is part of FHWA requirements for agencies. Independent assurance samples (IAS) are samples taken by personnel who are not a part of the usual acceptance process. The samples are then tested by an independent laboratory that is also not normally a part of the acceptance process. It is an independent evaluation of the sampling and testing procedures. The laboratories doing IAS testing must also be qualified.

Acceptance Testing

Acceptance tests on paints used for corrosion protection are generally a combination of physical testing and wet chemistry testing. Physical tests include weight per gallon, viscosity, percentage vehicle solids (percent nonvolatile vehicle), percent total solids, and percent pigment, among others. Chemical tests can include type and amount of pigment and type of resin (vehicle). Chemical tests usually involve the separation of the pigment from the resin so that the chemical tests can be performed.

In days past, most pigment analysis involved the wet chemistry extraction of elements or compounds of interest. The amount of element present was then determined either gravimetrically or stoichiometrically.

Although wet chemistry hasn't been totally eliminated in the process today, a good deal of the analysis is done instrumentally. For inorganic pigments, atomic absorption (AA) spectroscopy and inductively coupled plasma (ICP), x-ray fluorescence, and x-ray diffraction are popular techniques. For vehicle and solvent analysis, infrared spectroscopy (IR), gas chromatography (GC) and mass spectroscopy (MS) are used. Not all of the tests are quantitative. Some only provide qualitative data. For example, IR is a good technique to identify if an oil is present, but it will not identify the type or amount of oil present. To identify the type will require saponification and methyl esterification of the extracted oil. The resultant compound is injected into a gas chromatograph to produce an elution time. This time can be compared to the elution time for a standard or known methyl ester.

Certain resins require the presence of a specific amount of a particular type of bond linkage or reactive sites. Not all resins with the same generic name have the same number of reactive sites, and, therefore, their crosslink density is different. For example, a polyurethane resin can have a varying amount of nitrogen-carbon-oxygen (NCO) bonds depending on the particular resin used by the manufacturer. The use of an IR scan alone will show that NCO bonds are present, but will not quantify them. In order to have a consistent quality of product, the agency must determine the NCO value needed, put a requirement in the specification, and then test for that amount.

Alternatively, if a performance qualifying process is used, then the qualifying laboratory needs to do the necessary analysis so that when the product is actually produced and subsequently sampled, these chemical values, as well as physical values, are available for verification comparison. If the values are not determined on the qualification samples, then there is no basis for later comparison.

CONTRACTOR QUALIFICATION

The proposed FHWA qualification program will assure that a properly tested and accepted coating will arrive on the project. This testing effort assures the ability of the coating to perform, unless it is applied incorrectly or the necessary surface preparation is not attained. This program does not ensure that a properly qualified contractor will perform the work.

Agencies usually have a prequalification process to ascertain that a contractor is financially capable of completing a project. An equally important part is whether the contractor is technically capable of performing the work. Most governmental agencies do not have a technical qualification program for the protection of exposed structural steel in their specifications, although this is beginning to change. Seven states now require that contractors be certified by the SSPC's Painting Contractor Certification Program (PCCP).

PCCP has three plans—QP1, QP2, and QP3. QP1 certifies contractors as to their painting ability. QP2 certifies contractors as to their ability to remove hazardous coatings and requires that a contractor be QP1 certified before he can be certified under the QP2 requirements. QP3 is for painting in fabrication shops. An integral part of the program is the contractor's quality control program, which has to be in place prior to his certification. This aspect of the program, or one similar to it, has the potential to be a basis for establishing an agency QC/QA program.

In order to be certified, the contractor has to have more than just a QC program. PCCP rates the contractor on his worker protection plan, worker compensation rating, equipment, QC plan, safety plan, and plan to address the relevant environmental issues. The contractor is only certified for the type of work that he has the equipment and experience in performing. A contractor who has only done powertool work would not be certified to do blasting. This program certifies the contracting firm, not individuals.

If an agency decides to use such a program, there is no guarantee that the contractor will perform all the aspects of the painting properly. He will not, however, be able to argue that he has no knowledge of the issues. Hence, the need for a monitoring or acceptance program by the agency. Agency personnel need to be as knowledgeable as the certified contractor.

INSPECTOR QUALIFICATION

For agency personnel involved in coating inspection matters related to corrosion, there are two sources of training. The National Highway Institute (NHI), the training arm of the FHWA, sponsors a bridge coatings inspector training short course, which is available to state DOT employees. If a state elects to use this course, it is taught in the state and is specifically related to bridge painting, including the use of instruments.

The other course is by the National Association of Corrosion Engineers (NACE) under its International Coating Inspector Training and Certification Program (NICITCP). This program provides training in all of the relevant issues regarding painting; corrosion protection; environmental and worker protection; and training in the use of the instruments needed to perform the various aspects of coating inspection. There are various levels of training based on the experience of the inspector. This program is a certification program and, to be certified, the individual must have been qualified through three levels of training and written examinations. In addition, the candidate must pass an oral peer review examination. This course is taught at various sites in the country and covers all coating work, not just bridges.

Under an agency QC/QA program, the NACE program can easily be the basis for a QA program on the agency's part. The agency can use the program to train its own workers or it can be used as a specification requirement that independent inspectors hired by the agency are required to meet. Just as OSHA has a requirement for the contractor to have a competent person on site when dealing with lead in construction, NICITCP could be the basis for such a competent person on the agency side for painting. It is a logical next step that a combination of PCCP and NICITCP could form the basis for a QA/QC program.

Usage

No respondent to the survey indicated the use of the NACE program for coating inspection. The NHI course has been used extensively to train agency personnel. NHI is in the process of developing a course to address the issues related to maintenance of bridges coated with hazardous paints.

ENVIRONMENTAL TESTING

While there are environmental regulations and tests that cover many aspects of construction and maintenance activities, only certain ones specifically relate to the corrosion protection of steel. By far, the greatest impact of the regulations is in the removal of lead-based coatings from structures.

Soil testing may be performed on a site before work commences and after work has been completed. The "before" or baseline tests are used to indicate the background condition prior to the contractor beginning work. When compared to test results after the work is completed, the results are a measure of how well the containment worked. Cleanup or mitigation procedures can be determined from these results. As an added bonus, it also aids in dispute resolution. The EPA has proposed that a background level of 500 ppm total lead be used for remediation *(86)*.

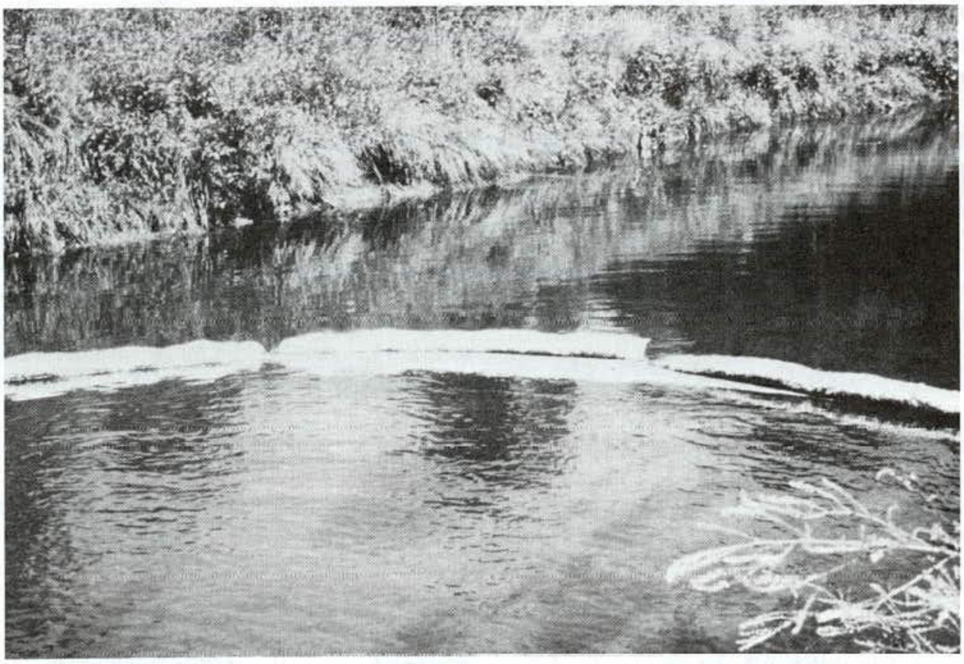

FIGURE 28 Containment boom on water.

NAAQS testing is designed to assess point source air pollution on local environments over relatively long time periods. The use of high-volume TSP and PM10 monitors at bridge paint removal sites has become more common in recent years. These monitors collect data based on EPA approved methodologies. The risk associated with lead dust emissions, particularly in populated areas, has created the need for a reliable and responsible monitoring strategy. Some local agencies have adopted NAAQS testing to monitor intermittent emissions from bridge sources. The FHWA and several states are currently researching and testing various air monitoring strategies for bridge paint removal operations.

By placing a boom downstream on waterways, as in Figure 28, a visual test is provided for surface contaminants on the water (dust and debris escaping from containment). If this occurs, then samples can be taken from the waterway for chemical analysis *(10)*.

Visible emission testing is a visual assessment for airborne particulate matter performed by estimating the opacity, with the opacity limit not to be exceeded over certain time limits. Identifying fugitive emissions from containment based on opacity is an air pollution assessment test for particles. It is not intended to be used as a measure of fugitive lead emissions or for any other material being emitted for which there is an ambient air quality standard. It is not a hazardous material or waste test. Visible emission testing does not meet the OSHA requirements for determining hazardous material exposure to employees.

TCLP testing has to be performed for a particular constituent on the collected waste stream to determine if the waste is hazardous for the toxicity characteristic. In the TCLP test procedure, there is a 20-fold dilution in the analysis process. Thus, if a waste has a total content less than 20 times the toxicity value, it can never be a hazardous waste. The toxicity level for lead is 5 ppm. If a sample has less than 100 total ppm, it can never be a hazardous waste based on this federal limit. States may impose stricter limits. California uses a 10-fold dilution in its test method (CA Title 22). The de minimus level in this case would be 50 ppm. The test for total lead is simpler and less costly than the TCLP leachate test. Depending on its permit, some landfills also require the total concentration in addition to the TCLP number.

Table 4 illustrates one of the problems that can be encountered in the selection and use of materials from an environmental standpoint, and how judicious selection of the material can eliminate possible problems. The table lists the results from samples of zinc dust taken from two fabricating plants and tested for lead and cadmium *(87)*. Three sample results are above the 20-fold dilution level for lead and two results are above the 20-fold dilution for cadmium, which is 20 ppm. Technically, these materials are above the de minimus level and have the potential to produce hazardous waste and could trigger soil testing if much overspray is allowed to fall to the ground.

TABLE 4

ZINC DUST CONTAMINANTS

Company	Lead (ppm total)	Cadmium (ppm total)
A1	1330	286
A2	416	72
B	566	<10
C	32	<10

Agencies can reference ASTM D520 regarding zinc dust in their specifications. There are two types of zinc dust, based on the contaminant level present. Type I is unrestricted for the lead and cadmium content, whereas Type II has limits of 100 ppm for lead and 100 ppm for cadmium. Even at these levels, Type II has the potential to be a hazardous waste for cadmium because it cannot be automatically eliminated. To do so, agencies can engineer out the problem by specifying contaminants to be no more than the 20-fold level, that is, 20 ppm for cadmium and 100 ppm for lead. Using these limits produces fewer issues for possible conflicts and may also simplify future corrosion repair work. Fewer conflicts means that the quality of the work has the potential to increase.

Usage

Thirty-one agencies indicate that they use soil testing on projects. Sixteen agencies use TSP monitoring, 20 use PM 10 testing, 22 use water testing, 28 use visible emission testing, and 7 do no testing. Eight agencies do TCLP testing alone. The high use of visible emission testing, which is probably visible emission observation, is obvious. Visible emission tests provide an immediate indication of leakage from containment. All the other tests require that samples be taken and the results obtained later.

WORKER PROTECTION

In the corrosion protection arena, worker protection problems are most likely to result from the removal of coatings containing hazardous constituents, and the application of products containing hazardous constituents. While the known hazards can cause problems, the unknown ones can create havoc. Unrevealed conditions quite often create disputes and result in claims.

From an environmental standpoint, it may have some value to limit the lead and cadmium content in the zinc dust in order to avoid a hazardous waste issue during application of the product or future removal. Worker exposure is not solved. While it is intuitive that the lower the level of the contaminant present, the less likely there is to be an exposure, it does not remove the issue.

Paint to be removed can contain hazardous constituents other than lead compounds that can cause problems. In addition to materials such as chromates that may have been added in the manufacturing process, naturally occurring contaminants can also cause problems. Lead ore can contain cadmium. OSHA has cited contractors for not training their workers in the risks associated with potential cadmium exposure *(88)*. Cadmium as well as lead may be found in zinc rich paints, depending on the source of zinc dust.

There is no formula that equates "total amount present" to "amount that a worker may be exposed to" in the breathing zone. However, the values in Table 4 would indicate a potential for exposure. The OSHA lead exposure rules are in place for any measurable quantity of lead. The cadmium rules are not stated the same. Its PEL is one-tenth that of lead at 5 mg/m^3 of air [29CFR 1926.63] *(89)* and would imply that a lower quantity would be a problem for exposure.

Research has been recently completed by the SSPC on worker exposure for contaminants in inorganic zinc rich paint. This work indicates that worker exposure above the AL is unlikely when the lead content is below 100 ppm and cadmium content is below 6 ppm. These levels apply to mixing, spraying, and removing inorganic zinc paint only *(90)*. At these levels the waste is not a RCRA hazardous waste. Agencies can specify ASTM D520 Type II with a lowered cadmium level of 6 ppm to assure no hazardous waste and a high probability of no worker exposure problems. The SSPC research did not address organic zinc rich paints.

The incidental contaminants listed in Table 2 do not mean that the products should not be used. It means that the contractor has to recognize the potential problem so that he can train his workers accordingly. Unfortunately, the MSDS may not be much help in this regard. The levels that SSPC found likely to expose workers above the AL for lead and cadmium are below the requirements for reporting on the MSDS.

Even the test method used by the testing laboratories can cause trouble unless the laboratory recognizes what the source of the sample is. False test results for cadmium can be obtained in the presence of iron, which acts as an interference if ICP instrumentation is used for the analysis. The analyst performing the ICP procedure needs to have the background information in order to correct the analysis for background interference. This particular background interference is not usually a problem if AA is used for the analysis.

Forty percent of the respondents indicate that they have no requirement for worker protection for the contractor other than that the contractor be in compliance with the necessary OSHA requirements or Canadian requirements, depending on location. Virginia and Hawaii require that the contractor have a certified industrial hygienist (CIH) plan with the necessary monitoring being performed by the hygienist on the job site. West Virginia and Florida depend on the training requirements of QP2. There is a lot of variation among the agencies when it comes to their own personnel, ranging from requiring nothing to requiring that the contractor train and test the agency personnel along with his own. The most intensive programs appear to be those in Connecticut and Maryland.

PARTNERING

Partnering is a management strategy designed to reduce costs, paperwork, and litigation while at the same time improving schedules. The intent is not dispute resolution, but dispute avoidance. It is intended to get everyone involved from the top down, and requires that everyone involved be committed to the effort so as not to create unnecessary obstacles *(91,92)*. Where it has been successful, large savings have been reported primarily through value engineering.

Conflicts can directly affect the quality of a job. Partnering is all about how to avoid misunderstandings in the design and construction processes. How states approach partnering varies, but the main emphasis is better understanding on the front end to avoid misunderstandings on the back end. Items not well communicated in the bid process are going to cause conflicts and possible quality problems.

From a corrosion protection aspect, painting of a structure in the past was a low-cost pay item *(93)* relative to other pay items in the contract. Lesser costs tend to receive less emphasis than higher cost items, based on the cost of that item to the project. Now, it is not unexpected for the cost of removal of a lead-based paint to approach the cost of new steel *(94)*. In addition, paints are being used that require a higher degree of skill to mix and apply, making quality workmanship more important than ever. Partnering can help to communicate this heightened emphasis on workmanship and environmental issues.

Figure 29 illustrates some quality problems. The diaphragms are poorly designed from a corrosion standpoint (back-to-back angles), poorly painted (missed edges), poorly stored (no provision to prevent abrasion damage) and poorly inspected (since all this is occurring). The quality of this structure, and hence the maintenance cost, was compromised from the day it was designed. Partnering, as a concept, is intended to help improve the quality of work by having all participants realize the importance of various aspects of the construction and maintenance process: from design to completion and beyond. Construction is a one time cost. Maintenance is a lifetime cost.

Agencies' use of partnering as a concept to improve quality is high *(88)*. What is different is how it is implemented or practiced by various agencies, as reported in Appendix B. Some agencies use a direct approach. The use of partnering may be mandated in the contract, i.e., the contract is bid with the stated purpose of the work being performed under a formal partnering aspect. Connecticut uses a permissive approach in that the contractor can request to do the work under a partnering arrangement after he has the bid but before beginning the work. Other agencies use an indirect approach. Joint meetings and conferences are used to foster understandings and to build team-like relationships. Committees may also be formed that are composed of designers, contractors, and agency personnel to develop joint specifications and produce training programs.

The first step to successful partnering is commitment to the process. This can be as simple as a consensus statement of mission to which the various participants in the process can agree *(91,92)*. Regardless of an individual's role in the construction project, all involved personnel have some goals in common, such as finishing the project on time, safety of workers and the motoring public, and quality workmanship, to name a few. The common goals and objectives should be stated for everyone's concurrence so that it is understood what the partnering effort wishes to achieve and how to measure that it has been achieved. The potential for disputes to arise must be recognized and a system created that removes barriers to resolution in an expeditious manner. An up-front team building approach brings together personnel from the vested parties, i.e., the contractor, the agency, and the designer, in an attempt to identify potential problems and effect a solution before it becomes a claim *(91,92,95,96,97)*.

A valuable part of a partnering effort is constuctibility reviews that include the design process itself *(98,99)*. The idea is to remove problems that can cause conflicts even before the work begins. Design deficiencies and unknown site conditions are well-known causes of conflict. The corrosion protection industry is not immune from these types of disputes. For example, if the correct welding procedure was not followed, the effect of correction on an applied coating system can be disastrous.

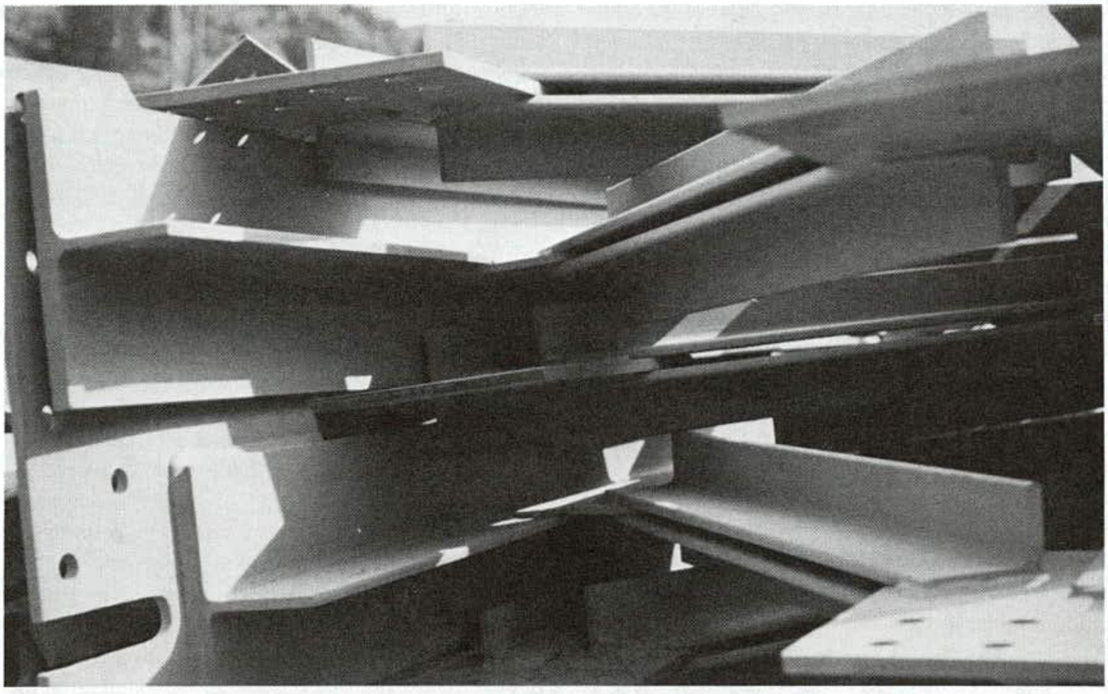

FIGURE 29 Quality problems.

