

NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT

265

REMOVAL OF LEAD-BASED BRIDGE PAINTS

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REPORT

265

REMOVAL OF LEAD-BASED BRIDGE PAINTS

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Midwest Research Institute
Kansas City, Missouri

RESEARCH SPONSORED BY THE AMERICAN
ASSOCIATION OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS IN COOPERATION
WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

MAINTENANCE
CONSTRUCTION AND MAINTENANCE EQUIPMENT
(HIGHWAY TRANSPORTATION)
(RAIL TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C.

DECEMBER 1983

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The program is developed on the bases of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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FOREWORD

*By Staff
Transportation
Research Board*

This report addresses the environmental and physical problems of safely and effectively removing lead-based bridge paints from structural steel. Reviews of existing information and its application to bridges, recommendations for actual practice, and suggested improvements in environmental data, equipment, and overall removal operations are presented. Bridge maintenance and construction engineers, materials engineers, specification writers, equipment manufacturers and suppliers, painting contractors, and project planners, particularly those concerned with environmental issues, will find valuable information in the report. The report also is recommended as a source of environmental information and requirements useful to equipment developers in designing removal techniques that are effective as well as environmentally safe.

Individuals involved in the removal of paint, especially, lead-based paint, from the structural steel of bridges encounter a variety of troublesome issues. The potential pollution and toxicity caused by the debris from the paint and removal operation must be considered. Such considerations lead to the selection and proper use of appropriate removal and disposal techniques. However, creating and maintaining environmentally safe operating conditions, whether based on fact or as regulated, do not always coincide with the most effective removal and disposal techniques, and as a consequence pose the dilemma and need for research.

Under NCHRP Project 10-23, "Removal of Lead-Based Bridge Paints," Midwest Research Institute reviewed existing information bearing on the environmental issues and the methods for removal of lead-based paint from structural steel. Information from many sources was synthesized for the specifics of bridge application. Guidelines for recommended practice and suggested improvements in environmental data and removal and disposal techniques also resulted. Practitioners and researchers, both, will find valuable advice, information, and suggestions. Environmental pollution and toxicity aspects including potential impacts, methods for analyzing lead in environmental samples, and reviews and commentary on environmental regulations are presented. Techniques for the removal, containment, and recovery of lead-based paints and cleaning debris are described, compared, and assessed to include some suggested improvements, particularly for abrasive blasting. Although no absolute, universally applicable solutions were discovered, the report provides important background for coping with individual situations.

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REMOVAL OF LEAD-BASED BRIDGE PAINTS

SUMMARY

This report presents the results of a study that reviewed problems associated with the removal of lead-based bridge paints. The overall objectives of the project were: (1) to identify the severity of toxicity and pollution resulting from the removal of lead-based paint during bridge cleaning operations; and (2) to evaluate available techniques for removal, containment, and recovery of lead-based bridge paints and recommend improved techniques. Fulfillment of the first objective was accomplished by determining the environmental pollution and toxicity associated with the removal and disposal of lead paint; by identifying the environmental regulations that pertain to the removal of lead paint from bridges; and by describing the environmental test methods for lead paint residues. The second objective was met through technical and cost evaluations of techniques that have been used to remove, contain, and recover the debris generated during the removal of paints from bridges and other steel structures, concepts for improvements of existing techniques, and evaluation of new techniques under development.

Basic Findings

Environmental Pollution and Toxicity. The type of bridge paint removal operation that has the most impact on the environment and human health is abrasive blasting. Deposition of the greatest concentration of particulates occurs within 200 yd of the removal operation. With a light wind (4 mph), about 50 percent of the removed lead is deposited somewhere beyond 300 yd of the operation. However, this lead deposition will occur over an extremely large area because the dust plume from abrasive blasting is widely dispersed by the time it reaches a distance of 200 yd; therefore, the amount of lead deposited at any one point in this area will be very low. The lead contribution to the soil and other surfaces, nevertheless, could be considered significant in many urban environments. The inhalable fraction (particles less than 15- μ m diameter) probably makes up about 10 percent of the total emissions. Because very few of the leaded particles are less than 2.5- μ m diameter, the contribution of lead from abrasive blasting to the total atmospheric lead load appears to be small.

The two air pollution concerns created by abrasive removal operations are: (1) inhalation of lead compounds during operations, and (2) the ultimate fate of the particulates deposited in the area exposed to the abrasive plume. No evidence was found that the federal ambient air lead standard is being violated by removal operations, even though temporarily high concentrations of lead do occur in the dust plume. The fate of this material varies. Deposition of leaded particulates occurs on soil, sidewalks, streets, and in other areas where the dust can be resuspended or tracked into houses and buildings.

Most of the paint debris sinks immediately upon landing on the surface of a stream or lake. The smaller particles float for awhile and can form a scum on the water surface, which is the most objectionable aspect from a water pollution standpoint. All the particles eventually sink. There is no information as to whether there are long-term detrimental effects on aquatic ecology by the lead paint particles deposited on the bottom. The lead compounds in the particles have extremely low water solubilities, which is probably why no violations of state water quality lead standards were found during the study. However, the lead levels in urban stream sediments are already high; therefore, the addition of more lead to streams in these areas can only result in further degradation of the aquatic environment.

Lead contamination of soil by bridge paint removal operations poses the greatest threat to human health and the environment. The residence time in the soil surface profile is probably several thousand years. While in the soil surface, the leaded paint particles can be resuspended by wind and deposited at some new location; can be tracked into homes and public buildings by people and pets; can be carried away by surface runoff during rainfall; can be ingested by children playing in the soil and putting their hands in their mouths; and can provide lead for uptake by vegetation grown on the contaminated soil. High lead levels are not uncommon in urban soils, but evidence indicates that soils under and around lead-painted bridges are likely to have extremely high levels of lead in the surface profile. Children playing in these areas are in the greatest danger of exposure.