When routing a utility pipe under a bridge, the state may very well have its specifications in place for coating exposed steel that may not agree with the utility company and its program. Maintenance painting contracts can get quite controversial, particularly if it was not revealed that there was a lead-based paint on the structure.

In Europe, there is a high degree of partnering, from research all the way to contract administration *(100)*. Domestically, the Connecticut Road Industry Surveillance Project (CRISP) program is an example of a direct partnership between worker protection industry and the Connecticut DOT *(101,102)*. The primary emphasis of this program is to lower worker exposure to lead and to monitor the effort to determine how successful the effort was. Another direct partnership effort involved the deleading of the Williamsburg Bridge in New York *(78)*. Its primary emphasis was on containment of the lead-based paint being removed from the suspension cables to avoid releases in the densely populated area.

Value Engineering

Value engineering (VE) is an integral part of the partnering process *(95,99)*. VE is a process in which designs or methods alternate to those specified are allowed, based on a cost-sharing element between the agency and the contractor. It is usually a method for reducing costs, but it can be used for higher priced options when the value is compared. The Society of American Value Engineers defines "value engineering as the systematic application of recognized techniques by a multi-disciplined team that identifies the function of a product or service, establishes a worth of that function, generates alternatives through the use of creative thinking and provides the necessary functions, reliably, at the lowest overall cost" *(103)*. The result is to a produce a product of equal or better value.

While cost effectiveness and life-cycle costs are an integral part of the VE evaluation, value or function is what is being assessed. The function or end result has to be clearly defined or identified so that a valid comparison can be made. A comparison between a high-strength weathering steel structure and a painted high-strength (nonweathering) steel structure is likely to be a comparison of first cost only, if the expected value is the ability to carry the load. It is likely to be a different comparison if weathering steel is not recommended for use on a particular bridge site. In this case, any shortened life expectancy and extra maintenance has to be taken into account in the analysis to determine cost effectiveness.

Life-cycle costs based on the expected remaining life can show that the use of overcoating is more cost effective than a total removal of the lead paint *(34)*. If the value is to provide corrosion protection and the existing coating is capable of supporting the overcoat, then this can be a valid comparison. Overcoating and surface-tolerant approaches have not proven to be as long lasting as total removals *(60,63)* and will likely require more frequent repaints. This aspect has to be captured in the analysis. If the existing paint is marginally adhered, then the probability of premature catastrophic failure is high and that cost has to be factored into the analysis. For example, if the lead-based paint is delaminating from a bridge and falling into a drinking water reservoir, the value is to stop the contamination by stopping the delamination, in addition to protecting the steel. Overcoating may carry too high a probability of failure, which would exacerbate the reservoir problem. In this case, the comparison is likely to be a different one, a comparison of the various methods of removing the lead-based paint, for example.

Life-cycle analysis typically does not take into account the probability of success or failure. Therefore, it may be more appropriate to use a decision matrix based on probability when risk of failure is moderate to high. This involves factoring into the life-cycle analysis an assessment of the expected life of the structure with the expected life of the coating to be applied, and the probability of achieving the expected life. The idea behind painting is to provide corrosion protection by stopping the corrosion cycle. If the products selected for the particular surface preparation do not do this for the anticipated time period, then the limited resources are wasted. There is no value in an early failure. Premature failure may even have a negative value if there has to be an environmental cleanup. A probabilistic approach is a valid method of analysis when uncertainty of the end result is a factor.

Of the responding agencies, Missouri is the only agency that reported using VE to decide to do overcoating versus a total removal of the existing lead-based paint on a structure. VE was performed in the design process as opposed to being submitted after the bid process. The structure was determined to have an expected life of 20 years. It was estimated that the total removal would cost $2.3 million. Overcoating was estimated to cost $1.3 million with a subsequent repaint cost of $0.68 million.

CHAPTER SEVEN

MAINTENANCE

There are nearly half a million bridges in the United States *(104)*. This represents a very large investment in the infrastructure. It also means that a large amount of funding is needed to maintain these structures.

A series of events has contributed to a major demand for bridge maintenance funds. In the mid-1950s, the development of the Interstate Highway System caused a large number of structures to be built. These structures are now beginning to approach their design life. In addition, the mobile public's ever increasing demand for travel has resulted in large-scale use of deicing salts to keep the roads open in the areas of the country that experience ice and snow. This heavy use has placed demands on the corrosion protection systems on steel bridges to perform and to be maintained. In addition, more and larger trucks have taken their toll on the roadways and bridge decks that are an integral part of the need for maintenance funds *(52,105)*.

Maintaining a bridge is different from building one. There are generally not as many options available and usually the issues are different. The surface conditions on existing structures that need to be repaired are often contaminated or deteriorated. Access to an existing structure is also more difficult, which creates its own impact. The demand for maintenance is a bottom-up function, whereas new construction is a top-down function. The structure exists and, therefore, has its funding needs, which increase with time. A new structure makes no demands on maintenance funds until it is built.

ISSUES OF CONCERN

Environmental

The maintenance of steel bridges, as well as other construction and maintenance practices in general, have become even more expensive because of the impact of various environmental regulations. Lead-based paint and its related environmental issues have increased maintenance costs for 80 to 90 percent of existing steel bridges that are treated with lead-based paint. The large number of structures means that the problem is not going away any time soon. Agencies' attempts to provide maintenance corrosion protection is closely interconnected with environmental issues. A program change on the environmental side usually results in a direct cost increase on the painting side. None of the other bridge maintenance functions dealing with repair and rehabilitation has as intensive an environmental and worker protection phase as that dealing with lead-based paint on existing steel bridges.

Containment is necessary to prevent the discharge of lead-containing waste onto the ground, and into the water and the environment. Containment devices as shown in Figure 30 can get quite elaborate and expensive. Testing of the waste is necessary to determine if the lead-containing waste is hazardous. Treatment is necessary if the material is a hazardous waste, and proper disposal is necessary whether or not treatment is required. There are a limited number of disposal sites that can

FIGURE 30 Containment.

accept the lead-containing solid waste. The potential volume of solid waste will impact landfill space. Public agencies, as owners of the structures treated with lead-based paint, have a "cradle to grave" responsibility for any hazardous waste generated.

The VOC issue, at present, may play only a small part in the cost issue. This is because, at the AIM proposed VOC level, there are products available for use. Relative to other aspects of a maintenance paint job, the cost of paint versus the other costs has always been low. Paint is expected to remain one of, if not the least, relative cost items. Of course, individual areas or regions need to be more restrictive or a change in the proposed limits may change the relatively low cost of paint.

Worker Health and Safety

The exposure of workers is a major focus of OSHA. There is a Special Emphasis Program underway by OSHA regarding the exposure of workers to lead *(106)*. OSHA is issuing major fines on contractors who do not comply with the worker health requirements. In the largest fine ever levied by OSHA, $5 million on a Pittsburgh contractor, $2.3 million was upheld by the Administrative Law Judge. OSHA had cited for 202 willful violations with many of the citations being on an instance-by-instance basis. This was a new policy approach which was validated by the decision. Both OSHA and the contractor are appealing *(107)*.

Funding

Maintaining bridges, providing safety projects to reduce accidents, and providing congestion relief and new capacity are all priorities seeking funding. Funds for maintenance work come from a variety of sources. There are state funds, federal funds, and even private funds, although private funds have been mostly on the construction side. Funds may be raised using bonds, tolls, and taxes, either special use or general fund.

Special use taxes include items such as gasoline taxes, fuel taxes, motor vehicle rental taxes, and registration fees. These funds are collected with only one use in mind and are dedicated to that use. The funds may go directly to the agency or they may be appropriated by the legislature. In addition, legislatures may appropriate other funds as it deems necessary. Most agencies have to have either legislative approval or voter approval to issue bonds. These bonds may be paid off either by the legislature from the general fund revenues or by a special surtax used to generate the repayment, or by using tolls. Tolls may be used to generate funds to retire bonds and to provide operational funds.

Although used extensively in colonial times, privatization is just now making a comeback. Privatization is when a road, such as the Dulles Greenway in Northern Virginia, is built by a private corporation using their own funds. The corporation is allowed to recoup its investment and to earn a profit. The arrangement could be for a stated number of years after which the ownership reverts back to the state, or it could be permanent.

Federal funds are administered by the FHWA. The funds are primarily generated by a federal gasoline tax and deposited into the Highway Trust Fund for redistribution. Congress then appropriates the use of the funds through legislation. Presently, the Intermodal Surface Transportation Efficiency Act (ISTEA) funds the Highway Bridge Replacement and Rehabilitation Program (HBRRP), the Surface Transportation Program (STP), and the National Highway System (NHS). HBRRP funds can only be used for bridges that have been rated as deficient under FHWA's definitions. STP funds can be used for all highways including bridges, which do not have to be deficient for federal funds to be used. NHS includes the Interstate system, major arterial, and National Defense highways.

To be eligible for HBRRP funds, a structure has to be rated as deficient and qualify under the FHWA sufficiency rating program. Various elements, such as protective system, superstructure, substructure, rebar, and deck, are rated as to their condition. The sufficiency rating is based on a grouping of certain element condition ratings. The ratings are grouped to form factors for Structural Adequacy and Safety (55 percent), Essentiality for Public Use (15 percent) and Serviceability and Functional Obsolescence (30 percent) *(104)* and then weighted using the indicated percentages to form a sufficiency rating. If the weighted rating is below 80, the structure may be rehabilitated. It may be rehabilitated or replaced with HBRRP funds if the sufficiency rating is less than 50 *(104,108)*. Low ratings on structural elements cause a bridge to be rated as structurally deficient, as opposed to functionally obsolete, which refers to a structure's geometric concerns, such as clearances and deck widths. Once eligible, states can then select which structures are to be rehabilitated, replaced, etc., based on their own selection or ranking criteria.

ISTEA specifically identified painting as being eligible for federal funding and NHS legislation specifically allowed preventive maintenance when demonstrated to be a cost-effective means of extending the useful life (Title, 23, United States Code{USC}, Section 116). The role of the FHWA in the maintenance area is expanding primarily because the major road system created with federal funds, the Interstate Highway System, is approaching completion. A large portion of the system is also approaching 50 years of age and many bridge structures are deteriorating. Although the painting of structures is now a maintenance element for which federal funds can be used, there has not necessarily been an increase in the amount of funds available for that use. ISTEA's authorization expired in 1997, but new legislation is pending.

In 1986, the FHWA reported that 220,000, or 38 percent, of the nation's 576,000 inventoried structures were eligible to receive federal funding under HBRRP *(104)*. In 1994, the number of eligible structures was 187,000, or 32 percent of the 590,000 inventoried bridges *(109)*. While this indicates a slight reduction in the number of structures eligible for federal funds, it would also imply a possible reduction in the amount of total funding needed. This is likely not the case since the cost impact of environmental regulations came into play after 1986, with the resultant increase in unit cost.

High Costs

The direct costs associated with the environmental and worker protection issues are not inexpensive. Painting costs (for total removals) have risen by almost 10,000 percent since the 1970s, from about \$1.08 per m^2 (\$0.10 per ft^2) to about \$108 per m^2 (\$10 per ft^2). In some cases, this is almost equal to the cost of steel, based on surface area cost *(93)*. In addition, containment has to be used to collect debris. While containment may be lessened during removal of lead-based paint by the use of alternative methods, such as vacuum-assisted tools or VAB, these methods are slower in terms of production and cleaning rate. Slower production rates mean that the contractor will be in the roadway longer, which will result in increases in traffic control and congestion or user costs. Depending on the method of surface preparation, not all of the contaminants are removed, which increases the possibility of lowering the life expectancy of the newly applied coating.

The environmental and worker protection issues have increased the cost of work to the point where the environmental and worker issues can be two to four times the cost of the painting work. This extra cost increases the demand on limited funding without regard for the budgetary restraints of most transportation agencies. This is particularly relevant in terms of accommodating change. When the budgetary cycle is ahead of regulatory change, budgets are negatively impacted as well as the amount of work to be accomplished. Even after the regulatory process, it takes a period of time until the budgetary process can catch up. As always, emergencies may deplete other budgets and upset the best plans.

Uncertainty

Because of higher maintenance costs, different options or approaches are being considered for corrosion protection. The various approaches should be weighed against their costs to obtain life-cycle costs. Some of the approaches are new. There is no long-term experience with either the methods or the products to be used. There will undoubtedly be limits to the approaches or products, which may not have been well defined. For example, how much contaminant can the material tolerate or how well adhered is marginally adhered for overcoating? The risk factors are not always recognized, or well understood even if recognized. These unknowns create an element of uncertainty when it comes to deciding on the best approach to allocate or optimize the use of the limited funds.

ANALYSIS ISSUES

Because the funds to perform maintenance work are limited or lacking, it is important that the available funds be spent wisely. In order to begin to form a plan of corrective action, the actual condition of the bridge has to be determined or assessed. The structure must then be ranked with other structures to determine funding priority. The ranking can be condition based on cost or need: it can be ranked based on cost benefit or life-cycle cost; or it can be ranked by optimization to provide the largest use of funds *(110)*.

Condition Analysis

Condition analysis is the most commonly used approach and first or initial cost is the most common basis for decision making *(50)* because the ranking requires no sophisticated calculations. Factors *(65)* used to assess the actual condition should include:

Current coating system type, thickness and number of coats, and whether the structure has been repainted: This information is needed to determine if there is any basic incompatibility between the new coatings and the existing coatings if they are not the same generic type. Also, the type can help determine the presence of any particular toxins that need to be addressed. Previous paintings may mask a condition that could play a role in the coating decision. For example, there is an aluminum-containing coat underneath and the anticipated removal method is a chemical stripper. If the stripper is alkaline in nature, there may be a reaction that will retard the process or stop it altogether. Some structures may have no coating, such as unpainted weathering steel, others may have a surface that requires special procedures, such as a galvanized surface.

Condition of the substrate under the existing coating and the extent of substrate rehabilitation necessary: Does the structure contain mill scale? Is it intact and adherent? Has corrosion begun underneath the coating through undercutting or other processes? In addition to removing coating, will it be necessary to remove the mill scale?

Configuration of the surface: Large planar surfaces of coating that are marginally adherent may provide a higher likelihood for disbondment, particularly if the existing coating is multilayered or thick. Complicated angles or areas may preclude the use of certain types of application procedures based on the coating products to be used.

Degree of flexing anticipated in the steel surface: If the steel surface to be painted is particularly flexible, the use of a nonflexible coating may be a problem. Stress can develop between vastly different layers of paint, which can lead to delamination. This can be particularly true when there have been multiple repaints with coatings of different generic resins.

Variability in temperature: The application of coatings that are very expansive or contractive with heat and cold will add more stress to an existing coating than ones that more closely match the existing coating. This is particularly true in environments with large annual or daily temperature swings.

Overall condition of the existing coating, including the adhesion, eroded paint film, corrosion pattern, pitting and percent of rusted service area: Lack of adhesion can eliminate overcoating as a viable choice if the existing coating is spontaneously delaminating. For coatings with slightly better adherence, the risk is not as easy to assess. Is there significant pitting or metal loss? Is corrosion concentrated or distributed across the surface? Corrosion that is spread out all over the structure, as opposed to that found mostly at expansion joints, will give a clue as to what type of preparation to specify. Zone painting with total removal may be the option for the expansion joint areas, whereas overcoating may be the choice elsewhere on the structure.

Presence of ionic or nonionic contaminants, such as chlorides, sulfates, bird droppings, grease, heavy dirt: Chloride and sulfate contaminants must be reduced or removed in order for the newly applied coating to achieve its full life. If not, the coating must be able to tolerate the contaminant level. Grease or oil usually cause nonadherence of the new coating. Bird droppings change the pH of the surface and dirt acts as a collector for contaminants, creating a corrosion cell site as well as poor adhesion, if not removed.

Surface preparation history: If the surface was blasted initially, then that may provide more options in the recoating process. For example, UHPWJ would prepare the surface back to the original blasted profile, but may not easily remove tight mill scale. The resultant type of surface preparation limits the use of some types of coatings.

Condition-based analysis is used to a great extent because it is easier to estimate the costs. It is based on a short time analysis, usually one season. This analysis is typically done in response to a specific site condition or problem. Alternative options are not usually compared *(109)*.

A maintenance decision based on condition ranking is based on the actual condition or the actual cost to repair the condition. A typical condition rating scheme for a bridge might be that which is outlined in Table 5 *(111)*. Under the FHWA sufficiency rating system, the weighed condition ranking means that a bridge with a lower sufficiency rating receives a higher priority for improvement than the higher rated structure. An early intervention, when structures have just begun to deteriorate and repair costs are usually lower is, therefore, discouraged in this system. Paint and paint related matters are considered part of the protective element for bridges and hence are not a structural component *(110)*.

Other Costs

Traffic control and mobilization are significant issues that have to be dealt with and their costs ascertained accurately. Certain roadways have restrictions as to when lane closures can occur. The restrictions may alter the productivity of the contractor and therefore raise the cost of mobilization and traffic control. Night work changes the ambient conditions and the effect of such change has to be recognized. Containment structures do not lend themselves to being readily dismantled. Stretching out the project may extend the work into an unacceptable time of the year. Local weather conditions can be a problem also. Washington and Oregon use moisture-cured polyurethane products to coat structures in fog-prone areas. These products are surface-tolerant for the damp surfaces because moisture is used in the curing process. Likewise, in extremely dry conditions, it could be a problem to use this product or an inorganic zinc rich coating, both of which require moisture in the air to cure.

Contracts containing multiple structures in a similar area can result in economies of scale because mobilization costs can be amortized over a larger area of steel. Contracts with multiple structures with long distances to travel between the structures may lose the economy of scale due to increased travel time for the contractors. Short completion dates with multiple structures may increase the cost of the contract if the contractor needs multiple sets of high capital outlay equipment to perform the work in parallel as opposed to serially. The agency's decision on these matters, with their resultant costs, needs to be recognized. Otherwise, bids may be outside the engineering estimates, necessitating a rebid and the resultant cost.

Priority Assessment

Under priority assessment, in addition to the condition assessment, the expected life of the repair needs to be determined as

TABLE 5
CONDITION RATING SCHEME *(109)*

Condition Rating	Condition Description
9	New Condition—no maintenance required
8	Good Condition—no maintenance recommended
7	Fair Condition—recommend maintenance on minor items
6	Fair Condition—recommend maintenance on major items
5	Poor Condition—recommend major rehabilitation
4	Poor Condition—minimally adequate to operate with current use
3	Poor Condition—inadequate to operate with current use, recommend restricted operation
2	Critical condition—In adequate to operate with current use, recommend minimum restricted operation
1	Critical condition—inadequate to operate with current use, recommend ceased operation until rehabilitated
0	Critical condition—inadequate to operate with current use, recommend ceased operation until replaced.

well as the expected life of the structure. Then, a life-cycle cost can be calculated with preference for the most cost-effective option. Life-cycle analysis can also be used to decide the best time to intervene.

The major difference between a ranking system based on condition and a priority system based on life-cycle or cost-benefit is the issue of time. Costs for consideration in a condition ranking are usually first cost or the initial cost of the repair. Life-cycle costs are based on the costs over time, that is, the expected life of the repair or structure and includes all of the anticipated costs over that life.

In addition to the actual condition of the bridge, other factors may need to be considered *(62)*. Some of these factors may be:

Type of member: The difference in cost between a rolled beam and a plate girder can be significant. The cost of corrosion repair may nearly equate the cost of new steel, depending on the type of member or type of steel in the member. Weathering steel versus other steel types may dictate a different coating action.

Expected service life of the structure: This is needed if the life-cycle cost is to be determined so that the repair is not overdesigned.

Expected life of the coating to be applied: What is the expected life of the coating for the surface preparation to be used? A coating over a contaminated surface will not last as long as one over a clean surface. It is not appropriate to try to obtain a 30-year coating for a structure that is to be replaced in 5 to 10 years. Likewise, structures with long expected service life should be analyzed in terms of maintenance cycles. Using financial principles to obtain the time value of money, the initial cost of each expected cycle can be used to predict lifetime costs.

Whether the overcoatability of the applied coating is to be a significant factor: Is the coating that is used to overcoat a structure one that cannot be easily recoated? If, in order to overcoat the overcoat, it is necessary to sweep blast the structure to roughen the surface, then the purpose of the overcoat is defeated. If this is the last time the structure is to be painted before replacement, then it is a different choice.

Cost and logistics of structural replacement: The use of the structure may dictate that it cannot be out of service. The cost of replacement may be so significant that it is not feasible at the present time.