When considering lead toxicity in humans, the source of lead taken into the body is the overriding concern, not the chemical composition of the lead contaminant. Once in the body, all inorganic forms of lead are presumed to behave in the same manner. Thus, there are no safe lead-based paint compounds where human health is concerned. The difficulty in establishing levels of toxicity in children is that the minimum blood lead level at which there is an onset of recognizable symptoms has not been established. The Center for Disease Control has defined the safe childhood blood lead level as being below 30 µg/dl, but there are doubts as to whether this level can be regarded as safe in light of new evidence suggesting subtle abnormalities in mental development of small children at even lower levels. Blood levels in adults are considered elevated if they exceed 40 µg/dl.

Environmental Regulations. The only federal regulations relevant to bridge paint removal are the ambient lead standard, the total suspended particulate standards, the Occupational Safety and Health Administration (OSHA) standards for silica and inert dusts, and the Environmental Protection Agency (EPA) requirement to perform the extraction procedure (EP) toxicity test on wastes (paint removal residues). The federal drinking water standard for lead will not affect removal operations because of the low water solubility of the lead compounds in paint residues.

States have general air and water pollution regulations that could be applied to bridge paint removal operations and that can be enforced at their discretion. Some states stringently apply these standards to every operation in their state; most states apply these regulations only as the situation dictates. Some states have specific regulations they can apply to abrasive blasting, but most of these states usually apply them only to sandblasting of buildings.

Most of the cities surveyed regulate abrasive blasting operations; some require permits to perform abrasive blasting; some do not allow the use of silica sand as an abrasive. At both the state and local levels, the use of contract specifications requiring environmental controls on removal operations is the most effective way to protect human health and the environment in urban areas.

No instances were found where federal standards were being violated; however, few contractors or state transportation agencies are performing the EP toxicity test on paint debris. Reported violations of state environmental regulations by paint removal operations were not common, which does not necessarily mean these operations are not in violation of state regulations. All states have environmental regulations that, if stringently enforced, would necessitate the use of control measures on all bridge paint removal operations. States have chosen to use discretion in enforcing these regulations with respect to abrasive blasting on bridges.

Test Methods for Lead in Environmental Samples. The recommended method for sampling airborne particulates from bridge paint removal operations is with a high volume air sampler. The recommended analytical method for lead determination in different environmental samples is with flame atomic absorption spectroscopy. This method is the most cost effective and the most widely used because of the availability of the equipment. The recommended method for field analysis of lead is with portable x-ray fluorescence; however, this equipment is not widely available at this time and is very expensive.

Technical and Cost Evaluation of Existing Removal, Containment, and Recovery Techniques. A search of the literature revealed little information pertinent to removal, containment, and recovery techniques for bridge paints. Most of the information contained in this report was obtained directly from highway and transportation agencies, equipment developers and manufacturers, shipbuilders, aircraft maintenance organizations, and painting contractors.

There has been a lack of engineering effort in the development of cost-effective techniques to contain and recover the debris generated by bridge paint removal. This lack of effort is due to earlier general unconcern about providing such techniques. Equipment manufacturers did not perceive a significant need for such equipment. As a consequence, much of the present equipment has been developed by the bridge painting contractors to meet local requirements.

Effective removal, containment, and recovery of paint from bridges is a difficult task. The popular paint removal technique of open abrasive blast cleaning generates large volumes of paint, abrasive, and other debris which are widely dispersed in the air, on the ground, and in the water surrounding the bridge. The wide variety of bridge construction, the multitude of comparatively small areas, joints, and crevices, the heights of the structures, and winds contribute to the problem.

A variety of techniques have been used in attempts to contain and recover the debris generated during the removal of paints from bridges. These techniques have included ground and water covers, water screens, vacuum blasters, drapes, water curtains, wet blasters, and blast enclosures.

The most effective technique presently used for bridge paint containment and recovery is the blast enclosure. Blast enclosures used on the Tobin-Mystic River Bridge in Boston are reported to recover 80 to 85 percent of the blast debris. Other blast enclosures have been used on bridges in California and Canada. Many of the present blast enclosures have been custom designed for a specific bridge or a specific section of a bridge; however, the basic techniques are applicable to other bridges. Generally, the estimated cost for blast enclosures (with the exception of the California type described in Appendix D) is greater than that for all other existing paint containment and recovery systems.

Two techniques used to remove and recover paint and other debris from ships and other structures may be applicable to bridges. These are the centrifugal blasters and vacuum-shrouded hand tools. Centrifugal blasters are presently designed for large, flat surfaces that are not normally found on bridges. Small centrifugal blasters, expected to be applicable to bridges, are now being developed. Powered hand tools equipped with vacuum shrouds that are used in other industries but generally have not been used in bridge maintenance might be adaptable to bridge structures.

Concepts for Improvements. Ideas were conceived during the course of this study to improve the performance and reduce the costs of existing techniques for containment and recovery of bridge paint debris. These improvements include: (1) a method (side covers) to reduce the effect of crosswinds on ground and water covers, (2) a suction-equipped dam for more effective collection of floating paint debris, (3) a technique (flexible seal) for better sealing of blast enclosures, (4) a method (recycling abrasive recovery system) to minimize the costs of disposal of spent abrasives and paint debris, (5) a special floor design to reduce the time and labor required for removing debris from large enclosures, (6) a technique (trough collection system) for collecting runoff from water curtains, (7) a new water nozzle design for abrasive blasters to increase production rates and minimize airborne dust. These concepts for improved performance or reduced cost should be developed and tested. They are described in detail in Appendix D.

Evaluation of New Techniques. Several new techniques for removal and recovery of paints from surfaces are presently under development, including cavitation blasting, flash blasting, and strippable coatings. The most promising of these techniques is cavitation blasting, assuming that acceptable cleaning rates and surface characteristics are demonstrated. A cavitation blasting system with a paint debris recovery system is being developed for the Navy and is scheduled to be tested in summer 1983. Cavitation blasting systems have also been developed for FHWA, but have not included debris recovery. The advantages of strippable coatings are that the chemicals used for cleaning corroded metal surfaces are economical, nontoxic, and the material can be applied with a brush or roller. However, the present mixture is effective only for rust, not paint, and the cured material must be stripped by hand. The two types of flash blast systems (xenon lamps and CO₂ lasers) are presently in the early stages of development and tests have not been conducted on bridges for either method (although the developer claims that the CO₂ laser system will have good ability to remove paints from metal and composite substrates, will not initiate corrosion, and will provide minimum cleanup costs).

Currently, the developing systems appear to be expensive, but because tests have not been concluded, assessment of their cost-effectiveness is premature. Along with the relative cost estimates of the various systems, the system effectiveness, paint removal rate, and adaptability should be compared to determine tradeoffs associated with each technique.

Recommendations

It is recommended that both government and industry undertake further research and development aimed at providing cost-effective techniques and equipment for containment and recovery of debris from bridge paint removal, applicable to the variety of bridges in the United States. The following specific activities are recommended.

- The Canadian type blast enclosures (described in Appendix D) should be evaluated on a variety of truss bridges.
- The Boston Tobin Bridge enclosures (described in Appendix D) should be adapted to other bridges.
- Suggested improvements of ground and water covers, water screens, blast enclosures, water curtains, and wet blasting should be developed and tested.

- Further research and development should be done on cavitation blasting for bridges. Attention should be given to obtaining higher production rates, to studies of the adhesion of paints to cavitation blast cleaned surfaces, and to the development of containment and recovery systems for cavitation blasting.
- Vacuum-shrouded hand tools should be developed and tested on bridges.
- Equipment manufacturers should be encouraged to conduct in-house development of cost-effective paint containment and recovery techniques for bridges.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

During the removal of old lead-based paints from steel bridges in preparation for repainting, particulate matter consisting of the old paint plus the grit used in abrasive blasting is deposited in air, water courses, and on adjacent land. Containing and disposing of lead-based paint waste is a very difficult and costly effort, and none of the new and conventional methods investigated by the individual states and the Federal Highway Administration (FHWA) have demonstrated the capability of economically removing and recovering old lead-based paint from most bridges in the United States. Because of the variability in the type and location of bridges, it is unlikely that any one removal or containment technique will be suitable for all conditions under which old paint poses a hazard.

Although the toxicity of lead is well documented, there is little evidence whether lead compounds used in bridge paints are hazardous to the environment when they are removed. Transportation officials, however, must be aware of not only the toxicity of lead, but also the related problems of dust pollution, silica sand toxicity, and solid paint waste disposal. In the event of high levels of toxicity, the wastes may have to be disposed at hazardous waste disposal facilities, which are limited in number and costly.

RESEARCH APPROACH

The research program had two principal objectives:

1. To identify the severity of toxicity and pollution resulting from the removal of lead-based paint during bridge cleaning operations.
2. To evaluate available techniques and recommend improved techniques for removal, containment, and recovery of lead-based bridge paints.

To meet these objectives the project was divided into two parts which were conducted concurrently. One part dealt with the environmental and toxicity aspects of bridge paint removal; and the other, with techniques for bridge paint removal, containment, and recovery of debris from bridge-paint removal operations.

Environmental and Toxicity Aspects

The environmental and toxicity aspects were concerned with identification of environmental regulations, environmental pollution, and human toxicity associated with lead-based paint removal from bridges. The scope of work also included a description of analytical methods to determine lead concentrations in environmental media and an assessment of the extent of environmental regulatory violations caused by bridge paint removal operations.

The first task was to determine the relevant environmental and other regulations that apply to lead paint removal from bridges. This entailed reviewing regulations at the federal, state, and local levels and included air, water, soil, and wildlife regulations. The review of local regulations was accomplished by selecting 10 major U.S. metropolitan areas (New York; Chicago; Philadelphia; Detroit; Metropolitan Boston - Northeast Region; Washington, D.C.; Houston; St. Louis County; Cleveland; Miami). Because metropolitan areas are more likely to have jurisdiction over their air quality than over their surface water quality, the 1982 Directory of Governmental Air Pollution Control Agencies was consulted in selecting these 10 major areas. Selection was based on the size of the air quality agency within the metropolitan area because it was felt that a larger professional staff with more inspectors in the field would have more input on the subject of environmental regulations. Dallas-Fort Worth, for instance, is ninth in population, but had in the directory an air quality inspection staff of only three; whereas St. Louis, 12th in population, had an inspection staff of 14. Los Angeles was not included in the list because it is in the South Coast Air Quality Management District, one of the regions contacted when the states were surveyed.

The next task determined the severity of lead-based paint toxicity and environmental pollution that results from bridge cleaning operations. The task was broken into several subtasks: (1) review the environmental pollution and toxicity data on lead paint removal and disposal; (2) determine the extent of regulatory violations caused by bridge paint removal; (3) assess the toxicity of lead-based paint residues; (4) describe analytical

methods for determining lead in various media; and (5) identify gaps in the toxicity and pollution data.

The information needed to complete these tasks was gathered through contacts with governmental and industrial sources and through searches of environmental and medical data bases. Because data pertaining to lead paint in the environment are limited, the research team often used data from environmental lead studies to draw conclusions about the environmental pollution and toxicity potentials of lead paint removal from bridges.

Removal, Containment, and Recovery Techniques

The second part of this project was concerned with techniques for the removal, containment, and recovery of lead-based bridge paints. The scope of work included a review and evaluation of existing techniques that have been used on bridges and other steel structures, suggested improvements for existing techniques, and identification of new techniques now under development.

The first task was to review pertinent information on the various techniques that have been used to remove, contain, and recover the paint from bridges and other outdoor steel structures, such as ships and storage tanks. Information was obtained through computerized and manual literature searches and review of the pertinent documents;

through contacts with federal and state highway agencies, bridge and structural steel painting contractors, paint removal equipment manufacturers, shipbuilding and aircraft maintenance organizations, painting associations, and foreign organizations; and through field trips to selected sites.