Available or allowable application methods: If spraying is not an allowable option due to location, then to specify coatings that can only be sprayed is not a wise decision and would limit the coating options.

Emission limitations regarding air, water, soil: Do site conditions dictate that the risk of a spill from maintenance painting or coating removal is plainly not allowed, such as a structure over a water reservoir or an oyster bed or a school or playground, for example? VOC limits in a particular area may be more severely limited than in others.

Future maintenance costs of applied coatings: These cost considerations go directly to how many future recoats may be needed when calculating life-cycle cost. Some coatings have a longer life expectancy and this needs to be recognized.

Limitations on surface preparation methods: If a blasted surface cannot be obtained, this will eliminate certain classes of coatings, such as inorganic zinc rich coatings. Power tools are not known to clean as well as blasting and the coating used must be accommodating to method and tolerance.

Degree to which a coating failure can be tolerated: If overcoating a marginally adherent coating with a high risk of delamination, public opinion may dictate that a premature failure for a highly public structure is not sound. Thus, another choice must be made. Lead-based paint chips falling off a bridge over a public beach the first year after application does not make for good headlines, nor does the cost of the potential cleanup.

Cost of overcoating as a percentage of the cost of abatement: As the cost of an overcoat approaches the cost of a deleading or total removal, then more consideration has to be given to eliminating the lead issue for future repaints.

Urgency of the action: If pitting is occurring such that it needs to be stopped to prevent structural problems, then the option of deferral is eliminated and makes the choice of action more critical. No chloride remediation means that the corrosion will likely begin to recur in a period as short as a year. Is this a time frame that can be tolerated? If the section loss is such that the additional section loss due to surface preparation will cause a hole in the steel, then painting is not the first option, but rather steel repair is first.

Necessity of structural preservation: A historically significant bridge and the necessity that it be preserved will preclude some of the options that are available.

In addition to the maintenance, repair, and rehabilitation, and improvement or replacement costs, other costs that should be included in the condition analysis are the cost of emergency work, in-house maintenance, traffic control and mobilization, engineering, inspection/assessment, and environmental/worker protection. These are usually considered agency costs, whereas the costs to the consumer are called user costs and could include detours, congestion, and work zone delays *(112)*. User costs also have to be considered in the analysis.

Life-cycle costs are usually based on a net present value concept using a discounted interest rate and compare all the costs of one option versus another over the expected life of the repair options. Life-cycle cost calculations are more involved than weighted rankings, in that multiple comparisons can be made for the same structure. Computerization can be used to limit the time and staffing burdens. Life-cycle cost may indicate that a particular action be performed or it may indicate deferral of any action to coincide with some other activity.

Deferral is presumed to be an economic benefit based on the assumption that a benefit is to be derived from doing a higher valued project. If deferral is the decision, then the cost of the deferral has to be included, that is, the penalty to be paid for the deferral *(112)* if there is one. Simplified corrosion curves, such as in Figure 31, are similar in shape to maintenance deterioration curves and are usually exponential with time *(113)*. Environmental exposure assessment needs to be site-specific and deterioration needs to be specifically determined so that the condition of the structure can be assessed as

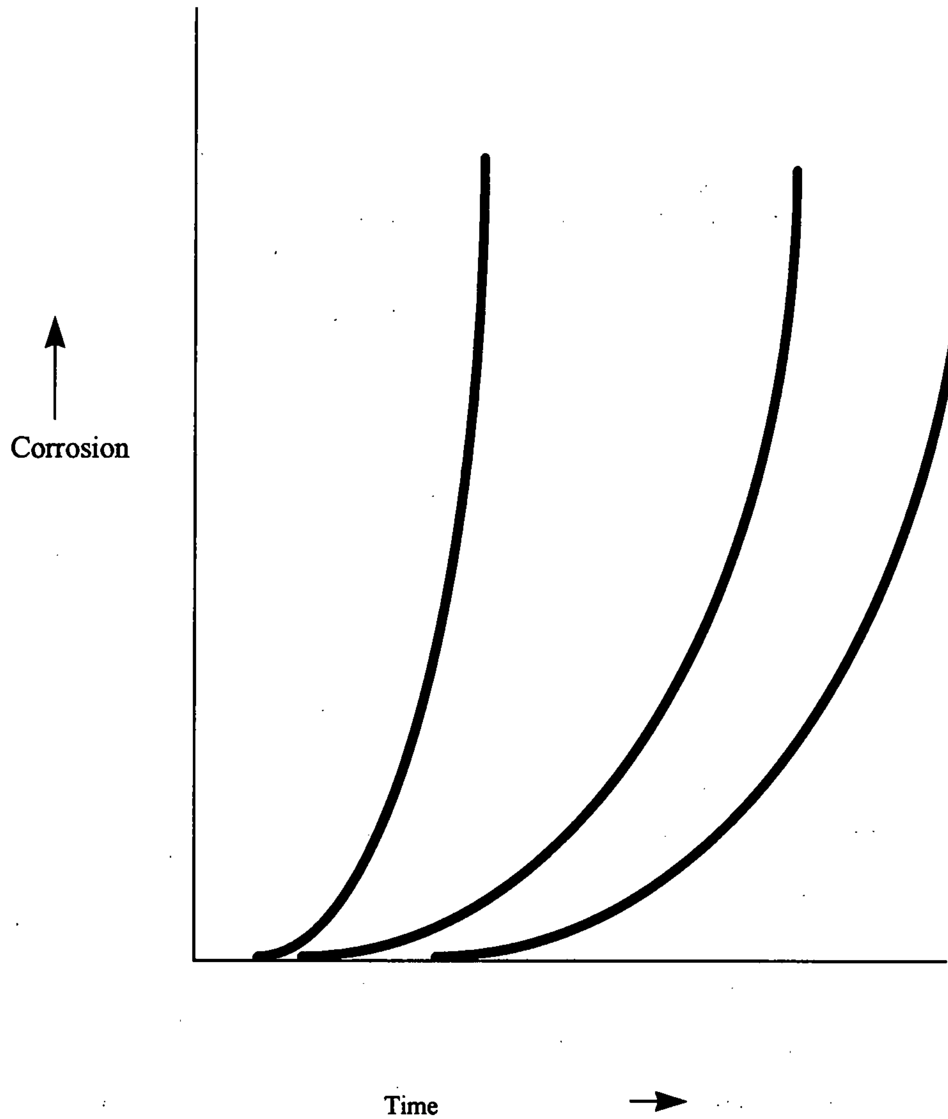

FIGURE 31 Deterioration curves.

to where the corrosion is on the corrosion curve. This is done to determine the best time to intervene, that is, to validate the process *(114)*.

A deferral of corrosion protection can incur a significant penalty if the deferral causes a more expensive future action to occur. A decision to defer based on the fact that the existing coating is intact but poorly adhered and requiring a total removal, incurs no penalty to perform a total removal at a later date. Likewise, if the bridge is to be replaced, then there is no penalty. If, however, the coating conditions were acceptable for overcoating, but the decision was to wait to combine this activity with another activity, such as a deck replacement, and the delay put the deterioration into the rapidly ascending portion of the corrosion curve or the coating's adhesion deteriorated or the coating became embrittled, now the paint option is not an overcoat repair procedure but a replacement procedure with the resultant increases in cost for total removal. This additional cost is the penalty of deferral as well as any cost for any additional reinspection and reassessment cost. These costs have to be captured for the life-cycle analysis benefit to be accurate.

Deferral of maintenance work generally increases the life-cycle cost because of continued degradation or deterioration of the structure due to corrosion. Deferral to the point at which there are no options, or severely limited or restricted choices such as replacement, has been called terminal maintenance *(Personal conversation, Eric Kline, KTA-Tator, December 1995)*. As the name implies, it is a plan that can have dramatic consequences and should be practiced with care. For a paint job, this would be allowing the paint to deteriorate from an acceptable repair condition to one where a total removal is the only option. In the worst case, the corrosion may cause such section loss as to cause the structure to be structurally unsound. From a corrosion standpoint, the same as from a maintenance standpoint, the deterioration curve can rise rather dramatically in a short period of time. The greater the penalty of deferral the more urgent the need to do the work.

There is a point at which the economics of the situation changes. For painting, the dynamics of the amount of surface preparation needed can influence the coating decision. Fifteen to 20 percent surface preparation is a point at which it may be more economical to remove all of the coating based on good painting practice *(115)*. Because this decision is based on amount of rust and the adhesion of the coating, it is entirely logical that a deferral of any work might be viable. As long as section loss is not an issue, it doesn't matter whether a structure is 15 percent rusted or 45 percent rusted for total removal. Because of concentration cells due to accumulated debris, corrosion may be occurring faster and become more severe at a specific site than elsewhere on the structure *(116)*. It is important to keep these localized areas in perspective when assessing the whole structure. It is also important to keep in mind that while rust may not be evident, the coating may be deteriorating in and of itself. Corrosion may be occurring under the paint film, particularly if the existing coating does not have a sacrificial primer.

Optimization Assessment

Neither ranking based on condition nor prioritization based on life-cycle cost give any indication of how to derive the maximum benefit from the funds available, that is, to optimize use of the funds to provide the most benefit. An optimization program using a mathematical algorithm can be used to maximize the net benefits from the budgeted amount *(117)*. Under this approach, it is not the structures that have the highest priorities that are necessarily worked on but the ones that provide the maximum benefit based on the funding available. Optimization might indicate that, if done on a statewide basis with accurate data input, the most benefit might be to correct the bridges in one district as opposed to spreading the funds over the state, which might be the case under prioritization schemes based on a regional approach *(110,118,119,120)*. Depending on how the algorithm is written, the posting or closing of a structure could be allowed for the greater benefit. Optimization is more of a strategic tool, whereas life-cycle costing is more of a tactical tool.

In both a condition-based ranking and a prioritization-based ranking of life-cycle costs, the ranking is performed first and then the funds are distributed to try to meet the needs. With optimization, the funding level is established first and then the projects are selected to maximize the overall benefit to the agency based on the limits in the formulas used in the mathematical algorithm.

Bridge Management Systems

These aspects of condition, prioritization, cost effectiveness, optimization, and deterioration are all interconnected and can be the basis for a managed approach to corrosion protection as well as other aspects of maintenance. When these aspects are put together formally, it is called a bridge management system (BMS). How to put all of these approaches together is a subject that was addressed by the FHWA and several lead states. They banded together to develop an expert system to integrate all of these aspects, resulting in a BMS called Pontis. The NCHRP produced a BMS known as BRIDGIT.

When Pontis or BRIDGIT systems are fully implemented, they can provide condition assessment sufficiency ratings, as well as prioritization, deterioration rates, life-cycle costing, and optimization. Developing a database is an essential part of both systems. In addition to having an accurate assessment of various elements of construction, both agency and user costs are critical in the calculations and need to be as accurate as possible to achieve the best results from the system. Agencies have a good understanding of replacement costs, but maintenance costs are frequently not well documented *(112)*. Hence, there is not good documentation for corrosion protection costs. A commercially available expert system that has costing data for corrosion protection options based on long-term data collection *(121)* is a possibility until agencies can develop their own cost data.

Level of service (LOS) is a ranking system based on deficiency points *(122,123)*. Both Pontis and BRIDGIT can provide maintenance, repair and rehabilitation (MR&R) options, and replacement and improvement options based on the LOS that the agency establishes *(110,118)*.

A BMS should simplify recordkeeping once it is implemented by the user agencies. Most data need to be transferred from project records, which are usually hard copies of records, into a computer database and into a form that the BMS can use. In addition, more information in terms of the number of elements is required. This impacts the amount of work that the inspectors have to do. Collecting and entering data and transferring existing data are labor-intensive activities. Funding and staffing needs have limited implementation of the various BMS programs *(112)*. In addition to that, there is the psychological resistance-to-change factor. Having an inspector look at the bridge and make a repair recommendation is straight forward. This project level, condition-based approach is simple and provides an easy means of seeing results *(109)*.

Maintenance activities generally fall into several classes of action. BRIDGIT defines routine maintenance as a preventive action such as washing decks, bearings, and cleaning drains. Scheduled maintenance is repair that is part of a scheduled program such as painting steel or repairing joints. These terms generally do not apply to structural or functional deficiencies *(110,120)*.

Repair is maintenance that corrects only elements in an unacceptable condition, whereas major repair maintenance is repair that corrects all the elements in both marginal and unacceptable condition. Rehabilitation is major repair and includes the removal of all functional deficiencies. It may involve the replacement of individual elements or the replacement of the superstructure. Structure replacement removes all functional deficiencies and also is designed to accommodate traffic for however many years into the future the agency determines are necessary *(110,118,119,120)*. These terms do not agree completely with the FHWA definitions, which do not define repair.

The FHWA uses minor rehabilitation, major rehabilitation, replacement, and preventive maintenance. Replacement is total replacement of a structurally deficient or functionally obsolete bridge with a new facility constructed in the same general traffic corridor. It must meet current geometric, construction, and structural standards required for the types and volume of projected traffic on the facility over its design life. Major rehabilitation denotes the primary work required to restore the structural integrity of a bridge, as well as work necessary to correct major safety defects (23CFR 650.405, Subpart D). Minor rehabilitation is work required to correct minor structural and safety defects or deficiencies, such as patching, deck resurfacing, deck protective systems, upgrading railings, curbs and gutters, and other minor bridge work *(124)*.

Paint is a protective system for a bridge element and can be repaired or replaced based on its cost estimate. It would fall in the minor rehabilitation category. The lowest cost paint job is usually one with the lowest cost of surface preparation, that is, no or minimal surface preparation. In today's environmental climate, this means disturbing the existing lead paint the least. This is painting to preserve the paint as opposed to painting to preserve the steel and has been called the "paint it when it does not need to be painted" scenario, a true preventive maintenance approach. The higher the amount of corrosion or deteriorated coating present, the higher the amount of lead-based paint disturbance, the higher cost of the project. In terms of the condition rating in Table 5, a proactive approach would mean that preventive maintenance painting should be performed at a rating of no lower than 7.

Painting when there is virtually no surface preparation other than the removal of accumulated dirt, bird droppings, chalking, etc., the items that a good washing will accomplish, solves some possible contract administration problems. If a painting contract requires the contractor to remove all paint, this is visually determinable. If the contract requires the contractor to remove the top two layers of a multi-layered, multi-colored paint system, this is visually enforceable also. If the contract requires that high pressure water washing or sweep blasting be used to remove loose paint, both of these methods are operator dependent. It is not known without testing whether the contract requirement was met. When specifying deterministic methods of surface preparation, the extra cost for inspection and testing needs to be considered in the cost equation. Otherwise, factor the probability of premature failure into the decision-making process.

In reality, since painting is quite often considered scheduled maintenance *(110)* or minor rehabilitation, the paint is allowed to deteriorate to some level of deficiency under a sufficiency rating system before repair is considered. In actuality, it is more likely that the amount of corrosion present is the actual assessment. It is the corrosion that will lead to a structural deficiency, that is, section loss. Preventive maintenance (PM) is allowed by the FHWA under the NHS legislation when it is demonstrated that the activity is a cost-effective means of extending the useful life of a federal-aid highway. Preventive maintenance is well known to provide payback several times more than the original investment *(112)*. A PM activity needs to be performed before deterioration occurs, thus making it a repair with high cost implications. Heavy equipment users and airlines practice PM by the use of engine oil analysis for wear metal analysis. When certain elements begin to show up in the oil, then it is known that parts are beginning to wear out and need to be replaced. This works well as a diagnostic tool since obviously, what is occurring inside the engine cannot be seen and failure can be catastrophic. Bridges do not have to have such an intensive program to recognize when deterioration of a coating is beginning. There are visual clues that deterioration is occurring, such as cracking, embrittling, or delamination. Rust is the ultimate indication of deterioration. Extensive rusting can have catastrophic consequences also.

As shown in Figure 32, there is an opportunity for PM in the life curve for a coating system. If deferred beyond a certain point, maintenance requires more extensive work and may no longer be preventive in nature but considered instead a repair, which does not need to proceed too much further to the terminal condition requiring a total removal. Most European countries do not appear to practice deferred maintenance, using instead scheduled or planned maintenance approaches more extensively with repainting being done on a regular schedule *(28)*.

Agencies are looking at overcoating and the use of surface-tolerant primers to lessen the amount of lead-based paint that has to be disturbed. This is a valid approach provided that all of the risks of such an action are assessed. When overcoating combined with a surface-tolerant primer is considered as a conditional repair, it will be a low-cost repair based on first or upfront cost. This is a straight forward deterministic approach; but, unless the condition of the existing coating has been determined to be acceptably adhered, and unless the contaminants in the rusty areas have been remediated or taken into account, then this approach has a high risk factor for catastrophic failure due to delamination or early rustback of the surface. Treating the life-cycle analysis probabilistically may provide a better indication of the effectiveness of the proposed action. Pontis is capable of doing this.

While there are coatings, usually ones that contain zinc dust, that can tolerate more contaminants than others, they have a limit. The use of a surface preparation technique that removes the contaminants to an acceptable level in conjunction with the contaminant-tolerant coating is a valid two-pronged approach that provides a higher probability of success. The BMS analysis must include the cost and the expected surface life for various surface preparation options and the probability parameters need to be established along with for various surface cleaning approaches.

Federal funding for functional improvements requires that all functional improvements be brought up to standard. This requirement has its impact in that it may make for a costlier repair to bring all of the substandard elements up to standard *(112)*. This may cause a deferral in the rehabilitation. For functional items, such as clearances and widths of lanes and loadings, there are standards. A bridge that is too narrow may be functionally obsolete but it can be structurally sound and a delay is not structurally critical.

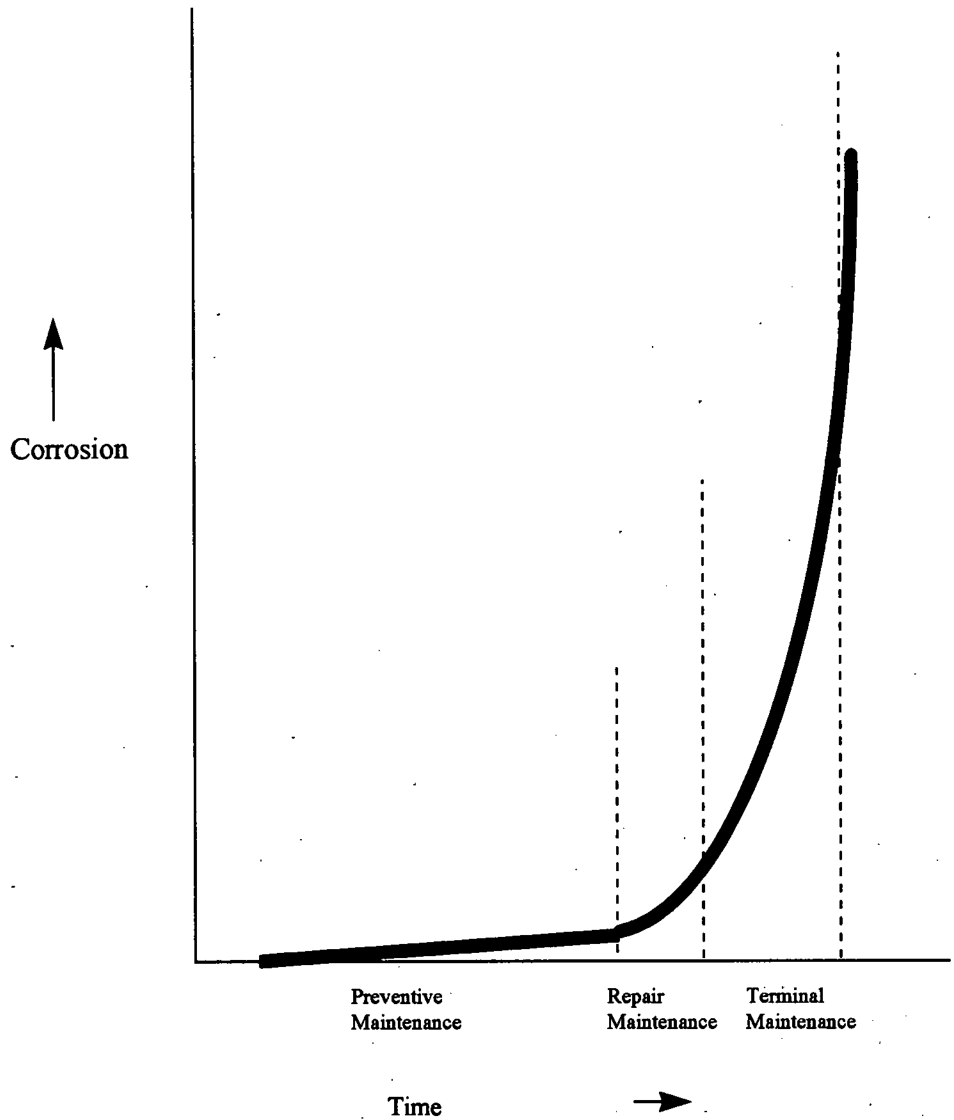

FIGURE 32 Deterioration curve.

There is no requirement or performance level, federal or otherwise, that paint or any corrosion protection system is required to meet. While there are standards for cleanliness, i.e., near-white, white, commercial, etc., there is no standard for contaminant removal. Agencies have to determine their own approach and strategy. Failure to adequately address the issues can mean that corrosion and section loss will continue.

Survey Results

As far as recordkeeping is concerned, the agencies report using various methods: 22 responses for project records, 19 for Pontis, 22 for other methods, and 13 for an agency BMS. Forty agencies indicate that they have a BMS and 34 indicate that it is implemented. Nine respondents indicate that they do not have a system. It is very clear by the responses that implementation is in varying stages and that the use of BMS is affected by the lack of manpower and funding. This lack of implementation and familiarity also caused mixed comments on how well the BMS meets the agency's needs. Responses to the questionnaire about the agency's systems being predictive of corrosion rates indicate a lack of understanding of the capabilities of the systems. There were both "yes" and "no" answers for the same Pontis system. Nine agencies report that the Pontis system is capable of recording physical aspects of the coating system, whereas 23 agencies indicate that it is not.

The respondents were not asked to specifically discuss maintenance terms in relation to corrosion protection. The responses in Table 6 as to the type of maintenance practiced may relate more to maintenance than specifically to corrosion protection. The responses may be skewed because of how the terms are understood by the respondent. Definitions were included in the questionnaire to try to solicit responses using the same definition. It is not clear that this happened.

TABLE 6
TYPES OF MAINTENANCE

Types	Responses
Preventative	37
Routine	41
Deferred	46
Conditional Based	53
Replacement	33
Rehabilitation	44
Prioritization	27
Major Maintenance	50

However, certain things are clear. All of the respondents indicate that they practice conditional based maintenance (CBM). As discussed, this is maintenance based and ranked on the actual condition. Emergencies would fall into this category but some agencies call emergencies "demand maintenance," probably because emergencies carry an element of urgency. The emergency condition demands a response that may or may not be subject to cost analysis. The severity may dictate an immediate repair or it may be scheduled with other ongoing work. It usually cannot be deferred or delayed for very long.

The terms conditional based, prioritization, and deferred have more to do with the ranking system used to select projects for work. The terms replacement, rehabilitation, major maintenance, preventive, and routine have to do with funding mechanisms and categorization for funding.

The definitions in the questionnaire could have been better framed as to the types of maintenance performed. Replacement could have been better defined as replacement of an element or a bridge replacement. The included definition implied bridge replacement, which is a more encompassing operation than element replacement.

Preventive is another category that would elicit different responses depending on how an agency views the process. Preventive, routine, and scheduled maintenance are all terms that have definite overlap in use.

It is logical that major maintenance (translate repairs) would show slightly more use than rehabilitation due to the different deficiencies that are corrected under each approach.

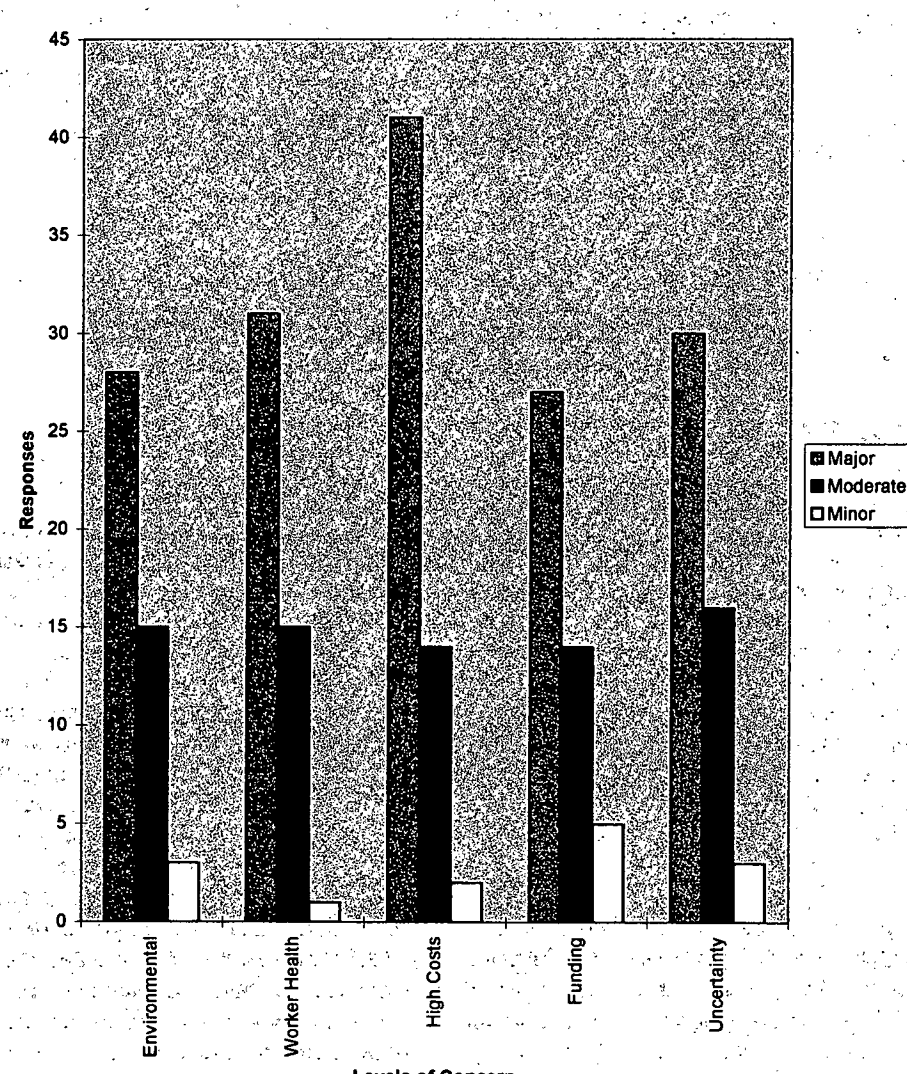

FIGURE 33 Issues.

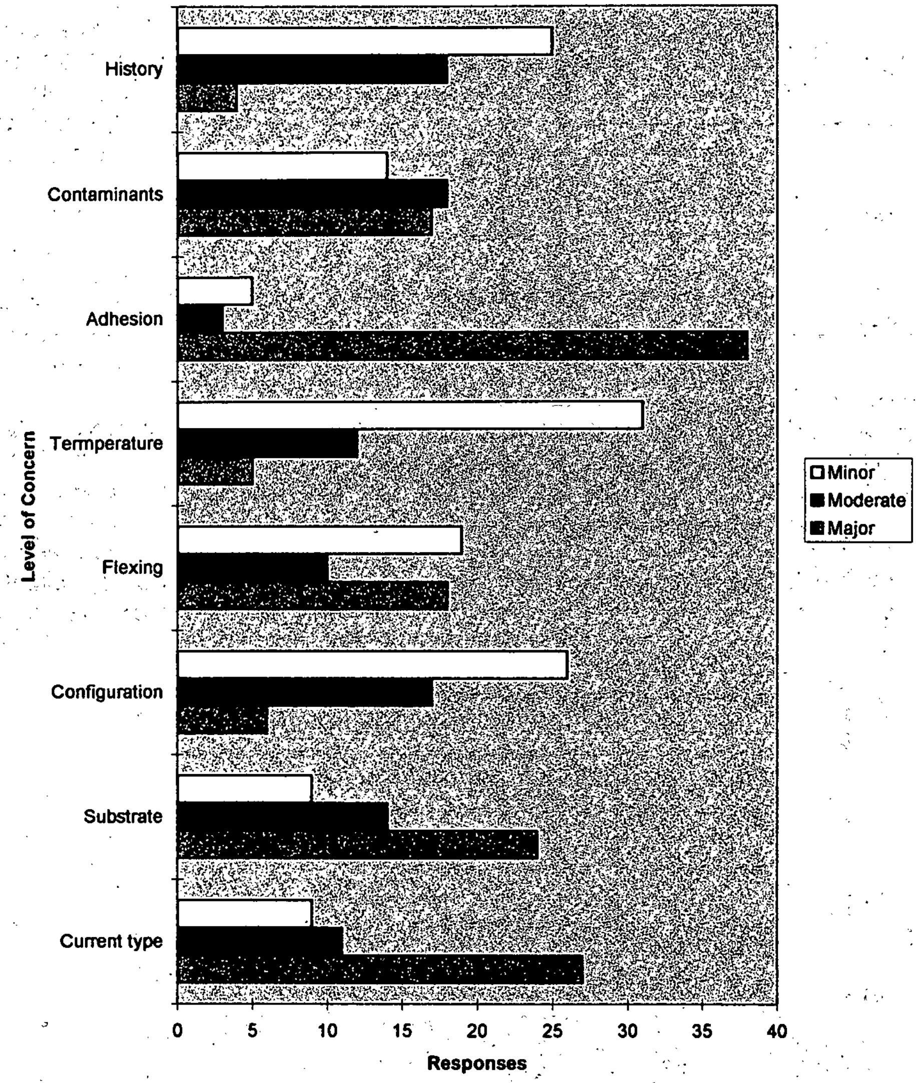

FIGURE 34 Structural conditions.

Deferral is high because of the lack of available funding but it would seem that the use of the term prioritization is misleading. Deferral by nature carries with it a prioritizing aspect unless one is deferring all projects. While prioritization is indicated to be taking place, it is not clear that all respondents use the term equally. A prioritization system uses life-cycle cost to determine the structures on which work is to be performed as opposed to determining which option is to be used for a structure under a condition ranked system.

As shown in Figure 33, the largest issue of concern has to do with high cost. This is not an unexpected response given the lack of funds versus the large amount of infrastructure needs.

Figure 34 shows the responses to structure conditions. The largest concern is with the adhesion of the existing paint since this logically determines the coating approach the engineer will be able to take. Poor adherence is a definite route to an early failure. It is surprising that more concern about the contaminants present was not expressed since this is a primary cause of early rerusting (rustback).

Figure 35 indicates that other factors or matters of high concern to the engineer are the expected life of the structure and the expected life of the coating to be applied. It would not make much sense to metallize a structure that is going to be replaced in the next 5 years, whereas a shorter term option, such as overcoating, might be viable. The urgency of an action is always a concern with the bridge engineer because failure of the structure cannot be tolerated. For corrosion protection, stopping section loss would be a possible example of an urgent action.

Limits on environmental emissions are of high concern. This is in part due to concern about how to comply and the ability to recognize how the rules apply. On the other hand, the agencies are only moderately concerned about tolerance for a coating failure and any resultant environmental cleanup.

Of high concern are the cost and logistics of structural replacement. As paint removal costs approach the cost of new steel, agencies have to seriously consider what is planned for the structure and where it is in its design life. Consideration has to be given to whether the structure can be replaced and how it can be done.

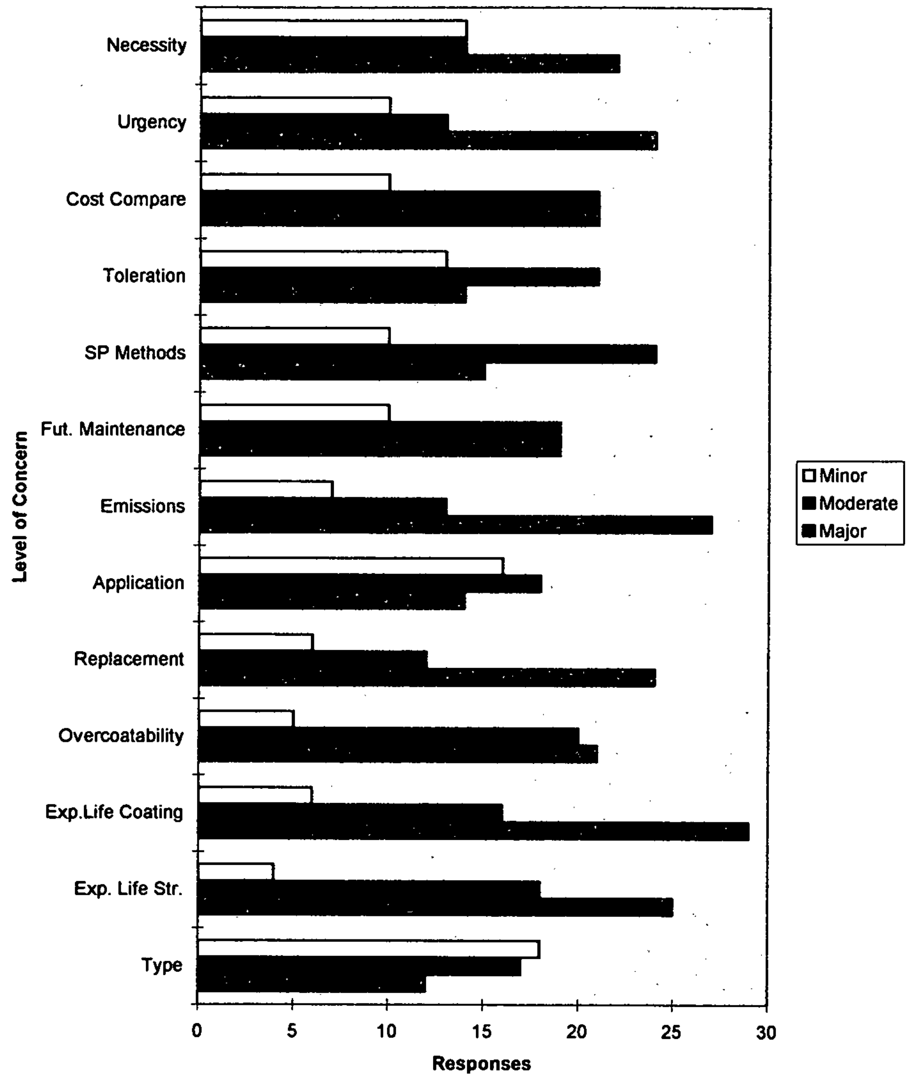

FIGURE 35 Mitigation factors.

All of the other survey issues are of moderate concern.

Seventy percent of the agencies report that they have a policy on how to deal with the lead-based paint issue. They range from overcoating policies to total removal policies. Twenty-five percent of the agencies report that they have replaced structures rather than deal with the cost of the lead-based paint removal issue. Half of the responding agencies indicate that they use zone and spot painting.

Forty agencies report that they have a rating system to determine need for maintenance painting. All 40 evaluate the amount of rust present, whereas only 25 of the 40 assess the adhesion of the existing paint. No agency reported any contaminant determination effort. Several agencies point out that section loss should also be a rating factor. Once the need is determined, half of the agencies indicate that they have a system to prioritize the structures.

All of the respondents take care of emergencies first. The difference is in approach. Some add to existing contracts and some issue special contracts. Some agencies have special funds set aside just for such contingencies, whereas most obtain funds by reducing other budgets. This of course means that some other project may not be funded for that cycle. Because of its emergency and situational nature, it is difficult to integrate this activity with other maintenance. However, it may be possible to integrate other maintenance with it. For example, an overpass is hit, damaging the steel and breaking up the parapets and the deck. This is a 35-year old structure, the deck is already in need of repair, and it contains lead-based paint. The road has to be closed anyway because of the damage. This is an excellent opportunity to replace the structure and to correct possible height deficiencies.

When questioned about waste reduction issues, 62 percent of the responding agencies indicate that solid waste reduction issues were considered, whereas 71 percent indicate that hazardous waste reduction issues were considered. Half of the agencies report the use of recyclable abrasives.

The responding agencies report that they have 55,079 lead-based painted structures out of 97,116 steel structures or 57 percent of the total. They indicate present painting needs of $550 million. This percentage differs from other percentages reported in the literature and is possibly due to lack of response or under reporting of cities, towns, or county structures.

When agencies are considering major maintenance versus rehabilitation versus replacement, the decision is based on the deficiencies present and the priorities placed on them. The respondents indicate that major maintenance is intended to repair a deficiency, a spalling deck for example. It generally is associated with a maximum cost. Rehabilitation is intended to correct all of the deficiencies and to restore the structure to its original design. Replacement is intended to correct all of the deficiencies and to improve the structure over its original design. Both of these concepts are in line with the FHWA definitions.

CHAPTER EIGHT

EXPECTED LIFE

The life of a corrosion protection system is directly related to its environmental exposure. Temperature, pH, humidity, and metallurgical and electrolyte composition all contribute to the rate of corrosion. In addition, some protective systems have different lives themselves. The thickness and permeability of a barrier coating will influence the corrosion rate. If it has no pigments that prevent underfilm corrosion, it may be aesthetically pleasing and corroding underneath. A thinner coating system that may be more permeable but with a sacrificial primer that resists underfilm corrosion may be longer lasting.

AGENCY EXPERIENCE WITH PROTECTION SYSTEMS

Agencies were asked in the survey to comment on the life expectancy of coating types being used and whether their expectations are being met. No distinction was made as to the types of painting systems being used to form the basis for the expectations. One of the problems is that the painting systems used today are so different from the systems used in the past for both shop and field applications. The degree of surface preparation achieved in the shop with the centrifugal blasters is much superior to the mill scale that was the prevalent surface condition until the mid-1970s. Existing steel also has to contend with deicing salts and other contaminants that most new steel does not have.

Figure 36 shows the range of life expectancy from the survey in Appendix B. The subsets A through G of Figure 36 break down the agency responses based on the actual expectancies. Table 7 lists the predominant expectancies with the percentage of respondents indicating that the expectancy is achieved or not achieved. Weathering steel and concrete are basically expected to be materials that will approach the life of the structure. The only coating that is expected to come close to this is galvanizing. Overcoating has the shortest life expectancy of the coating approaches. Repainting is expected to have a service life approaching that of new construction but the responses indicate that this is probably not occurring. In both overcoating and repainting, the results are probably a reflection of the amount of surface contaminants that are not being removed. There is a direct relationship between salt removal and coating performance. The responses of the agencies indicate that they are paying only moderate attention to contaminants or the adhesion of the existing paint when overcoating.

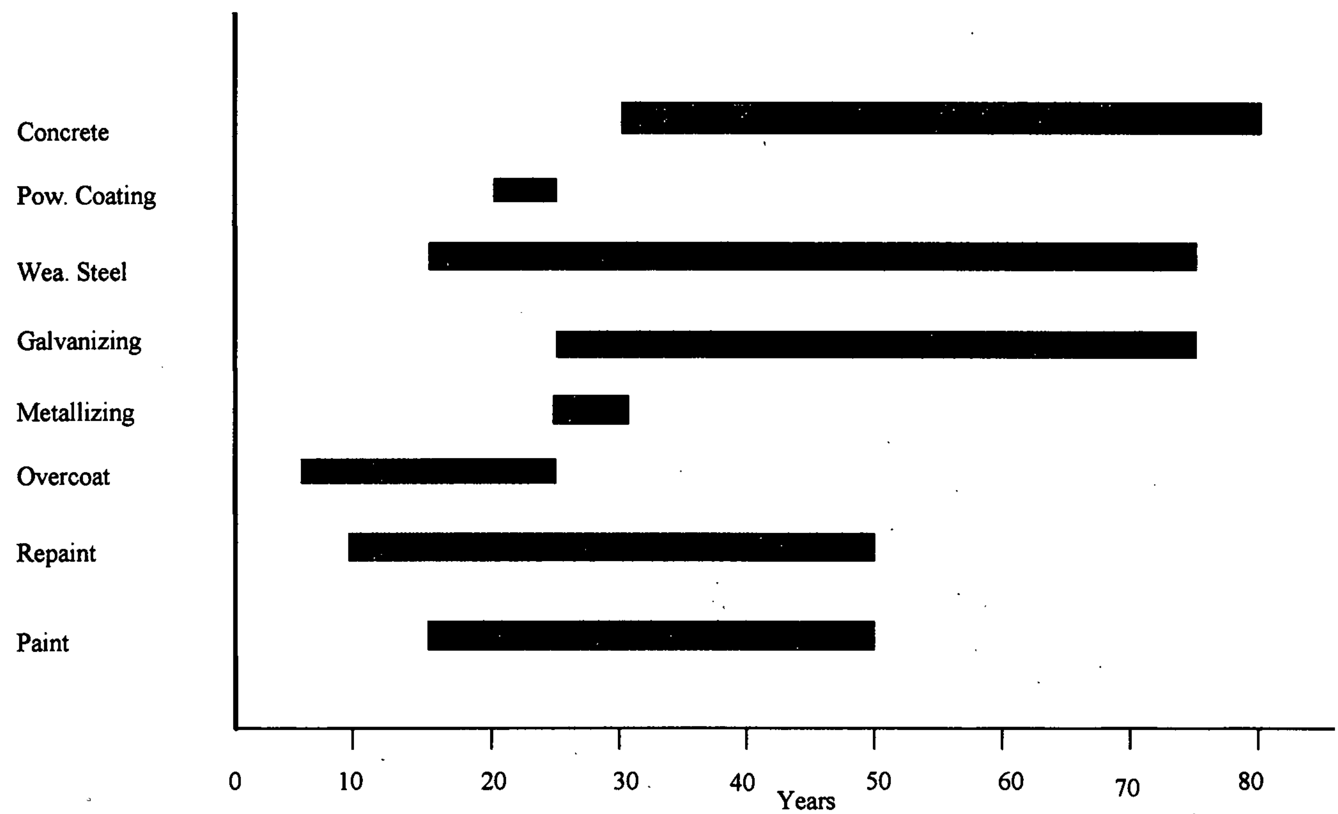

FIGURE 36 Range of expected life.