In addition to reviewing existing techniques, information was sought on new techniques for paint removal, containment, and recovery that may be applicable to bridge painting. Most of these, however, are still under development; therefore, information was obtained directly from the developers.

The next task was to evaluate each technique from the technical and cost standpoints, within the limits of available information. The technical evaluation included assessing the effectiveness of the technique in paint removal, containment, and recovery, the effect of the technique on the paint removal rate, its adaptability to various bridge structures, and other advantages and disadvantages. The cost analysis included capital equipment, labor, fuel, utilities, and supplies.

The technical evaluation revealed various deficiencies in some of the existing techniques. Ideas for overcoming some of these deficiencies were conceived and are recommended for development.

CHAPTER TWO

FINDINGS

ENVIRONMENTAL POLLUTION, TOXICITY, REGULATIONS, AND TEST METHODS

Environmental Pollution and Toxicity

The term "lead-based paint" encompasses a very large family of lead pigments or compounds. The lead compounds most commonly used in bridge paints are red lead, basic lead silicochromate, basic lead chromate, basic lead sulfate, and basic lead carbonate. The first two compounds, red lead and basic lead silicochromate, are the most commonly used. Because chromium has the potential to cause environmental problems, it was originally thought that lead chromate compounds should also be addressed. However, the chromium in lead-based paint is so unlikely to become biologically available, and the environmental and toxicity problems of lead so outweigh those of chromium, that it was decided to limit the environmental pollution and toxicity discussions to lead.

The results of this study indicate that environmental pollution and toxicity resulting from lead-based bridge paint removal operations are primarily urban problems. This assessment is based on conversations with environmental and transportation agencies in 50 states and 10 major metropolitan areas, and on environmental and human health lead studies in the published literature. Most of the environmental and health literature does not specifically address lead-based paint as

a contamination source. Consequently, assessments for this study often were based on data from other environmental lead studies. A detailed analysis of environmental pollution and toxicity resulting from bridge paint removal is given in Appendix A.

Lead Paint Residues in Air

The primary means of introducing lead compounds to the atmosphere during paint removal operations is through abrasive blasting. The size of the paint and abrasion particles created during a dry blast operation influences the length of time the particles remain airborne. The greatest concentration of particulates is deposited within 200 yd of the removal operation. About 50 percent of the smaller particles (less than 50- μ m diameter) can be deposited at much greater distances from the work site. With a light wind (4 mph), more than 50 percent of the lead can be deposited somewhere beyond 300 yd from the operation. However, this lead deposition will occur over an extremely large area because the dust plume from dry abrasive blasting is widely dispersed by the time it reaches a distance of only 200 yd; the amount of lead deposited at any one point in this area, therefore, will be very low. Nevertheless, this lead contribution to the soil and other surfaces could be considered significant in many urban environments. Transport distance can be even greater if wind speed is significant (i.e., over

10 mph) or if blasting is being performed very high above the ground (situations not uncommon in the upper reaches of some truss structures).

Only one study was found which examined particulate emissions from a lead bridge paint removal operation (1). In this study, most of the particulates (98.4 percent) from the abrasive blasting had a diameter of 2.5 μm or larger. The inhalable fraction (those particles less than 15- μm diameter) made up about 10 percent of the particulates and contained 16 percent of the lead removed.

The mass median diameter of lead-bearing air pollutant particles in the atmosphere is typically less than 1 μm . It is estimated that abrasive blasting produces very few leaded particles less than 2.5 μm diameter, which is the respirable fraction. Thus, the contribution of lead to the total atmospheric lead load by abrasive blasting of bridge paints appears to be small.

The type of abrasive used influences the percentage of small particles created during paint removal operation. The use of silica sand as an abrasive creates a large volume of very small particles (and more dust) because the sand particles shatter and break on impact. Negative human health effects can result from inhalation of too much silica dust; therefore, other abrasives, such as Black Beauty (a crushed metal refining slag) are recommended when abrasive blasting must be performed.

The two air pollution concerns created by paint removal operations are: (1) inhalation of lead compounds during operations, and (2) the ultimate fate of the particulates deposited in the area exposed to the abrasive blasting plume. With respect to the first concern, no evidence was found that the ambient air lead standard is being violated by bridge paint removal. However, temporarily high concentrations of lead do occur in the dust plume during operations. In an urban environment where lead levels are already high, the addition of a little more lead can create adverse health effects to those living or working in the vicinity of the bridge, particularly small children. In a rural setting adverse health effects are unlikely.

The second air pollution concern is the ultimate fate of deposited lead-bearing particulates. Deposition occurring on soil, streets, sidewalks, driveways, and rooftops can have long-range consequences. Within an urban environment, the leaded dust particles are apt to be resuspended and re-deposited by complex wind currents created by buildings and street canyons, and by passing vehicular traffic. The deposited particles can be picked up on feet, hands, clothing, pets, etc., and carried inside urban households and offices. The dust can also enter directly through open windows and doors and be deposited throughout the household or building. Dust deposited in children's outdoor play areas can enter the body via inhalation of resuspended particulates and ingestion of dirt on the fingers. Dust particles that deposit on vegetation can become fixed in the waxy cuticle of the leaves and are often not removed by repeated washings.

Lead Paint Residues in Water

The fate of lead paint debris once it lands on a water surface depends on the size of the lead particle, the turbulence of the water, and the chemical form of the lead in the particle. Most

paint debris sinks immediately upon landing on water. However, the smaller particles often float for some time, creating a scum on the water surface. The distance this scum travels downstream and the length of time it remains on the water surface depend on the strength of the current and the amount of turbulence in the stream. The stronger the current, the greater the turbulence, and turbulence causes the debris to sink more quickly. In sluggish streams, the debris will be carried further downstream.

Paint debris deposited on the bottom of a body of water does not appear to pose an environmental problem. The primary reasons are: (1) the lead particles consist of insoluble compounds and thus contribute little dissolved lead to water; (2) even if all the lead in the paint debris were soluble, drinking water standards would be violated in few instances; and (3) lead paint residues do not appear to be a problem to aquatic organisms.

Most of the data pertaining to effects of lead pollution in water are based on dissolved lead and total recoverable lead. The total recoverable lead fraction includes such lead forms as the free ion and the hydroxide, carbonate, and sulfate salts. These forms are probably more toxic to aquatic life--or can be converted to more toxic forms under natural conditions--than lead associated with minerals, clays, and sands. However, the lead forms found in lead-based bridge paints are among the most water insoluble of all the lead compounds. Consequently, it is difficult to correlate the presence of these lead compounds in water to the data showing the effects of lead on aquatic biota. On the other hand, the addition of lead paint compounds to the bottom sediments of a stream or lake can in no way be construed as beneficial and, as more research is performed, may be shown to be harmful.

Biological magnification of lead in aquatic food chains is not apparent. Organisms at low trophic levels that are associated with the benthic zone (where lead is deposited) have the highest lead levels, while those at the top trophic level (fish) have the lowest.

The amount of lead that can remain in solution in water is a function of water pH and dissolved salt content. Studies show that lead content in natural water increases when the water is acidized; but no information is available on how pH affects solubility of the lead pigment compounds that are predominantly used: red lead, basic lead silicochromate, and basic lead carbonate (white lead). While a more acidic pH may affect the solubilities of these compounds, the effects on the aquatic ecosystem when the pH becomes more acidic are definitely negative. A pH change influences not only the biological balance of the lake or stream, but also the chemical balance. Therefore, it is not possible to single out any one chemical change as the primary menace to the aquatic ecosystem.

Even though lead pigment solubilities are low, addition of these compounds to already high concentrations of lead in urban stream sediments can result only in further degradation of the aquatic environment. Most lead in streams comes from runoff from land surfaces, and in urban environments the lead load in this runoff can be substantial. Consequently, control of water pollution from lead-based bridge paint removal operations should be more stringent in urban areas than it is in rural areas.

Lead Paint Residues in Soil

Soil contamination by lead-based bridge paints is the result of deposition of the lead-based paint chips and dust particles produced during removal operations. The fate of this material varies once it reaches the land surface: (1) it can remain in place in or on the soil surface profile; (2) some particulates can be resuspended by wind and transported away from the original place of deposition; (3) some particles can be carried away by surface runoff during rainfall; (4) some particles can be tracked into homes and public buildings by people and pets; and (5) some of the lead can eventually be assimilated by vegetation growing in the contaminated soil.

Information that exists on residence time of lead in soil indicates that its residence time is a few thousand years. Lead is not likely to leach once it enters the soil because it is concentrated in the organic fraction of the soil or forms insoluble complexes with anionic species in the surface horizon. Soils with high cation exchange capacities are the most efficient in immobilizing lead. No information exists on the rate of breakdown in soil of the chemically stable lead compounds used in paint. However, if lead were released to the soil ecosystem through breakdown of the compounds, it would be rapidly tied up in the surface horizon. Because lead resides in the soil for such a long time, a potentially severe lead contamination problem can occur under and around bridges on which lead based paint is used.

Resuspension of lead particulates from soil is often overlooked as a source of lead inhalation and ingestion by humans. The resuspended particles can be carried as dust into nearby structures and deposited. Lead concentrations in dust are twice as high in indoor, urban nonresidential buildings as in indoor, urban residences. Because children are closer than adults to the ground surface, they are more readily exposed to resuspended lead particles.

Lead paint particles may leave the soil surface via surface water runoff from rainfall events. Urban rainfall runoff is much higher in lead concentration than rural runoff due primarily to the higher density of vehicular traffic in urban areas, as well as to the greater impervious area available for deposition of lead-bearing dust. A thorough cleanup of the streets, sidewalks, and driveways in the immediate area surrounding a bridge paint removal operation will eliminate much of the paint debris in urban surface runoff.

As with suspended lead particles, lead paint particles in soils or on other outdoor surfaces can be tracked into homes, offices, and shopping areas where they are deposited on interior floors. Because children frequently play on the floor, the likelihood of their ingesting or inhaling lead dust particles is greater than it is for adults.

Mechanisms of plant uptake of lead are not completely understood. Most of the lead accumulated by plants remains in the roots, although some leafy vegetables seem to accumulate a substantial amount of lead in their leaves. There is no simple relationship between vegetables and the metal content of the soil in which they were grown; each vegetable species seems to have its own characteristic uptake. Of the total lead in soils, only 0.003 percent to 0.005 percent is available for plant uptake. But this is enough to create significant lead accumulation in vegetables grown on lead-contaminated soils.

Soil lead concentrations near lead-painted

bridges can be very high. Soil lead levels directly beneath the Tobin-Mystic River Bridge in Boston were found to range from 1,200 to 4,800 ppm, with an average of 2,700 ppm. The major source of this lead was shown to be the paint on the bridge which contained red lead and basic lead chromate. The average background lead concentration in soils in the United States is about 16 ppm. The very high lead levels in the soil near the Tobin Bridge are not unique to Boston; soils with over 500 ppm lead are common in other U.S. urban areas, also. Children playing where lead contamination is high are in the greatest danger of exposure. Even if lead-based paint on bridges is eliminated, lead residues in soils will still pose a threat to human health.

Lead Toxicity in Humans

When considering lead toxicity in humans, the source of the lead taken into the body is the overriding concern, not the chemical composition of the lead contaminant. Once in the body all inorganic forms of lead are presumed to behave in the same manner. Thus, no lead-based paint compounds are safe where human health is concerned.