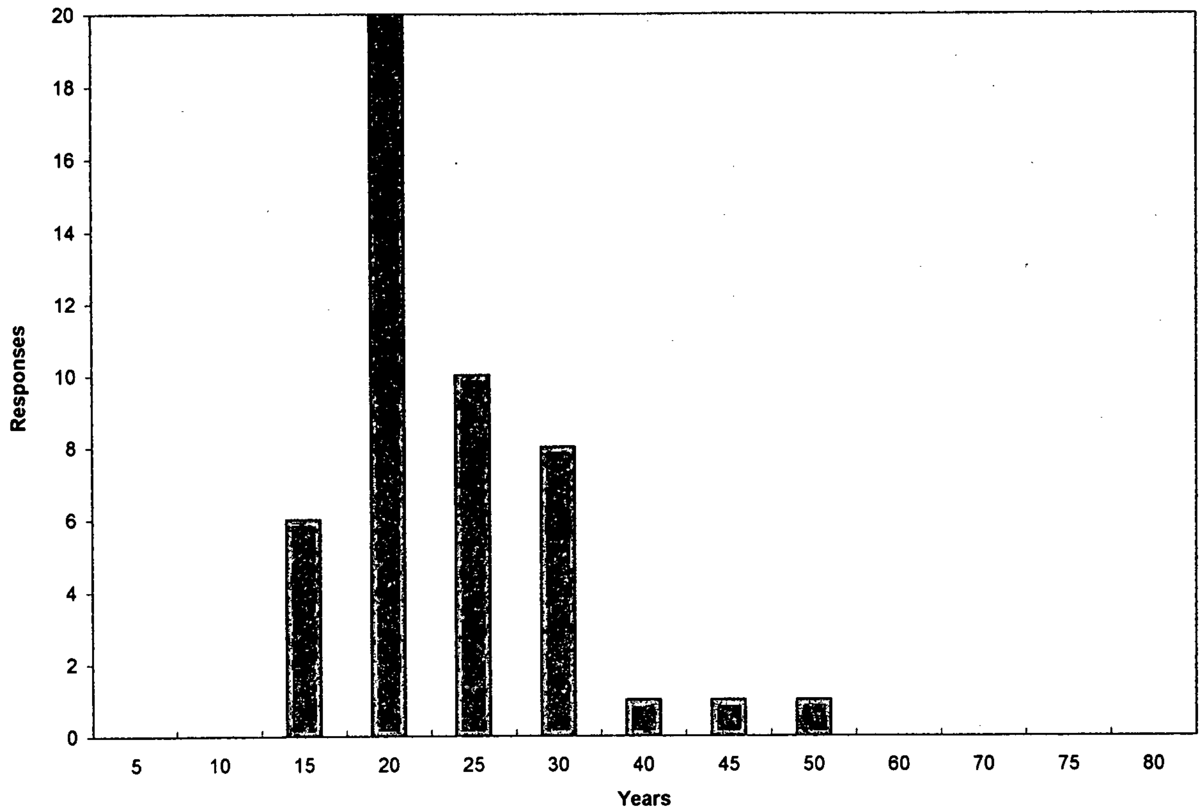

FIGURE 36A Expected life: paint.

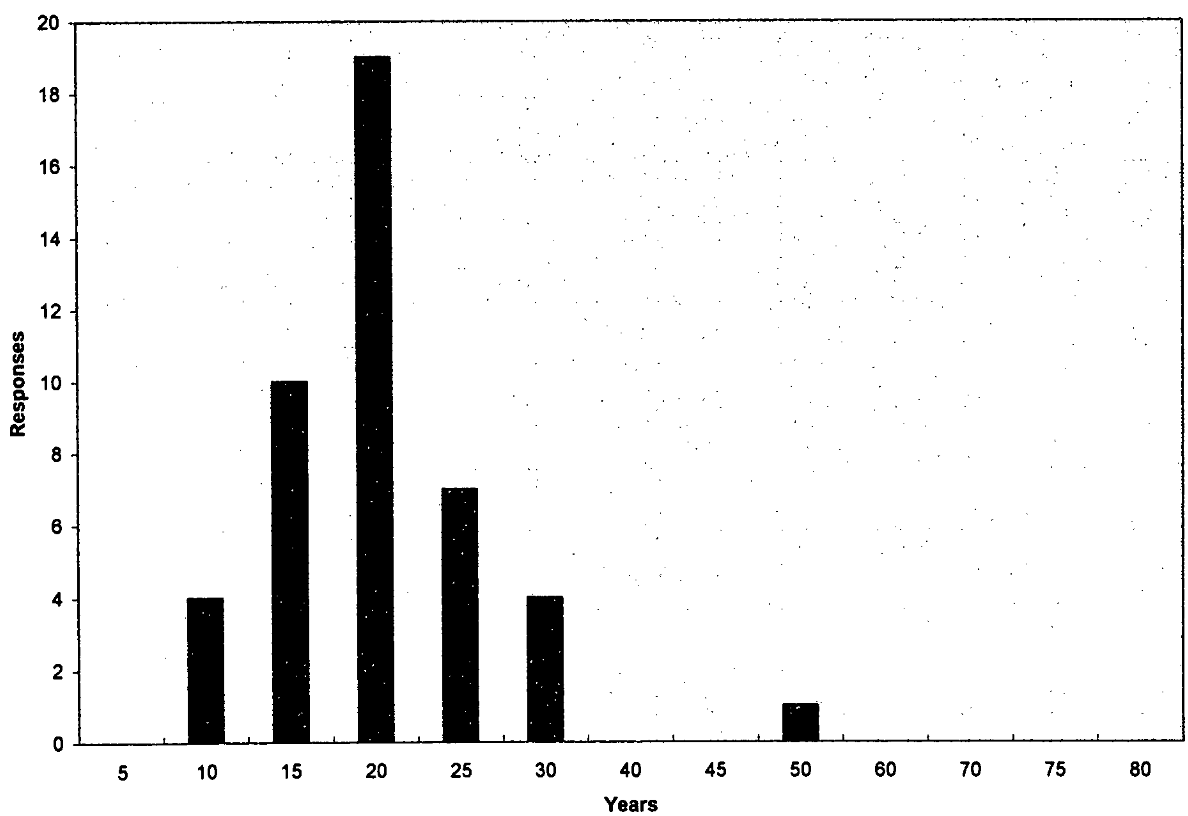

FIGURE 36B Expected life: repaint.

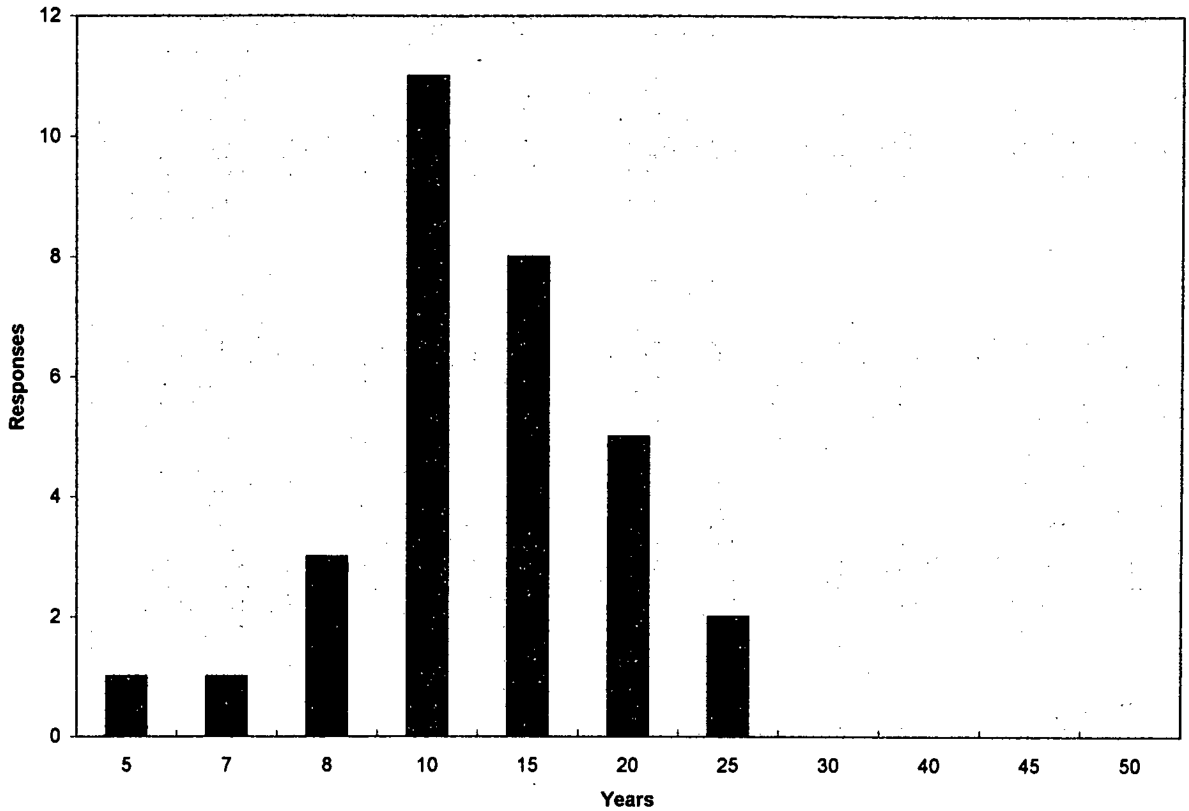

FIGURE 36C Expected life: overcoat.

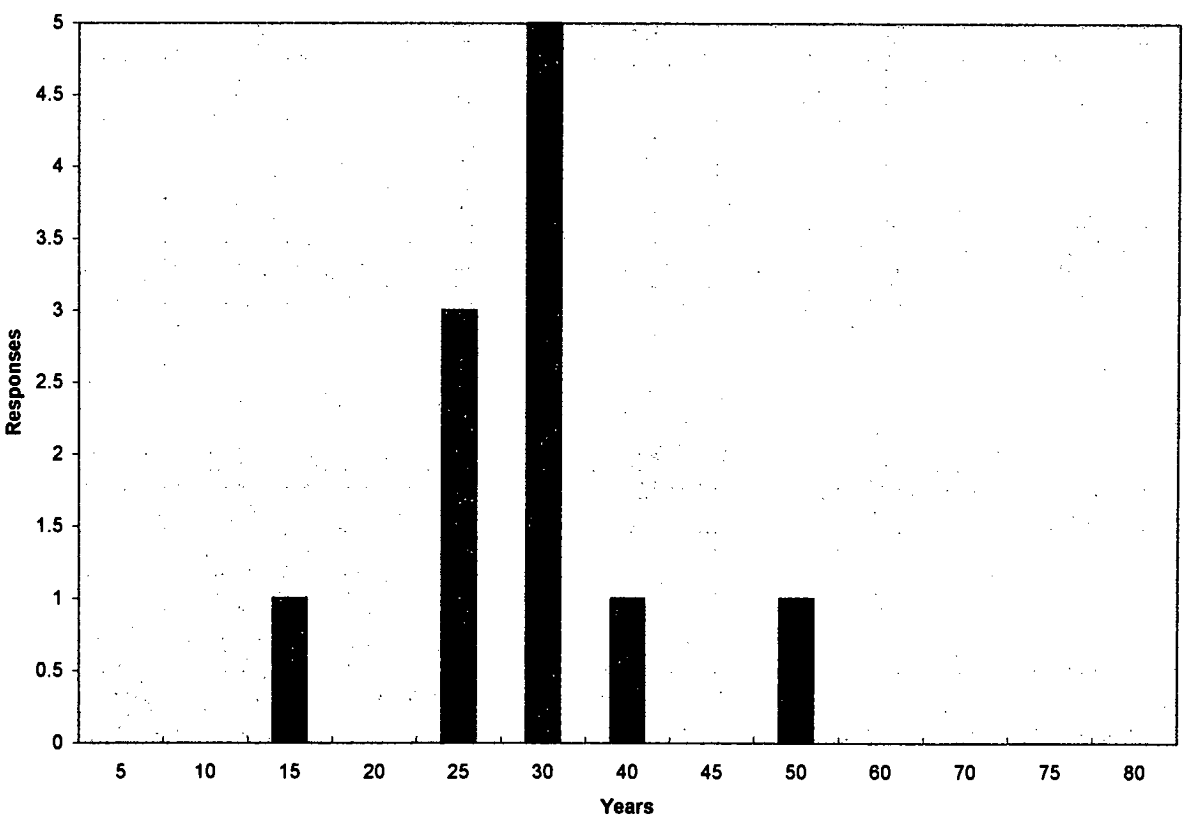

FIGURE 36D Expected life: metallizing.

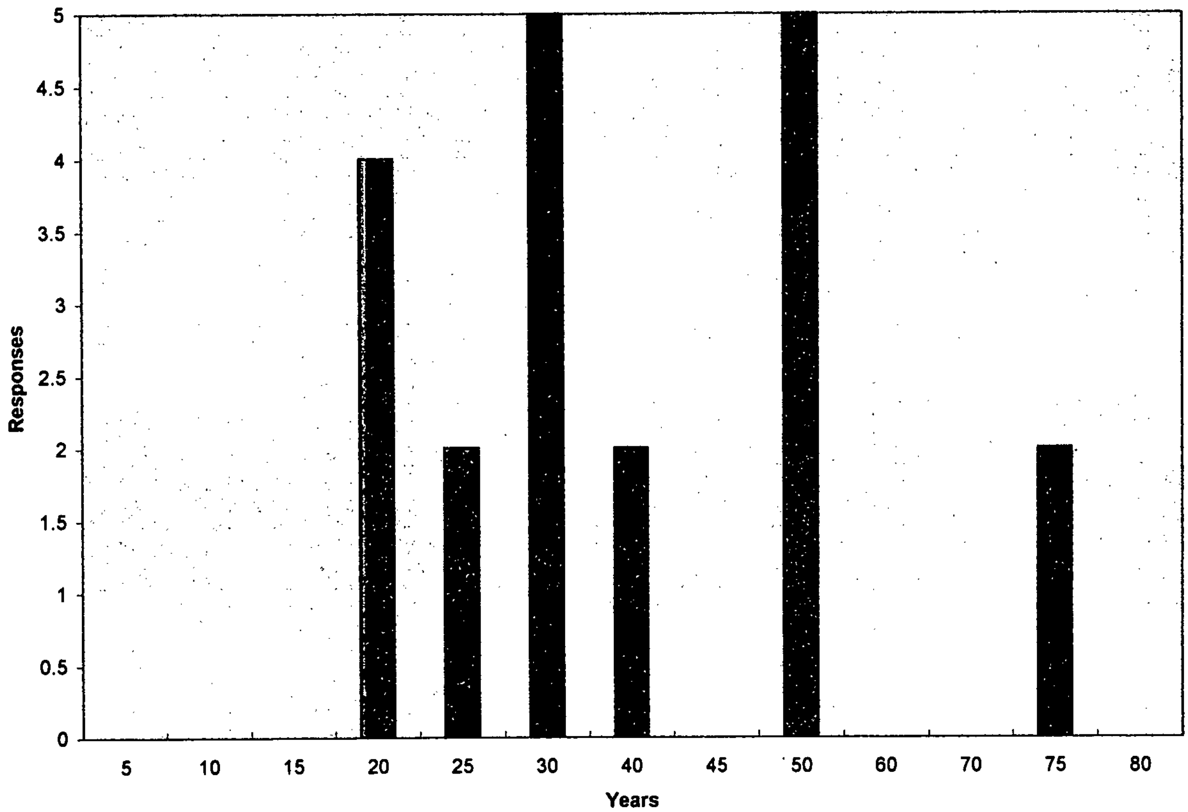

FIGURE 36E Expected life: galvanizing.

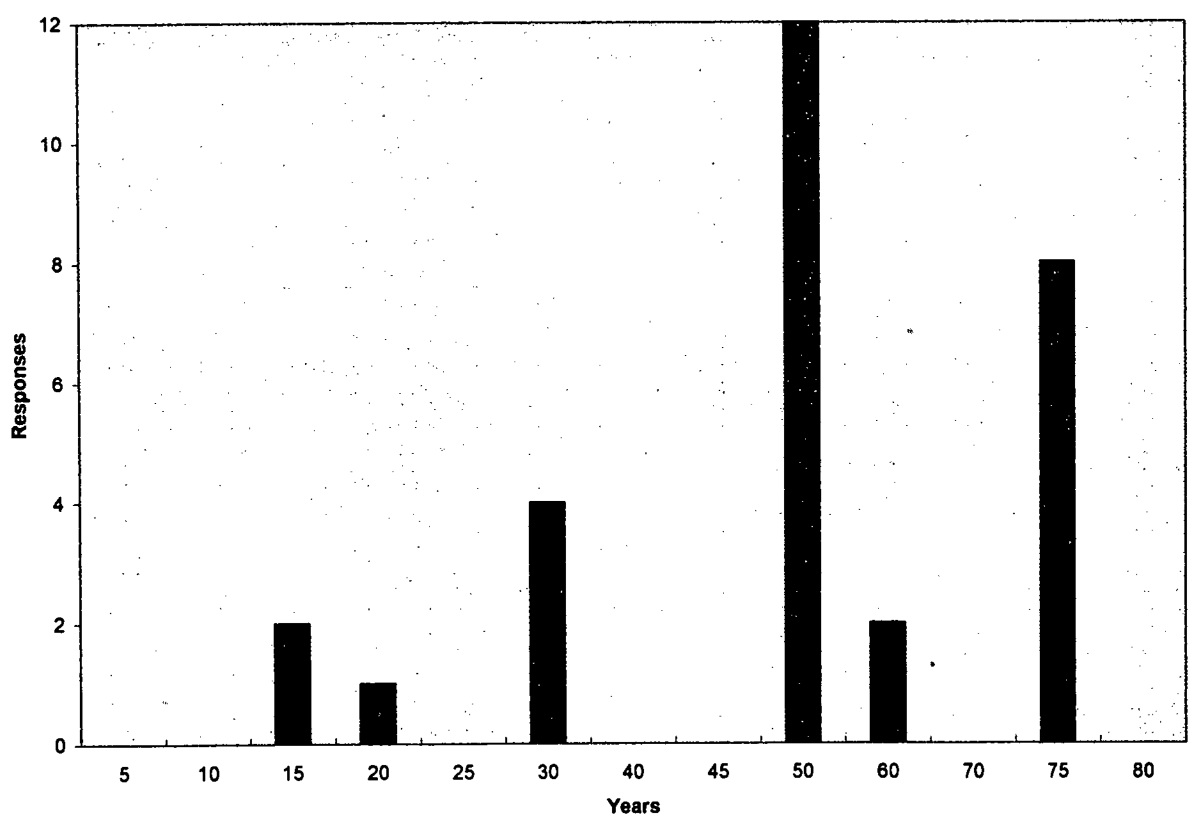

FIGURE 36F Expected life: weathering steel.