The most important aspect of lead toxicity in humans is that children have been identified as the population most at risk to the health effects of low levels of lead. The difficulty in establishing levels of toxicity is that the minimum blood lead level at which there is an onset of recognizable symptoms has not been established. Currently, the Center for Disease Control (CDC) has defined the safe childhood blood lead level as being below 30 µg/dl. It is estimated that approximately 4 percent of children between 6 months and 5 years exceed the CDC-defined safe level (approximately 780,000 children). There are doubts whether 30 µg/dl can any longer be regarded as safe in light of new evidence suggesting subtle abnormalities at even lower levels. Blood levels in adults are considered elevated if they exceed 40 µg/dl.

The two means of absorption of lead by humans which are applicable to lead paint removal operations are ingestion and inhalation. Absorption of ingested lead is substantially greater in children than in adults (five to six times greater). The biological effects on humans are numerous and can be categorized as follows: hematological effects; neurobehavioral effects; reproductive and developmental effects; and renal effects.

Anemia is one manifestation of lead intoxication. It occurs because of decreased production of hemoglobin and destruction of red blood cells.

Among the most deleterious effects of lead poisoning are those associated with central nervous system damage. Acute effects of high lead exposure include symptoms such as irritability, stupor, convulsions, and coma. The symptoms may progress to death within 48 hr. Irreversible neural damage is one of the aftereffects of non-fatal encephalopathy episodes. Symptoms range from behavioral changes, such as hyperactivity in children, to severe mental retardation. There is some evidence that blood lead levels below 30 µg/dl may affect the mental development of small children. However, in trying to identify these subtle neuropsychological deficits, it is difficult to distinguish between the effects of lead and the influence of sociocultural factors.

The effects of lead on reproduction and development fall into two categories: (1) effects on spermatogenesis and ovarian function, and (2)

effects on postconception events through delivery. Spermatic alterations have been found in workers with moderately high blood lead levels (50 µg/dl). The ovarian cycle of women 20 to 25 years old may be disturbed if the women are exposed to air lead levels around 7 µg/m³. There is general agreement that the fetus is vulnerable to the toxic effects of lead, although levels of exposure have not been correlated to abnormalities in the baby. Abnormalities such as hyperactivity, difficulty in task performance, deficiency in IQ, and nerve conduction deficits may be a result of prenatal lead exposure, but there is no way to determine if such lead exposure actually occurred or even if the symptoms were lead-induced.

Kidney damage results only after repeated or prolonged lead exposures. Most of the evidence on the adverse effects of lead suggests that nephritis occurs in individuals with a history of lead exposure and a corresponding blood lead level of about 70 µg/dl.

Environmental Regulations

A detailed discussion of environmental regulations that have relevance to bridge paint removal operations can be found in Appendix B.

Federal Level

The only federal standards that are likely to have relevance to bridge paint removal are the ambient lead standard, the total suspended particulate standards, the Occupational Safety and Health Administration (OSHA) standards for silica and inert dusts, and the U.S. Environmental Protection Agency (EPA) requirement for a leachate test to be performed on the waste (paint removal residues). Federal water standards and criteria for lead are not likely to affect removal operations because the lead compounds in the paint are insoluble in water and the standards and criteria address dissolved lead in water (see App. A, section under "Lead Paint Residues in Water").

The relevant federal standards are as follows:

- Primary and secondary ambient air quality standard for lead
1.5 µg/m³ - calendar quarter arithmetic mean
- Primary ambient air quality standard for particulate matter
75 µg/m³ - annual geometric mean
260 µg/m³ - maximum 24-hr concentration not to be exceeded more than once per year
- Secondary ambient air quality standard for particulate matter
60 µg/m³ - annual geometric mean
150 µg/m³ - maximum 24-hr concentration not to be exceeded more than once per year
- OSHA standard for human exposure to silica* (dust contains > 1% silica)
Respirable fraction - 10 mg/m³ divided by (% SiO₂ + 2)
Total dust - 30 mg/m³ divided by (% SiO₂ + 2)
- OSHA standard for human exposure to inert or nuisance dust* (dust contains ≤ 1% silica)
Respirable fraction - 5 mg/m³
Total dust - 15 mg/m³

* These values are the 8-hr time-weighted average limit for a worker in any 8-hr shift of a 40-hr week.

- Extraction procedure (EP) toxicity test on wastes (extract waste with acetic acid solution (pH 5) to determine whether hazardous)
Maximum concentration in leachate
Lead - 5.0 mg/l
Chromium - 5.0 mg/l

The secondary air quality standard for particulate matter is in effect in some areas at the discretion of the states. (The air quality standards for particulate matter are under review by EPA and may be revised soon.)

State Level

States have general air and water pollution regulations that could be applied to bridge paint removal operations and that they can enforce at their discretion. Some states stringently apply these standards to removal operations at all times, but most apply them as the situation dictates (e.g., if a complaint is received). Most state air and water regulations that can be applied to bridge paint removal can be best described as public nuisance standards. In other words, if the removal operation is creating conditions that can be considered a public nuisance, that endanger public health, or that damage the aesthetic value of the water, then the state at its own discretion can take action against the operation. Some states have specific regulations they can apply to abrasive blasting, but most usually apply them only to sandblasting of buildings. States' ambient water quality standards are based on the federal ambient water quality criteria, but these standards are not likely to be exceeded because of the insolubility of the lead-based paint compounds used in most bridge paints.

State transportation agencies in a number of states have contract specifications that require the paint contractor to use some type of control on the paint removal operation. Table 1 shows the states that have these specifications, how they are applied, the types of controls used, and the predominant types of paint used.

Local Level

As noted in Chapter One, 10 major metropolitan areas were surveyed for their environmental regulations pertaining to bridge paint removal. Most of the cities regulate abrasive blasting operations, some require permits to perform abrasive blasting, and some do not allow the use of silica sand as an abrasive. Water pollution usually comes under the jurisdiction of the state, but cities with pollution regulations pattern them after the state regulations. The use of contract specifications requiring environmental controls on removal operations was the most effective way to protect human health and the environment in cities. These specifications were usually developed by the metropolitan transportation authorities. Table 2 summarizes these specifications, types of controls, and types of paint.