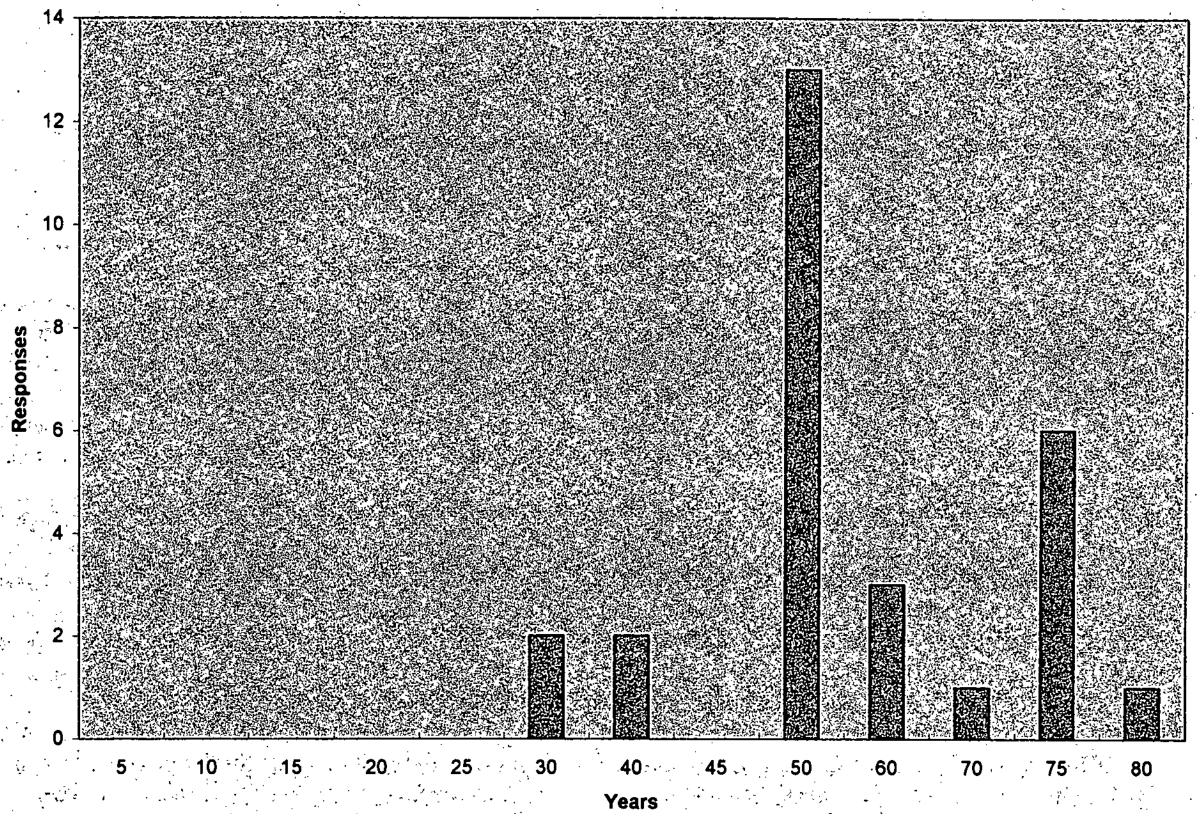

FIGURE 36G Expected life: concrete.

TABLE 7
SUMMARY OF EXPECTATIONS

System	Predominant Expectation (Years)	Expectancy Achieved %	Expectancy Not Achieved %
Paint	20	58	10
Repaint	20	36	15
Overcoating	10	45	10
Metallizing	30	30	10
Galvanizing	30–50	45	0
Wea. Steel	50	24	30
Concrete	50	47	3

As shown in Figure 36, weathering steel's life expectancy has the widest range of expectation. It is the only material to have more negatives than positives as to meeting life expectancy, as shown in Table 7. No distinction is made in the responses to indicate if this is weathering steel used prior to the FHWA recommendations or not.

Galvanizing is thought to have the longest life expectancy of the coating approaches. Metallizing is not thought to have an expected life greater than a painted structure. This is probably because of the limited use of the technology and, therefore, lack of familiarity with the process. Powder coating has received very limited use.

Half of the agencies determine the type of material to be used based on policy, as opposed to the one-tenth that allow the designer to make the decision. One-tenth of the respondents indicate that a combination is the choice. Only 60 percent of the respondents indicate that future maintenance costs enter into the up-front design.

CHAPTER NINE

ONGOING RESEARCH

Only two agencies, Kentucky and Virginia, responded with reports about any ongoing research evaluations dealing with corrosion protection. Both are in the area of overcoating. North Carolina included a report of work published in the *Journal of Protective Coatings and Linings*. Responses about research are included in Appendix C. Since the initial TRIS search, the system has been modified to report research in progress. A subsequent TRIS search indicates that several research evaluations are underway, namely in Michigan, North Carolina, Wisconsin, and Maine and by FHWA. Michigan is evaluating minimum surface preparation coatings and is also studying cost data for warranty versus nonwarranty paint jobs. Wisconsin is evaluating cleaning and painting procedures and materials from an environmental viewpoint, while North Carolina is investigating the use of a robotic system for surface preparation. Maine is looking at a waterborne paint system for new steel as well as an experimental system for existing bridges. FHWA is studying corrosion rates and performance of protection systems to develop guidelines for various environmental conditions that can be incorporated in bridge management systems. Also, the National Steel Bridge Alliance has recently initiated a testing program to evaluate edge preparation issues.

KENTUCKY

Kentucky has a large statewide overcoat program and indicates that all of its overcoating work for the past 6 years has been experimental. The program has painted some 70 bridges and entails the use of a particular paint system and application specifications for the whole structure. This approach is designed to allow for the evaluation of relevant application factors in addition to the subsequent performance of the specific paint system.

Various phases of the program have involved the use of different coating types in combination with different surface preparation techniques. The objective in all the phases was to achieve satisfactory environmental compliance and system performance at a low cost per square foot. Low-pressure water washing with no spot priming as well as the use of hand tool cleaning and power washing at approximately 17 MPa (2,500 psi) with a spot primer, intermediate, and topcoats have been evaluated.

Due to some early disbondment on two structures and the lifting of exposed edges when no spot primer was used, Kentucky's program has evolved to the use of hand and power tools with vacuum-equipped shrouds to remove rust; the use of chipping hammers to remove pack rust; the use of cold water washing at 34 MPa (5,000 psi) with potable water; and the application of a specific three-coat urethane paint system. Except for the washing, these methods are limited to areas where there is no existing paint.

Specifically, the water washing pressure is measured at the wand. The wand is equipped with a zero-degree spinner tip at a maximum standoff distance 300 mm (12 in.) between the wand and the surface being washed. The structure is draped with 85 percent wind screens to collect solid debris as the water drains through them. Chalking and diesel smoke on the existing surface may require additional cleaning.

The paint system consists of a Kentucky specification aluminum pigmented moisture-cured urethane as a spot primer with a full intermediate coat of the same paint being applied. The finish coat is a two-component high-gloss acrylic polyurethane. Brush application is required when applying the paint to the existing substrate. Otherwise, the specification is permissive as to method.

Hazardous waste removal is performed if lead-based paint is present. Kentucky applies for the generator permit with the contractor being responsible for the actual disposal.

Bid prices for 1996 ranged from \$13 to \$16 per m^2 (\$1.10 to \$1.50 per ft^2). Based on the 5-year exposure history to date, Kentucky expects to achieve a 10-year performance. Future projects will look at higher washing pressures as well as water jetting. Alternative polyurethane formulations are also to be assessed.

VIRGINIA

Virginia has a two-phase program underway, looking at multiple systems on several structures. One phase is to evaluate the use of overcoating approaches for structures that are exhibiting failures of the delamination type. The second phase is to apply the same overcoat candidates to a structure that is not exhibiting delamination but has a poor adhesion rating. The overcoats for the first phase were applied in the summer of 1995. Originally 10 systems were selected for application, but the project was scaled back because funds were unavailable. Table 8 lists the systems selected by the contractor from a possible 10 systems.

Surface preparation was specified to be steam cleaning and SSPC SP 3 power tool cleaning on rusted surfaces. At the end of the first year, five of the six systems are in varying stages of delamination from the mill scale. The exception is the leafing aluminum system. This system involved the application of the nonleafing/leafing aluminum pigmented system, both required to be 1 mil dry film thickness. All six systems are exhibiting pinhole rusting where rust was previously present.

The second phase is to apply the same systems over poorly adherent existing paint for which the primary mode of

TABLE 8
VIRGINIA OVERCOAT SYSTEMS

Type	Primer	Intermediate	Topcoat
alkyd	SSPC Paint 25	nonleafing aluminum	leafing aluminum
alkyd	SSPC Paint 25	–	MIO alkyd*
alkyd	proprietary	–	proprietary*
epoxy(1)	penetrating sealer	mastic	mastic
epoxy(2)	penetrating	mastic	mastic
waterborne acrylic	HG 54 acrylic	HG 54 acrylic	HGG 54 acyrlic

*Two-coat systems.

failure is corrosion. This part of the contract has not yet been advertised.

All of the bridges used in the program were built in the late 1960s. The structures in the first phase were maintenance painted in the early 1980s with an MIO oil alkyd system. In 1995, the paint system was beginning to delaminate to the mill scale. The structure for the second phase has not been repainted since its construction. It contains mill scale also. The cross-hatch adhesion value on both structures was zero B according to ASTM D-3359.

It was concluded that structures already exhibiting delamination are not likely overcoat candidates. Secondly, the type of coatings used are not acceptable unless more rigorous salt remediation of the contaminated surfaces is performed.

CHAPTER TEN

CONCLUSIONS

For the corrosion protection of new construction and replacement structures, agencies have a variety of design and material choices. When properly selected, these materials are cost effective, long lasting and compliant with regulations, be it unpainted weathering steel or coated steel construction. Regulations on both new and replacement structures have a greater impact on the maintenance side when dealing with corrosion protection issues.

Agencies have experienced increases in the cost of maintenance work for exposed structural steel due to the impact of regulations dealing primarily with the removal of lead-based paint. This cost increase is primarily in the containment, disposal, and worker exposure aspects as opposed to the material being used for the painting of existing steel. All of the agencies report a lack of funding at a time of high need and high cost.

Most of the major regulations appear to be in place, except one. The Environmental Protection Agency (EPA) has not issued its regulations regarding the training and certification of contractors and workers. Some 20 states have already moved in this direction by developing their own plans. While these plans may increase cost, it is not anticipated to be anywhere near the cost increase due to the other environmental considerations.

Recent Occupational Safety and Health Administration (OSHA) fines for violation of lead related matters are high in cost. The majority of the agencies do not take a proactive role in worker protection issues for contractor personnel. OSHA is being relied on to ensure this aspect. Agencies vary greatly in their requirements for such items as collecting wash water or the use of total suspended particulate (TSP) or particulate (PM 10) monitoring for material smaller than 10 microns. The cost of work is directly related to the attention paid to worker protection and containment issues.

Because of the high number of structures containing lead-based paint, they are not all likely to be replaced in the near future. Because of the cost, neither is it likely that all of the lead-based paint will be removed. It is more likely that the use of overcoating will increase. Judicious use of overcoating is a viable method to extend the life of a structure when conditions indicate that it is an option. However, with only a 5- to 10-year expected life, agencies will likely find that these overcoated structures will need repainting before they have caught up with the existing backlog, barring an unforeseen funding increase. In addition, structures are being painted that have marginal adherence of the existing coating. This makes future repaints an even less likely option if and when rerusting occurs.

To assist in this regard, more research is needed in the area of adhesion assessment, contaminant remediation methods, and performance of products. A comparative study of the relative merits of surface cleaning processes with worker exposure and with coating life would be useful to better define and optimize the parameters and their relationships. Data about successes and failures need to be collected from agencies that are doing overcoating and disseminated to the other agencies. Documentation of conditions and what products have worked or not worked under these conditions is needed.

Coatings are being increasingly selected based on accelerated laboratory weathering tests as opposed to the more traditional compositional type of specification. Zinc rich primer is the overall primer of choice for new steel and repaints in the field. A variety and number of topcoats are being used. Collaborative specifications and testing are increasing. While research has taken place as to the durability of certain types of coatings under varying conditions, there is no laboratory qualification program for evaluating a coating's ability to tolerate surface contaminants remaining after surface preparation. A standard rusted panel procedure has been developed that correlates with field performance. Development of a standard, contaminated rusted panel procedure to correlate field performance over contaminated marginally prepared surfaces is recommended.

Salt fog testing has long been the accelerated test of choice to select the longest lasting coating. It is now becoming clear that a cyclic type of test involving a freeze/thaw cycle, an ultraviolet/condensation cycle, and a salt fog plus pollutant/dry cycle is probably more predictive of actual field performance. Agencies may want to incorporate these cyclic tests into their qualification procedures.

Edge preparation on flame-cut steel is an issue. No specific evaluation was reported by the agencies to determine which coating system is best to use for sharp edges. Most agencies require that the edges be ground or rounded to remove the sharp edge and therefore it is not an issue to the states as to which system, if any, is best. Fabrication plants, however, would like to avoid the labor-intensive effort required to grind or round edges. Inorganic zinc rich coatings, the system of choice for new steel, have been shown to be poor performers on sharp edges. Because edges are usually one of the first places that corrosion will appear, edge preparation and protection are important issues. Agencies may want to adopt edge preparation evaluations as part of the qualification process for a coating system.

The Federal Highway Administration (FHWA) mandated laboratory qualification program has not yet been established. Any quality control/quality assurance (QC/QA) program in place for the acceptance of corrosion protection material is unique to the individual agency. While the FHWA program establishes a process for the quality assurance and acceptance of materials, requirements for laboratories performing qualification testing are not addressed. National Testing and Performance Evaluation Program (NTPEP) may address this through its collaborative testing program.

There is no established national quality assurance effort for corrosion protection work being performed. Programs such as the Society for Protective Coatings (SSPC) Painting Contractor Certification Program (PCCP) QP1 and QP2 and NACE's International Coating Inspector Training and Certification Program are two plans currently available which, when combined, can form the basis for a QC/QA program. Agency establishment of such a program is recommended to provide a complete cycle of QC/QA, from materials acceptance to work acceptance. Having a QC program for work performed in the field, along with the qualification of laboratories for qualifying and accepting materials, provides a basis for a major privatization of the effort. This type of private augmentation should assist agencies with staffing levels.

The formal use of partnering in the corrosion field is very limited. Agencies indicate that partnering is practiced more on an informal basis. To encourage more use of partnering as a means of reducing conflicts, agencies may want to consider having in place provisions that would allow all projects to be done under partnering after award of contract but prior to the start of work. This is not required partnering but allowed partnering.

Formal assessment programs are not being used by the agencies to determine where coatings are located on the deterioration curve and the best time of intervention. This is partly because of the lack of implementation of the bridge management system (BMS) programs. An assessment program is a vital part of the decision-making process. An expert system to model costs to augment the existing BMS program is needed until such time as the agencies can implement and develop costs for their BMS.

The uninformed use of weathering steel in the past has resulted in maintenance funds having to be used to correct excessive rusting. For new and replacement structures, the use of weathering steel in a no-joint situation and in the proper environment would appear to provide for a cost-effective steel structure. However, existing weathering steel is receiving mixed reviews on its performance. Although agencies indicate that they are now designing with weathering steel using the FHWA guidelines, a large number of agencies report that weathering steel is rusting too much. It is not clear from the responses, however, whether any of those structures reported to be rusting too much include any that were designed using the guidelines. It has been 7 years since the FHWA issued its technical advisory for weathering steel. A synthesis to assess the effectiveness of the guidelines is needed. Reevaluation will establish whether the guidelines should be strengthened or relaxed. Weathering steel has the potential to be a cost-effective option for both maintenance and environmental aspects if used properly.

Of the four major corrosion protection systems, painting, galvanizing, metallizing, and weathering steel, metallizing is the least used. Because of its superior performance, agencies may want to take advantage of this technology. A synthesis to better acquaint the bridge industry with the practice of metallizing would be a useful addition to those already published on all the other protection systems.

Although the FHWA has recognized the value of and allows the use of preventive maintenance (PM), there has not necessarily been an increase in funding for it nor has the FHWA defined what PM is from a corrosion protection standpoint or when it should be practiced. Painting is eligible for federal funds under the InterModal Surface Transportation Efficiency Act (ISTEA) and PM is allowed under the National Highway System (NHS) program. Therefore, PM painting is allowed. The most economical and cost-effective PM for lead-based paint is to overcoat before deterioration has begun. PM may be defined so that painting is done not to prevent deterioration of the steel but to prevent deterioration of the paint. Also, if PM funds for corrosion protection where lead-based paint is involved were a totally separate source of funds, they would not compete with other demands.

If the presence of a lead-based paint were considered a deficiency in and or itself, then it would not have to deteriorate to some level of rusting to be considered a deficient system. Hence, if the sufficiency process requirements were met more quickly, it would encourage earlier intervention in the deterioration cycle. Early intervention increases the likelihood of successfully rehabilitating the existing coating, lead-based or otherwise, as opposed to total removal. Once deteriorated, the cost of dealing with lead issues can equal or surpass the cost of dealing with the deterioration of the paint system alone. The earlier the intervention, the less the disturbance of the lead-based paint, the lower the cost. An eligibility system for funding that requires a level of deterioration in order to be considered deficient, in effect, discourages PM.

Approaches that make good sense on a first-cost basis may not be good for maintenance costs. From a maintenance standpoint, the reuse of steel should be discouraged unless the cleaning and surface treatment process is demonstrated to remove the contaminants that are present. Otherwise, the time to first maintenance is shortened, hence creating a demand for maintenance funds earlier than if new steel is used. Initial design considerations need to reflect the timeliness of future maintenance costs and the probability of that maintenance being performed in a timely manner. In actual practice, maintenance of bridges has not always been practiced in a timely manner.

To extend the time to first maintenance for corrosion protection coatings, the use of systems with the longest life expectancy should be considered. Galvanizing, because of its demonstrated life expectancy in the agency responses, and metallizing, because of its long-term success in Europe, are more deserving of consideration. Both metallizing and galvanizing are zero volatile organic compound (VOC) and both can be topcoated if desired. Mild exposure areas may not even need the topcoats.

It is not clear that deferred maintenance is practiced because it is cost effective. It is probably practiced because maintenance funds are insufficient for all of the needs.

Condition-based maintenance is practiced by all the responding agencies. The FHWA sufficiency rating is condition-based, and therefore, the frequent use of this type of maintenance is expected. Major maintenance and rehabilitation are practiced more than whole structure replacement.

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APPENDIX A

Survey Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 20-5, Topic 26-12

Alternate Methods of Corrosion Protection
for Exposed Bridge Steel Surfaces

QUESTIONNAIRE

Please answer the following questions concerning how your agency protects its exposed structural bridge steel. We are seeking comments about methods of protection for exposed steel above the splash zone including bearings, expansion dams, scuppers, downspouts, etc. Not included are suspension cables, signage, jersey barriers, light standards, railings and embedded steel. If there is not enough space provided for an answer, please feel free to attach additional sheets of paper or any other documents that will provide the information. Please indicate the section(s) to which the additional comments apply. Some of the questions are open ended discussion questions and will require some time and thought. Please send your responses to:

Tom Neal
T. W. Neal & Associates
2818 New Kent Avenue
Richmond, Virginia 23225
Telephone No: 804/231-9629

Please include:

Name of Respondent: ______________________

Agency: ______________________

Title: ______________________

Telephone No: ______________________

Thank you for your participation in this study. We would appreciate your response by **January 26, 1996.**

In order to avoid confusion, it would be appreciated if the following definitions are used when specific information is requested.

Definitions

Preventative Maintenance — the performance of a repair activity to lessen or prevent a future repair. For example, the painting of a steel surface when it did not need painting to avoid or minimize surface preparation. This would not involve the total removal of an existing coating.

Routine Maintenance — sometimes called ordinary maintenance activity, such as the washing of a bridge, that involves no repair.

Deferred Maintenance — the delaying of an activity to a later date to take advantage of combination with another activity. For example, a coating is poorly adhered, but there is little corrosion present and a total removal is delayed until another activity is performed, such as demolition of the structure

Conditional Based Maintenance — situational maintenance such as an emergency repair due to flooding or a girder being struck by a truck

Replacement Maintenance — an activity that involves replacement in kind. It could be as minor as bearing pad or a bearing shoe replacement or it could be as major as a total replacement if it was done in kind with no improvements or upgrade

Rehabilitation — an activity that involves an improvement to the structure. A total replacement of a structure with an upgrade to present loadings is an example.

Prioritization Maintenance — a system of ranking maintenance needs based on weighted factors. It could encompass all classes of maintenance

Major Maintenance — a relative term that implies that the activity performed is significantly more costly than another action for the same structure. It can apply to all the types of maintenance except routine maintenance.

Spot Painting — a procedure entailing surface preparation of isolated areas of corrosion or paint breakdown using appropriate cleaning methods and then the coating of the repaired, isolated areas only.

Zone Painting — a procedure entailing surface preparation of a defined area of corrosion or paint breakdown using appropriate cleaning methods and then the coating of the repaired defined area only.

Overcoating — a procedure entailing surface preparation on areas of corrosion or paint breakdown of a structure using appropriate cleaning methods and then the coating of the repaired area in addition to applying coating over remaining existing coatings.

Repainting — a procedure entailing the complete removal of the existing coating using appropriate cleaning methods and then the coating of the entire structure.

Please check answers where appropriate.

SECTION I	MATERIALS

A: PAINTS

A.1 For new steel, in addition to primer, does your agency require that intermediate and topcoats be applied in the shop? Y☐ N☐

A.2 Is your agency aware of the proposed Volatile Organic Compound(VOC) Limits being proposed for the maintenance of industrial structures(includes bridges) by the EPA? Y☐ N☐

A.3 The proposed VOC limits for intermediate and topcoats applied in the field will generally be lower than the limits presently in force for paints applied in fabricating shops. How does your agency plan to address the issue of not being able to touch up in the field with the same paint as applied in the shop?

____

____

A.4 Is your agency using bolts that are:
- Hot dipped galvanized Y☐ N☐
- Mechanically Galvanized Y☐ N☐
- Black and painted in the field Y☐ N☐
  - With what? ___________________
- Other? Y☐ N☐
  - Please describe ___________________

A.5 For box girders, are the interiors required to be painted? Y☐ N☐
If YES, with what:
- Same system as exterior? Y☐ N☐
- Special Immersion Coating? Y☐ N☐
- Other? Y☐ N☐
  - Please describe ___________________

A.6 Why are interiors required to be painted: (Please check all that apply.)
- Corrosion Protection? Y☐ N☐
- Ease of Inspection? Y☐ N☐
- Visibility? Y☐ N☐
- Other? Y☐ N☐
  - Please describe ___________________

A.7 What preparation is required of flame cut or sheared steel edges prior to painting?
- Radius to a certain arc Y☐ N☐
- Ground to break the edge Y☐ N☐
- Nothing Y☐ N☐
- Other Y☐ N☐
  - Please describe ___________________

A.8 Why are the edges prepared as indicated above? (Please check all that apply.)
- Always done this way Y☐ N☐
- Needed to remove carburized steel so as to be able to impart profile Y☐ N☐
- Non ground edges rust first Y☐ N☐
- Other ___________________

A.9 For existing structures, is your agency doing (Please check all that apply.)
- Repainting (Total Removal) Y☐ N☐
- Spot Repair and Spot Topcoating Y☐ N☐
- Spot Repair and Full Topcoating (Overcoating) Y☐ N☐
- Zone Painting Y☐ N☐

Table A is intended to solicit information about the paint system(s) that your agency uses. If there is not enough space because of the use of multiple systems, please make multiple copies of table A or attach any documents that will provide this information. **A filled in example of Table A is included at the end of the questionnaire.**

NCHRP Project 20-5, Topic 26-12
Agency: ___________________

Table A

	New	Existing			
		Repaint lead ☐ nonlead ☐	Spot lead ☐ nonlead ☐	Zone lead ☐ nonlead ☐	Overcoat lead ☐ nonlead ☐
Primer					
Inter-mediate					
Top Coat					
VOC require-ment					
How Applied					
Surface Prep					
Primer slip value					
Specifi-cation					
Cost*					

* includes surface preparation, labor, materials, containment and disposal. **Please check in first (top) row whether information is for an existing structure that contains lead coatings.** See example at end of document.

NCHRP Project 20-5, Topic 26-12
Agency: ________________

Please provide comments on or discuss any research in progress for paints or painting

____
____
____
____

B: Metallizing

B.1 Does your agency use metallizing for bridge steel? Y☐ N☐ (If No, go to section C)

B.2 Was the metallizing performed in the shop ☐ or in the field ☐ ?

B.3 Is this practice current ☐ or since discontinued? ☐

B.4 What areas have been metallized? (Please check all that apply.)
- Bearings Y☐ N☐
- Girders/Beams
  - New Y☐ N☐
  - Existing Y☐ N☐
- Zones Y☐ N☐
- Other ________________

B.5 What is the number of metallized structures? ________________

B.6 What is the oldest metallized structure in terms of length of service for the metallizing? ___________.

B.7 What type of metal was used for the metallizing?(please check all that apply)

		Thickness(mils)
Zinc	___	___
Aluminum	___	___
Zinc/Aluminum (85/15) alloy	___	___
Other	___	___

B.8 What was the type of surface preparation required? (Please check all that apply.)
- White metal SSPC SP5 Y☐ N☐
- Near White metal SSPC SP10 Y☐ N☐

B.9 What type of spray was specified? (Please check all that apply.)
- Flame Y☐ N☐
- Electric Arc Y☐ N☐
- Manufacturer's Recommendations Y☐ N☐

B.10 Were the surfaces
- Sealed? Y☐ N☐
  - With what ________________
- Painted? Y☐ N☐
  - With what ________________
- Sealed and Painted? Y☐ N☐
  - With what ________________
- Not sealed and/or painted Y☐ N☐

NCHRP Project 20-5, Topic 26-12
Agency: ________________

B.11 What was the cost per square foot?
- New ________
- Existing ________

B.12 What is your agency's specification for the metallization?
- Your Agency Y☐ N☐
- American Welding Society Y☐ N☐
- Other Y☐ N☐
  - Please describe ________________

B.13 How is handling or erection damage repaired? ________________

Please provide any comments on or discuss research in progress for the metallizing area.

____
____
____

C: Galvanizing

C.1 Has your agency galvanized bridge steel? Y☐ N☐ (If answer is NO, go to section D)

C.2 Is the practice current ☐ or since discontinued? ☐

C.3 How many structures have been completely galvanized? ________________

C.4 What is the oldest galvanized structure in terms of length of service of the galvanizing? ________

C.5 Is galvanizing being used in conjunction with another approach to corrosion protection
- Cross frames for precast concrete girders Y☐ N☐
- Insert plates and bearings for precast girders Y☐ N☐
- Bearings for painted steel Y☐ N☐
- Bearings for weathering steel Y☐ N☐
- Other Y☐ N☐

____

C.6 Have existing structures been taken down and galvanized? Y☐ N☐

C.7 What is the longest member that has been galvanized? ___________

C.8 How is handling or erection damage repaired? ________________

C.9 What is the cost? (cost per pound installed)
- New ________
- Existing ________

Please comment on or discuss research in progress within your agency.

____
____
____
____

NCHRP Project 20-5, Topic 26-12
Agency: ____________________

D: Weathering Steel

D.1 Is your agency designing with weathering steel(ASTM A588)? Y☐ N☐

D.2 Is it painted? ☐ unpainted? ☐

D.3 If painted, what areas are painted:
- Whole structure? Y☐ N☐
- Zones? Y☐ N☐
  - Which zones? ____________________

D.4 Is your agency using the FHWA guidelines for designing with weathering steel? Y☐ N☐

D.5 What is the total number of weathering steel bridges in your state? ______

D.6 What is the number that are performing satisfactorily? ______

D.7 Has your agency experienced problems with existing weathering steel structures? Y☐ N☐

D.8 What is the number that are performing unsatisfactorily? ______

D.9 What are the problems (Please check all that apply):
- Rusting too much? Y☐ N☐
- Pack rust? Y☐ N☐
- Other? Y☐ N☐
- Please detail ____________________

D.10 What remedial action has been taken:
- Replacement? Y☐ N☐
- Painting? Y☐ N☐
  - With what paint system? ____________________
- Other Y☐ N☐
  - Please detail ____________________

D.11 Is there a moratorium on the use of weathering steel by your agency? Y☐ N☐

Please provide comments on or discuss any research in progress within your agency.
____
____
____

E. Powder Coating

E.1 Has your agency used powder coatings for structural steel? Y☐ N☐ (If answer is NO, please go to section F.)

NCHRP Project 20-5, Topic 26-12
Agency: ____________________

E.2 What kind of exposed steel has been powder coated?
- Girders/Beams Y☐ N☐
- Bearings Y☐ N☐
- Diaphragms Y☐ N☐
- Other Y☐ N☐
- Please describe ____________________

E.3 Is the practice current ☐ or since discontinued? ☐

E.4 What type of powder coating is used? ____________________

E.5 What is the thickness of the coating(s)? ____________________

E.6 What repair or touch up product allowed? ____________________

E.7 How long did the system perform until first maintenance? ____________

E.8 What was the cost of the coating per square foot? ____________

F: Concrete

While not part of the overall scope of the project, it is thought that it would be beneficial to obtain your agency's practice regarding the use of concrete in lieu of exposed steel bridges.

F.1 Does your agency use precast or cast in place concrete structures in lieu of steel structures? Y☐ N☐

F.2 Where applicable, are concrete structures preferred Y☐ N☐ or an equal alternate to steel? Y☐ N☐

F.3 In addition to steel bearings, insert plates, etc., are concrete girders used in combination with exposed steel diaphragms and/or girders? Y☐ N☐

F.4 How is the steel protected:(check all that apply)
- Galvanization? Y☐ N☐
- Painting? Y☐ N☐
- Weathering Steel? Y☐ N☐
- Metallized? Y☐ N☐
- Other? Y☐ N☐
  - Please describe ____________________

F.5 Have steel structures been replaced with concrete ones? Y☐ N☐

NCHRP Project 20-5, Topic 26-12
Agency: ____________

G. Expected Life

G.1 What is the expected life of the materials that your agency has used:(Please answer all that apply.)

	Expected(yrs.)	Achieved
Paint?		
New	____	Y☐ N☐
Repainted	____	Y☐ N☐
Overcoated	____	Y☐ N☐
Metallization?	____	Y☐ N☐
Galvanization?	____	Y☐ N☐
Weathering Steel?	____	Y☐ N☐
Powder Coating?	____	Y☐ N☐
Concrete?	____	Y☐ N☐

G.2 How does your agency determine which of the available materials is to be used? For example, is it by policy or by designer? Please discuss.

____

____

____

G.3 Does possible maintenance costs or problems enter into the selection of the material used? Y☐ N☐

SECTION II	Quality Control/Quality Assurance

1. What methods of acceptance for corrosion protection materials are used on a project?

Testing(batch sampling)	Y☐ N☐
Certification	Y☐ N☐
Certified Test Results	Y☐ N☐
Approved List	Y☐ N☐
Other	Y☐ N☐

Please describe ______________________________

2. What quality control tests for acceptance are performed by your agency when testing is done by your agency? ______________________________

____

____

3. What tests are required if certified test results are provided by the supplier?

____

____

____

4. Does your agency have a published QA/QC approach? Y☐ N☐

5. Does your agency participate in the AASHTO proficiency testing for paint? Y☐ N☐

6. Does your agency obtain independent assurance test samples of corrosion protection materials used on federal aid projects. Y☐ N☐

NCHRP Project 20-5, Topic 26-12
Agency: ____________

7. Is your agency aware of the new FHWA requirements for QA/QC procedures published in the Federal Register, June 29, 1995? Y☐ N☐
If yes, do you see an impact on your present operations? Y☐ N☐
Please describe ______________________________

____

____

8. Is QA that is performed on a project being done by(Please check all that apply.)

Agency inspectors	Y☐ N☐
Independent inspectors	Y☐ N☐
Others	Y☐ N☐

9. What are the inspectors charged with doing?

____

____

10. Are the contractors required to do any quality control testing? Y☐ N☐ If yes, what and how is the information used in the acceptance process.

____

____

____

11. Is the contractor required to be certified under the Steel Structures Painting Council Painting Contractor Certification Program for either QP1(Painting) or QP2 (Removal of Hazardous Paint)? Y☐ N☐

12. Is there any interest or intention to require this certification by your agency? Y☐ N☐

13. Is partnering used by your agency? Y☐ N☐

14. Where used, has it proved to be an advantage. Y☐ N☐
Please explain your answer.

____

____

____

____

____

15. What testing is done in order to determine environmental compliance?

None	Y☐ N☐
Soil Testing	Y☐ N☐
Air Sampling	
TSP Testing	Y☐ N☐
PM10 Testing	Y☐ N☐
Water testing	Y☐ N☐
Visible Emissions Testing	Y☐ N☐
Other	Y☐ N☐

Please describe ______________________________

16. How are worker health and safety issues addressed for the contractor personnel?

____

17. How are worker health and safety issues addressed for agency personnel?

____

18. Please discuss any training or experience requirements that are required of agency personnel as well as contract inspectors.

____

19. Please discuss any training or experience requirements that are required of contractor personnel.

____

SECTION III	Funding

1. How are maintenance and construction projects funded?(Please check all that apply.)
   - FHWA ☐
   - State
     - Bonds ☐
     - Special use Taxes ☐
     - General Fund ☐
   - Capital Outlay ☐
   - Privatization ☐
   - Tolls ☐
   - Other ☐
     - Please describe ____________________

2. Do construction and maintenance have their own individual sources of funding? Y☐ N☐

3. Please discuss or comment on any unusual or unique funding sources.

____

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SECTION IV	Design Criteria

1. What design criteria does your agency use to reduce the amount of potential future maintenance:(Please check all that apply.)
   - Jointless bridges? Y☐ N☐
   - Continuous bridges Y☐ N☐
   - Longer life coating system Y☐ N☐
   - Replacing steel Y☐ N☐
   - Other Y☐ N☐
     - Please explain ____________________

2. Have warranted or guaranteed paint jobs been used by your agency? Y☐ N☐

3. Are warranted paint jobs currently being used by your agency? Y☐ N☐

4. If warranted paint jobs have been or are currently being used, please discuss the benefits or pitfalls of such an approach.

____

SECTION V	Maintenance Philosophy

1. Does your agency have a bridge maintenance system? Y☐ N☐

2. Has this system been implemented? Y☐ N☐

3. If NO, what are the impediments?

____

4. Does your agency practice:(Please check all that apply.)
   - Preventative Maintenance? Y☐ N☐
   - Routine Maintenance? Y☐ N☐
   - Deferred Maintenance? Y☐ N☐
   - Conditional Based Maintenance? Y☐ N☐
   - Replacement Maintenance? Y☐ N☐
   - Rehabilitation? Y☐ N☐
   - Prioritization Maintenance? Y☐ N☐
   - Major Maintenance? Y☐ N☐

5. How is condition based maintenance integrated with other maintenance activities in your agency?

____

6. If your agency practices preventative maintenance, what distinguishes this approach from other maintenance activities?

____
____
____
____

7. What are the deciding factors in determining when to rehabilitate versus replace a structure?

____
____
____
____

8. Does your agency have a policy of deferring maintenance activities? Y☐ N☐ What are the criteria for such decisions?

____
____
____

9. For your agency, what defines a major maintenance activity? How is that different from rehabilitation versus. replacement?

____
____
____
____

10. After the determination is made of a maintenance need, how long is the budgeting process, before the funds are allocated for the work to go to bid.

____
____
____
____

11. For the following issues that face you as a maintenance manager for the corrosion protection of exposed structural steel, please prioritize your concerns. **Use a value of 1 for major concern, 2 for moderate concern, 3 for little or no concern**

Environmental Issues? _____
Worker Health & Safety Issues? _____
Funding Issues? _____
Uncertainty about what to do? _____
High costs issues? _____
Other? ____
____

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12. For the following, please indicate the factors that your agency considers when putting together a maintenance painting contract. **Use a value of 1 for major concern, 2 for moderate concern, 3 for little or no concern to indicate your agency's concern.**

_____ a. Current coating system type, thickness and number of coats
_____ b. Condition of the substrate under the existing coating,(millscale present, etc) and extent of substrate rehabilitation necessary
_____ c. Configuration of the surface(flat, angular, complex)
_____ d. Degree of flexing anticipated in the steel surface
_____ e. Variability in temperature
_____ f. Overall condition of the existing coating, including adhesion, eroded paint film, corrosion pattern, pitting and percent of rusted service area.
_____ g. Ionic or non Ionic contaminants present, such as chlorides, sulfates, bird droppings, grease, heavy dirt
_____ h. Surface preparation history

13. For the following, please indicate the factors which your agency uses to mitigate risk when putting together a maintenance painting contract. **Use a value of 1 for major concern, 2 for moderate concern, 3 for little or no concern to indicate your agency's concern.**

_____ a. Type of member such as primary, secondary, fracture critical, fatigue prone, fascia, interior secondary bracing, bearing
_____ b. Expected service life of the structure (in years)
_____ c. Expected life of the coating system to be applied
_____ d. Whether the overcoatability of the applied coating is or is not a significant factor
_____ e. Cost and logistics of structural replacement, i.e., whether usage, alternate traffic routes, alternate structure to be used in the interim
_____ f. Available or allowable application methods
_____ g. Emission limitations regarding air, water and soil
_____ h. Future maintenance costs of applied coatings
_____ i. Limitations on surface preparation methods, e.g., noise limits or proximity to playgrounds, schools, homes etc.
_____ j. Degree to which a coating failure can be tolerated
_____ k. Cost of overcoating as a percentage of the cost of abatement
_____ l. Urgency of the action(is do nothing a realistic option)
_____ m. Necessity of structural preservation(is demolition a possibility)

14. Has your agency formulated a policy dealing with how it will handle painting structures with existing lead based paint? Y☐ N☐ Is your policy:

All lead based paint work will be a total removal of the lead based paint	Y☐	N☐
All lead based paint work will be overcoating	Y☐	N☐
All lead based paint work will be spot painting until major maintenance when steel will be replaced	Y☐	N☐
Do no paint work and replace steel at a later date	Y☐	N☐

Other ____
____
____

15. Has your agency replaced steel rather than deal with the lead paint removal? Y☐ N☐
If YES, what was the rationale?

____
____

16. Is your agency using zone and/or spot painting as an active part of your maintenance strategy? Y☐ N☐

17. Is there a rating system that is used to determine that a structure is in need of maintenance? Y☐ N☐

18. If yes, what are the rating factors that are used?(Please check all that apply.)
    - Amount of Rust Y☐ N☐
    - Adhesion of Paint Y☐ N☐
    - Other Y☐ N☐ Please describe. ____________

19. Is there an overall rating system to prioritize the structures that need maintenance? Y☐ N☐

20. Are waste reduction issues for the amount of solid waste Y☐ N☐ and the amount of hazardous waste generated Y☐ N☐ considered by your agency?

21. Does your agency specify the use of recyclable abrasives in order to reduce the total amount of waste generated? Y☐ N☐

22. How many steel structures does your agency have? ____________

23. How many structures are painted with lead based paint? ____________

24. What is your agency's annual bridge construction budget? ____________

25. What is your agency's annual bridge maintenance budget? ____________

26. Of the maintenance budget, how much is dedicated to corrosion protection measures(painting, etc.)?
____

27. What is the estimated amount of corrosion protection needs for your agency? ____________

28. What is your agency's method of record keeping for corrosion protection materials:
    - Agency BMS system Y☐ N☐
    - Pontis system Y☐ N☐
    - Other software system Y☐ N☐
    - Project records Y☐ N☐
    - Other methods Y☐ N☐

29. Please discuss whether the available systems meet your agency's needs.
____
____
____

30. Is your agency's system predictive of corrosion deterioration rate? Y☐ N☐ Does it record the physical aspects, such as coating thickness, amount of rust present, adhesion, etc. of the existing corrosion protection material? Y☐ N☐

31. What is the one area of corrosion protection for steel in which you think that research is needed?
____
____
____

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Table A Example

	New	Existing			
		Repaint lead ☐ nonlead ☐	Spot lead ☐ nonlead ☐	Zone lead ☐ nonlead ☐	Overcoat lead ☐ nonlead ☐
Primer	inorganic zinc	organic zinc			
Inter-mediate	Epoxy Polyamide	moist cure Mastic			
Top Coat	Aliphatic polyureth	moisture cure Mi0 polyureth			
VOC req.	< 3.5 lbs/gal	no limit			
How Applied	Manuf. rec.	brush & roll all coats			
Surface Prep	Near white	commercial			
Primer slip value	Class B	not appl.			
Specifi-cation	NEPCOAT	State System B			
Cost*	$2.75 per sq. ft.	$8.35 per sq. ft.			

APPENDIX B

FHWA Technical Advisory on Weathering Steel

U.S. Department of Transportation

Federal Highway Administration

Technical Advisory

Subject

UNCOATED WEATHERING STEEL IN STRUCTURES

Classification Code	Date
T 5140.22	October 3, 1989

Par. 1. Purpose
2. Background
3. Guidelines
4. Discussion

1. PURPOSE. To provide engineers with suggested guidelines for proper application of uncoated (unpainted) weathering grade steels in highway structures and recommendations for maintenance to ensure continued successful performance of the steel.