Regulatory Violations

No instances were found in which federal standards were being violated. Few contractors or state transportation agencies are performing the EP toxicity test on paint debris, which may indicate that the states do not consider the wastes to be hazardous or that the requirement for the test

Table 1. Status of bridge paint removal controls and paints used in the 50 states.

[illegible]

1. Water curtains have been used and also burlap in conjunction with a water curtain.
2. Use 2 mil plastic around scaffolding to keep dust from spreading.
3. Use fine mesh screen under bridges.
4. Have used vacuum blast equipment on railroad bridges; method is reportedly not very effective.
5. Florida has used water blasting to clean in municipal areas.
6. Rhode Island has tried water blasting but felt the method used needed changes to improve it.

Table 2. Status of bridge paint removal controls and paints used in 10 large metropolitan areas.

		METROPOLITAN AREA									
		Boston	Chicago	Cleveland	Detroit	Houston	Miami	New York	Philadelphia	St. Louis	Washington D.C.
Status of Paint Removal Controls	Specific Control Techniques Required										
	Control Required, But Techniques Not Specified	•	•	•							•
	Controls Used Only As Situation Dictates				•			•	•	•	
	Currently No Specific Policy Related to Control					•	1				
Permit or Notification Required		•	•	•							•
Type of Control Measures Used	Tarps	•	•	•	•			•	•	•	
	Water Booms								•		
	Boats and Barges				•						
	Other	2	3								4
Common Removal Methods Used	Abrasive Blasting	•	•	•	•			•	•	•	•
	Power Tool			•		•	•	•			•
	Hand Clean		•	•		•	•	•			•
	Other										
Paints Currently Used	Red Lead	•	•	•							
	Basic Lead Silicochromate	•	•		•		•	•	•		
	Zinc Rich	•		•	•		•	•			•
	Other (Iron Oxide, Aluminum, etc.)	•	•	•		•	•	•			

1. Abrasive blasting not allowed because they are in aquatic preserve area. They also have drawbridges whose mechanisms can be fouled by blast grit.
2. Total enclosure specially constructed for Tobin - Mystic River Bridge.
3. Chicago Transit Authority has used a movable enclosure that consists of a large room with tarps for walls.
4. Requirement to contain emissions has only recently been enforced; no control methods have been designated yet.

has not been incorporated into bridge painting contracts.

Only a few instances of violations of state environmental regulations by paint removal operations have required the state to intercede. This does not mean that most removal operations do not violate state regulations, however. All states have environmental regulations which, if stringently enforced, would necessitate the use of control measures on all bridge paint removal operations. States have chosen to use discretion in enforcing these regulations with respect to abrasive blasting on bridges.

Most problems with regulatory violations are found at the local level. This is usually because abrasive blasting creates nuisance conditions and is perceived to be a health hazard more often in urban environments than in rural environments.

Environmental Test Methods for Lead

A comprehensive discussion of environmental test methods for lead is included in Appendix C. For each method described in the appendix, details include: their essential features and ease of use; reliability and repeatability; costs; frequency of use; and acceptability by regulatory agencies.

Any of a number of instrumented analysis methods can be employed to measure lead in a range of environmental samples and at a range of levels, from high levels in paint chip particulates to quite low levels in natural waters. A specific sample preparation scheme is employed to permit optimum use of any one of these methods. The sample preparation method is a function of the sample type, lead concentrations anticipated, and the

instrumental analysis methods available for use. In most cases more than one instrumental analysis technique will be available. One typically matches up instrumental analysis capabilities with the environmental type and lead concentration. Then a sample preparation and instrumental analysis method is used that satisfies the technical and cost requirements of the environmental study.

The recommended method for sampling airborne particulates from bridge-paint removal operations is with a high-volume air sampler. The recommended laboratory analytical method for lead determination is flame atomic absorption spectroscopy. This method is the most cost effective and also the most widely used because of the availability of the equipment. For analysis of lead in the field, x-ray fluorescence is the recommended method because portable equipment has been developed and because the equipment can give fast, "ball-park" ranges of lead contamination. However, this equipment is very expensive, is not widely available, and can be used only when high lead contamination levels are suspected.

REMOVAL, CONTAINMENT, AND RECOVERY TECHNIQUES

Literature Search

Computerized and manual searches of the literature on bridge and steel structure painting technology and personal contacts produced 145 documents. A review of these documents indicated that most are concerned with the performance of various paints on bridges and other steel structures and the preparation of the surface prior to repainting. Only 21 documents (88 to 108) are concerned with paint removal, containment, and recovery.

The following discussion is based on this review, and on information obtained directly from highway and transportation agencies, equipment developers and manufacturers, shipbuilders, aircraft maintenance organizations, painting contractors, and field trips to selected sites (Loveland, Iowa, highway bridge paint recovery system; Boston, Massachusetts, Tobin Bridge paint removal system; St. Louis, Missouri, structural steel sandblasting; Wichita, Kansas, vacuum blast equipment; and Burlington, Ontario, bridge paint removal enclosure system).

Existing Techniques

A variety of techniques have been used in attempts to contain and recover the debris generated during the removal of paint from bridges and other steel structures. These techniques may be categorized into nine groups, namely: (1) ground and water covers, (2) water screens, (3) blast enclosures, (4) vacuum blasters, (5) drapes, (6) water curtains, (7) wet blasters, (8) centrifugal blasters, and (9) vacuum-shrouded hand tools. Detailed descriptions of these groups and variations within groups are given in Appendix D. Following are brief descriptions of each group.

Ground and Water Covers

This technique consists of sheets of canvas, plastic, or other appropriate materials that are spread on the ground or suspended below the bridge and are capable of catching and holding the waste material. The waste is manually collected from the covers and disposed. The equipment is inexpensive, easily installed on the ground, and does not affect the normal production rate of

sandblasting. However, the technique is not very effective when the wind blows, it is somewhat difficult to suspend the covers from the bridge, and collection of the waste is labor intensive.