2. BACKGROUND

a. Uncoated weathering grade steels have been available to the bridge engineering profession for many years. The cost-effectiveness of use of this material has been demonstrated in both short and long-term savings. The additional cost of this grade of steel is offset by the elimination of the need for initial painting of the structure. These steels are currently supplied under American Association of State Highway and Transportation Officials (AASHTO) Specification M270 (ASTM A709) with grades 50, 70 and 100 available. Where enhanced atmospheric corrosion resistance is desired, the letter "W" follows the grade.

b. Environmental benefits also result from the use of this material. The reduction in initial painting reduces emissions of volatile organic compounds (VOC) when oil based coatings are used. The elimination of removal of the coating and disposal of contaminated blast cleaning debris over the life span of the structure is another significant environmental benefit. There are documented cases where the estimated cost of the collection and disposal of materials from a structure repainting project were so great that the structure was either abandoned or replaced with a new bridge.

(1) At the same time, there are documented cases where application of this material in improper locations or under improper conditions has resulted in less than desirable performance of the structure.

DISTRIBUTION: Level 2: Headquarters(RD,NR,FL,HO,HS)
Regions(ST)
Divisions(BR)
All Fed. Lands Offices
Level 3: SHA's(Through Divisions)

OPI HNG-32
HRT-10

(2) In most cases, this poor performance was the result of a lack of understanding of the limitations of weathering grade steels, or from poor detailing which caused exposure conditions which would cause distress in any structure, coated or uncoated, concrete or steel.

c. To better define the performance record of this material, the FHWA sponsored a Weathering Steel Forum in July of 1988 where knowledgeable speakers from across the nation were invited to present case histories and research data on the performance of this product in highway structures. The outgrowth of this forum was the suggested guidelines included herein. If these guidelines are followed, the potential for satisfactory performance and long term durability of weathering grade steels in highway structures is greatly enhanced. Proceedings from this forum are available from the Federal Highway Administration Office of Implementation, HRT-10.

3. GUIDELINES. If the proposed structure is to be located at a site with any of the characteristics noted in paragraph 3a or 3b below, the use of uncoated (AASHTO M270 Weathering Grade) steels should be considered with caution and a study of both the macro-environment and micro-environment by a corrosion consultant may be required. In all environments, the designer must pay careful attention to detailing, specifically noted in paragraph 3c, and the owner should implement, as a minimum, the maintenance actions as noted in paragraph 3d.

a. Environment

(1) Marine Coastal Areas.

(2) Frequent High Rainfall, High Humidity or Persistent Fog (Condensing Conditions).

(3) Industrial Areas where concentrated chemical fumes may drift directly onto the structure.

b. Location

(1) Grade Separations in "Tunnel-Like" Conditions.

(2) Low Level Water Crossings.

(a) Ten feet or less over stagnant, sheltered water.

(b) Eight feet or less over moving water.

c. Design Details For uncoated steel in bridges and other highway structures, the following items should receive careful consideration:

(1) Eliminate bridge joints where possible.

(2) Expansion joints must be able to control water that is on the deck. Consider the use of a trough under the deck joint to divert water away from vulnerable elements.

(3) Paint all superstructure steel within a distance of 1 1/2 times the depth of girder from bridge joints.

(4) Do not use welded drip bars where fatigue stresses may be critical.

(5) Minimize the number of bridge deck scuppers.

(6) Eliminate details that serve as water and debris "traps".

(7) "Hermetically seal" box members when possible, or provide weep holes to allow proper drainage and circulation of air.

(8) Cover or screen all openings in boxes that are not sealed.

(9) Consider protecting pier caps and abutment walls to minimize staining.

(10) Seal overlapping surfaces exposed to water (to prevent capillary penetration action).

d. Maintenance Actions

(1) Implement maintenance and inspection procedures designed to detect and minimize corrosion.

(2) Control roadway drainage:

(a) Divert roadway drainage away from the bridge structure.

(b) Clean troughs or reseal deck joints.

(c) Maintain deck drainage systems.

(d) Periodically clean and, when needed, repaint all steel within a minimum distance of 1 1/2 times the depth of the girder from bridge joints.

(3) Regularly remove all dirt, debris and other deposits that trap moisture.

(4) Regularly remove all vegetation which can prevent the natural drying of wet steel surfaces.

(5) Maintain covers and screens over access holes.

4. DISCUSSION

a. General. Controlling the corrosion of steel highway bridges and other steel appurtenances and mitigating the corrosion related damage is a major problem facing bridge owners. A special aspect of the problem is ensuring that highway structures utilizing uncoated (AASHTO M270 Weathering Grade) steels are located in an environment, and incorporate details, that will ensure cost-effective performance over the expected service life of the structure. For existing weathering steel structures, where proper guidelines have not been followed, another part of the problem is controlling the corrosion damage of uncoated steel. In a number of cases, bridges, light poles and guardrail have experienced excessive corrosion damage, and some have ultimately experienced loss of section and/or localized structural failure because of improper applications of this material. Further work is needed to quantify and understand the performance of uncoated weathering steel in a variety of circumstances and conditions. These guidelines are intended to aid the engineer in making a prudent decision to use coated or uncoated steel in highway environments and applications. A more precise technical evaluation of the suitability of uncoated weathering steel for a particular site may be obtained from a corrosion consultant, from conducting standardized environmental tests, or from both. If serious doubt remains after applying the guidelines in the selection process, then engineering judgement should lean towards coated steel.

(1) Application of these guidelines will be reflected in decisions to use uncoated versus coated steel for new structures, in decisions on geometrics and design, and also in future maintenance activities to control corrosion damage. Many of these guidelines apply to coated structures as well and represent good engineering practice for all steel structures. The guidelines are structured as follows:

(a) Environmental/Climatic factors effecting the selection of type of steel for new structures.

(b) Geometric and location features considered for new structures.

(c) Design details for new structures.

(d) Maintenance actions to maximize the service life of existing structures.

(2) Fatigue Damage - The question of fatigue damage to uncoated weathering steel members as a result of corrosion is not addressed by these guidelines. However, application of the guidelines will minimize unexpected corrosion damage and provide more fatigue resistant details. The question of fatigue life of uncoated steel is being addressed by an AASHTO Task Force.

b. Selection of Type (Uncoated or Coated) of Steel for Highway Structures

(1) Environment/Climate. The following situations represent conditions where uncoated weathering steel cannot be expected to perform as intended and continuing corrosion could result in significant damage:

(a) Marine Coastal Areas - Salt-laden air that is generated along the Atlantic, Pacific, and Gulf Coast may be transported inland by the prevailing winds. The level of chloride concentration caused by the salt-laden air and its effect on the performance of uncoated weathering steel structures depends on the direction of the prevailing winds, the distance from the shore line, and the topographical and environmental characteristics of the area. Thus, the weathering behavior of uncoated weathering steel structures can vary significantly from one location to another along the three coastlines. The suitability of uncoated weathering steel for use at a specific site in marine coastal areas can be determined from the behavior of neighboring metal and concrete structures and, when necessary, by measuring the average daily ambient chloride concentration as determined by the ASTM Test G92 "Characterization of Atmospheric Test Sites," Method B, using the "Wet Candle" method. This method is extracted from a referenced paper in the ASTM Specification. ASTM is currently balloting for approval of the "wet candle" test procedures. In the interim, the International Standards Organization draft proposal ISO/DIS #9225 "Corrosion of Metals and Alloys-Corrosivity of Atmospheres-Methods of Measurement of Pollutants" can be utilized. The United Kingdom Department of Transport Standard BD/7/81, "The Use of Weathering Steel for Highway Structures" suggests that uncoated steel should not be used when the chloride level exceeds 0.1 mg/100 cm^2/day, average.

However, corrosion rates in the United States are substantially lower than in the United Kingdom, presumably because of lower latitude and, therefore, shorter times of wetness in the United States. Therefore, a higher level of chloride contamination can be tolerated in the United States. It is known for example, that at the 250 meter lot at Kure Beach, North Carolina, where average chloride levels are determined by wet candle tests, over a 30-year period, ambient levels range from 0.8 to 1.8 and average 1.0 mg/100 cm^2/day. Under these conditions weathering steels perform satisfactorily in this location when boldly exposed as flat panels, although the performance may be marginal for actual structures containing crevices and sheltered areas. Based on available information, it is estimated that weathering steels can be used safely in the United States at chloride levels up to at least 0.5 mg/100 cm^2/day, average.

(b) Areas of Frequent High Rainfall, High Humidity or Persistent Fog - These climatic conditions can result in excessive condensation and prolonged periods of wetness of the steel. Selection of uncoated steel for use in areas where these conditions persist should not be made without an evaluation of the expected time of wetness of the steel at the particular bridge site. This factor can be evaluated by employing ASTM Test G84 "Time of Wetness Determination (On Surfaces Exposed to Cyclic Atmospheric Conditions)." Some areas in the Pacific Northwest, West of the Cascade Mountains, are examples of these conditions where high annual rainfall can contribute to excessive corrosion of uncoated steel. If the yearly average time of wetness exceeds 60 percent, caution should be used in the use of bare weathering steel (see ISO/DIS draft proposal #9223 "Corrosion of Metals and Alloys - Classification of Corrosivity of Atmospheres)

(c) Industrial Areas - in heavy industrial areas with chemical and other manufacturing plants the air may contain chemical impurities that can be deposited on and decompose the steel surfaces. The United Kingdom Department of Transport Standard BD/7/81 advises that when the threshold level for sulfur trioxide exceeds 2.1mg/100 cm^2/day average, uncoated weathering steel should not be used.

(d) If necessary, the suitability of uncoated weathering steel for a particular site can be determined by a corrosion consultant.

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October 3, 1989

(2) Location and Geometrics - the following factors have a major impact on the performance of steel highway structures and should be carefully considered in the decision to use uncoated or coated steel:

(a) Grade Separations - the so called "tunnel effect" is produced by the combination of narrow depressed roadway sections between vertical retaining walls, narrow shoulders, bridges with minimum vertical clearances and deep abutments adjacent to the shoulders as are found at many urban/suburban grade separations. These roadway/bridge geometrics combine to prevent roadway spray from being dissipated by air currents and can result in excessive salt in the spray being deposited on the bridge steel. The illustration below is representative of situations where use of uncoated weathering steel should be avoided where winter deicing salt use is significant.

- Depressed Roadway (Tunnel-like condition)

NOTE: Where the longitudinal extent of the vertical walls is limited to the deep abutment (i.e. short or no approach retaining walls) there is no evidence of salt spray causing excessive corrosion.

(b) Low Level Water Crossings - sufficient clearance over bodies of water must be maintained so that spray or condensation of water vapor does not result in prolonged periods of wetness of the steel. Clearance to bottom flange of at least 10 feet over sheltered, stagnant water and at least 8 feet over running water is recommended.

c. Design Details - Proper design of structural features and details will eliminate many conditions which lead to excessive oxidation of steel structures. The following guidance should be applied to both coated and uncoated steel but it is most critical in the case of uncoated weathering steel:

(1) Controlling Roadway Drainage - This is the first line of defense against localized corrosion - eliminating the exposure of the steel to contact with drainage from the roadway above, especially in areas where roadway salts are used.

(a) Joints:

1 To the extent possible, bridge joints should be eliminated. Jointless steel bridges have been used to lengths of 400 feet and greater (and up to 1600 feet with joints only at the ends) in some States with no problems identified due to lack of joints. Virtually every bridge with joints has problems (corrosion, rideability, maintenance) attributable to the joint.

2 Extensive experience has shown that obtaining a permanent water-tight bridge joint is an elusive goal. Therefore, when joints are necessary, the assumption should be that the joints will leak and that drainage will contact the steel. Therefore, all steel within a minimum distance of 1 1/2 times the depth of the girder from the joint should be coated. In addition, measures must be incorporated to control the water that passes through the joint. Properly designed and maintained troughs beneath the joints will intercept most drainage runoff and prevent damage to superstructure and substructure elements.

3 Drip bars on the top and bottom of the lower flanges can be effective in intercepting drainage and preventing it from running long distances along the flange and causing corrosion of the uncoated steel. However, welding of any attachment to the tension flange should be considered only after a thorough analysis of the impact of the attachment on fatigue life of the member.

4 Fascia Girders - there is no evidence that coating the entire fascia girder will add to the service life of an otherwise uncoated bridge. On the other hand, coating the fascia girder does create future maintenance needs and aesthetic concerns.

(b) Scuppers:

1 The spacing between drainage scuppers should be maximized in accordance with established hydrologic and hydraulic design. The FHWA Report No. FHWA/RD/87/ 014 "Bridge Deck Drainage Guidelines", provides sound recommendations in this regard. As scupper spacing increases, the volume of water required to pass through each scupper increases, thus creating velocities high enough to flush outlets clogged by deposits from low volume rainfalls. Where open (finger type) expansion joints are used, they will function as a drain. Again, increased flow into the joint will flush the below deck drainage trough.

2 Scupper downspouts should be designed and placed such that drainage will not contact the steel surface. However, details used to connect scuppers to drain pipes have often created more problems than they have prevented, by providing flat runs of piping and elbows which clog or connections that separate. Careful detailing is critical.

3 Scupper drain pipes should not be routed through closed box sections where leakage inside of the box is possible, and may go undetected for long periods of time.

(2) <u>Other Features</u>:

(a) Water Traps - all details must be designed to provide natural drainage. Small copes in corners of plates or small drain holes are easily plugged, and should not be relied on to provide drainage.

(b) Box Sections -

1 Box sections which are too small to provide for adequate visual inspection and access for maintenance personnel should be hermetically sealed, or provide weep holes to allow proper drainage and circulation of air.

2 Larger boxes should be detailed to minimize the entrance of water, debris and dirt which can promote corrosion. They must also provide for natural drainage of water that may enter and adequate access for inspection, cleaning and maintenance when necessary. Precautions should include:

a Locked covers or screens over access holes to prevent the entry of animals and birds or unauthorized personnel. Covers over manholes should be on hinges and provided with a lock to allow easy access by inspection personnel.

b Provision of positive drainage and adequate ventilation to minimize the wetting of the interior surfaces from water or condensation.

(c) Concrete Surfaces - after passing over uncoated weathering steel, drainage leaves dark, non-uniform and often unsightly stains on concrete surfaces. This problem can be mitigated, if desired, by using one or more of the following approaches:

1 Wrapping the piers and abutments during construction to minimize staining while the steel is open to rainfall.

2 Allowing/requiring the contractor to remove staining with a commercial solvent after completion of construction.

3 Applying epoxy or some other material to coat and/or seal the concrete surfaces against staining.

(d) Overlapping surfaces - if water is allowed to flow over overlapping joints, capillary action can draw the water into the joint and cause "rust-pack" to form. Therefore, the contact surfaces of overlapping joints must be protected from intrusion of rainfall and runoff. This applies to non-slip-critical bolted joints as well as to overlapped joints such as those in tapered high mast lighting poles. The faying surfaces should be painted or sealed to prevent the capillary penetration. In slip-critical bolted splices, "rust-pack" should not occur when the bolts are spaced as per AASHTO specifications.

d. Maintenance Actions - effective inspection and maintenance programs are essential to ensure that all bridges reach their intended service life. This is especially true in the case of uncoated weathering steel bridges. The following maintenance actions should be routine:

(1) Inspection - implement inspection procedures that recognize the unique nature of uncoated weathering steel and the conditions resulting from excessive corrosion damage. Develop inspection guidelines that highlight the structural features to be inspected and also illustrate the difference between the desired oxide coating and excessive rust scaling.

(2) Controlling Roadway Drainage - to the extent feasible the following should be done:

(a) Divert approach roadway drainage away from the bridge structure.

(b) Clean troughs of open (finger) joints and reseal "watertight" deck joints.

(c) Maintain deck drainage systems (scuppers, troughs, etc.) in order to divert deck drainage away from the superstructure steel and substructure units.

(d) Periodically clean and repaint all steel within a minimum distance of 1 1/2 times depth of the girder from bridge joints.

(3) Other Maintenance

(a) Remove dirt, debris and other deposits that hold moisture and maintain a wet surface condition on the steel. In some situations, hosing down a bridge to remove debris and contaminants may be practical and effective. Some agencies have a regularly scheduled program to hose down their bridges.

(b) Maintain screens over access holes in box sections to prevent entrance by animals and birds.

(c) Remove growth of nearby vegetation that prevents the natural drying of surfaces wet by rain, spray or other sources of moisture.

Thomas O. Willett
Director, Office of Engineering

GLOSSARY

Action Level—the maximum airborne concentration of a compound, without regard to the use of respirators, to which a worker may be exposed based on an 8-hr time-weighted average

Alkyd—a resin system based on the use of ester due to reaction of polybasic alcohol and a polyhydric compound, typically an anhydride, such as phthallic anhydride

Attainment areas—areas that meet the Clean Air Act standard for ozone

"Black" fasteners— steel fasteners that do not receive a protective coating prior to installation

Competent Person—a person who is capable of identifying existing and predictable hazards for a particular compound in surroundings or work area and has authorization to take prompt corrective measures to eliminate them

Crevice Corrosion—corrosion at or near a crevice formed by the contact of one metal with another

Dry Fall—a paint characteristic of fast drying such that overspray is essentially dry when it falls to the ground

Epoxy—a resin system based on use of an epoxide ring

Epoxy Polyamide—a resin system based on epoxide ring and an amide modification

Mill Scale—a heavy oxide formed on steel during hot fabrication at the steel mill

Moisture cured polyurethane—a resin system using isocynates and atmospheric moisture to initiate curing mechanism to form a polyurea

Oil—a resin system using a vegetable oil (usually)

Permissible Exposure Limit—the maximum worker exposure for a compound based on an 8-hr time-weighted average

Pigment—inorganic compounds (usually) used to impart color, or for hiding, chemical properties, or corrosion resistance

Polyurethane—a resin system using isocyanates and polyols to form a polyurethane polymer

Resin—the glue that holds coating ingredients together and adheres it to substrate

Rust Back—the rerusting of a steel surface after rust has been removed

Volatile Organic Compound—any compound of carbon—excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates—that participates in atmospheric photochemical reactions

Zinc Rich—a coating that utilizes a high zinc dust content to give electrical conductivity to allow galvanic protection

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Note: Excellent discussion of Protective Coatings, Types and Properties, can be found in *Protective Coatings*, Hare, C.H., Technology Publishing Co., Pittsburgh, Pennsylvania (1994).

ACRONYMS

AA—Atomic Absorption
AASHTO—American Association of State Highway & Transportation Officials
ACGIH—American Conference of Governmental Industrial Hygienists
AIM—Architectural & Industrial Maintenance
AL—Action level
Al—Aluminum
ASTM—American Society for Testing Materials
AVB—Abrasive Vacuum Blasting

BIRL—Basic Industrial Reference Laboratory

CAAA—Clean Air Act Amendments
CERCLA—Comprehensive Environmental Resource & Conservation Recovery Act
CFR—Code of Federal Regulation
CWA—Clean Water Act

DOT—Department of Transportation

EP-TOX—Extraction Procedure Toxicity
EPA—Environmental Protection Agency

FHWA—Federal Highway Administration

HSWA—Hazardous and Solid Waste Amendment

ISTEA—Intermodal Surface Transportation Efficiency Act
MIO—Micaeous Iron Oxide
MSDS—Material Safety Data Sheet

NAAQS—National Ambient Air Quality Standard
NACE—National Association of Corrosion Engineers
NEPCOAT—Northeastern Protective Coatings
NHI—National Highway Institute
NHS—National Highway System
NICITCP—NACE International Coating Inspector Training & Certification Program
NPDES—National Pollutant Discharge

OSHA—Occupational Safety & Health Administration

PEL—Permissible Exposure Limit
PM—Preventive Maintenance
PMMP—Painting of Miscellaneous Metals Part

QC/QA—Quality Control/Quality Assurance

RCRA—Resource Conservation Recovery Act
RQ—Reportable Quantity

SARA—Superfund Amendments and Reauthorization Act
SCEF—Structural Committee for Economical Fabrication
SEP—Special Emphasis Plan
SSPC—Society for Protective Coatings, formerly Steel Structures Painting Council
STP—Surface Transportation Program
SWD—Storm Water Discharge

TCLP—Toxic Characteristic Leaching Procedure
TLV—Threshold Limit Value
TRIS—Transportation Research Information System
TSCA—Toxic Substances Control Act
TSD—Treatment Storage & Disposal
TWA—Time Weighted Average

UHP—Ultra High Pressure
UHPWJ—Ultra High Pressure Water Jetting

VE—Value Engineering
VOC—Volatile Organic Compound

WAB—Wet Abrasive Blasting
WC—Water Cleaning
WJ—Water Jetting

PCCP—Painting Contractor Certification Program
PM 10—10 micron particulate matter

Zn—Zinc

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ADDRESS CORRECTION REQUESTED