Water Screens

Water screens are used to collect paint debris that falls into the water under the bridge and floats on the surface. Floating straw-faced dams, anchored to the banks, are placed either downstream or on both sides of the bridge to screen out the floating paint debris. The technique is limited to small, slow-flowing streams, is difficult to maintain, and does not protect the air or ground from debris. Therefore, even though the cost is relatively low, this technique is not particularly cost effective.

Blast Enclosures

Blast enclosures are designed to completely enclose one or more abrasive blast operators and thereby confine the blast debris. The enclosure floor is equipped with funnels to divert the captured debris into trucks parked below the bridge. In one design, a suction system is used to remove the airborne dust from the enclosure and the particles are removed from the air with a wet scrubber. The enclosures are moved as the work area progresses. Blast enclosures are very effective in containing and recovering abrasive blast debris. However, they are presently custom designed for a particular bridge or a specific area of a particular bridge. They are relatively expensive, except for the California type (see App. D), and tend to slow down the overall cleaning rate because of the time required to move the enclosure as the work progresses.

Vacuum Blasters

Vacuum blasters are designed to remove paint and other surface coatings by abrasive blasting and simultaneously to collect and recover the spent abrasive and paint debris with a suction system surrounding the blast nozzle. The abrasive is automatically reclaimed and reused. The blasters are made in a variety of sizes, but only the smaller hand-held units are presently applicable to bridges. Even the smaller units are comparatively heavy and awkward to use on bridges, however. Furthermore, the production rates of the small units are low, and costs are relatively high.

Drapes

Drapes on both sides of a truss-type bridge have been used to divert abrasive blast debris downward into a barge or lined net under the bridge. The top of the drapes are tied to the top of the bridge structure. To reduce the wind effect the drapes are porous. The technique is relatively inexpensive but not very effective because dust penetrates the porous drape and spillage occurs due to wind effects.

Water Curtains

A water line with a series of nozzles is laid along the edges of the bridge. The water spray from the nozzles is directed downward creating a water curtain so that debris from abrasive blasting below the water line is washed down to the

ground. This technique is relatively inexpensive, but presently it is useful only to reduce the amount of airborne debris. Its disadvantage is that the debris-laden water spills onto the ground or into the water under the bridge.

Wet Blasting

Wet blasting techniques include wet abrasive blasting, high-pressure water blasting, high-pressure water and abrasive blasting, and air and water abrasive blasting. Wet abrasive blasting is accomplished by adding water to conventional abrasive blasting nozzles. High-pressure water blasting systems include an engine-driven high-pressure pump, high-pressure hose, and a gun equipped with a spray nozzle. Abrasives are introduced to the system to produce high-pressure abrasive blasting. A versatile wet blasting system is called air and water abrasive blasting, wherein each of the three materials can be varied over a wide range. All wet blasting techniques feature dust-free removal of paint, rust, and dirt from structural steel, so that airborne debris is minimal, as compared to dry blasting. The debris is carried away with the water.

Centrifugal Blasters

Centrifugal blasters use high-speed rotating blades to propel the abrasive against the surface to be cleaned. These blasters also retrieve and recycle the abrasive. The blast heads have suction covers so that little abrasive or paint debris escapes. Present centrifugal blasters are designed primarily for large, flat, horizontal surfaces such as ship decks. Some have been designed for use on large vertical surfaces such as ship hulls and storage tanks. Some effort is presently being made to develop small hand-held units for possible use on bridges and similar structures.

Vacuum-Shrouded Hand Tools

Numerous powered hand tools are available with vacuum shrouds. Such tools are used in various industries to minimize dust and debris generated by the tool. Although powered hand tools are used for bridge paint removal, they generally are not equipped with vacuum shrouds.

Improvement for Existing Techniques

A number of ideas were conceived in the course of this study to improve the performance and reduce the costs of existing techniques for containment and recovery of bridge paint debris. These concepts include: (1) a method to reduce crosswinds on ground and water covers, (2) a suction-equipped dam for more effective collection of floating paint debris, (3) a technique for better sealing of blast enclosures, (4) a method to minimize the costs of disposal of spent abrasives and paint debris, (5) a special floor design to reduce the time and labor of removing debris from large enclosures, (6) a technique for collecting runoff from water curtains, and (7) a new water nozzle design for abrasive blasters to increase production rates and minimize airborne dust. Detailed descriptions of these concepts are given in Appendix D. Brief descriptions follow.

Ground and Water Covers

To reduce the detrimental effect of crosswinds on ground and water covers, side covers are added (Fig. D-35 in App. D). The side curtains are hung on each side of the bridge and extend from the bridge deck to the ground. The bottoms are anchored to the ground. In those cases where the ground and water covers are suspended from the bridge structure, the side curtains are anchored to the covers. The curtain is made from porous material to minimize the wind force.

Water Screen

To reduce the difficulty of gathering the floating debris, it is suggested that a floating suction system be used (Fig. D-36). Such systems are used to recover oil spills on bodies of water. This technique is useful for both stationary and flowing water. For flowing water, only one dam (downstream) is required. For stationary water, two suction dams are required, one on each side of the bridge.

Blast Enclosures

Some leakage of abrasive and paint debris at the joints between the blast enclosure and the bridge structure currently occurs in the Tobin Bridge, paint-debris containment and recovery system. Although an attempt is being made to seal the joints with canvas, this is not very effective, particularly when the blast is directed into these areas. A suggested method (Fig. D-37) to minimize leakage from the joints is to fasten a flexible seal made from rubber, plastic, or thin metal to the inside edges of the enclosure walls. The end of the flexible seal rests on the bridge structure. This technique is similar to that commonly used for prevention of air leakage under house doors, for prevention of lubricant leakage around automobile axles, and for other similar applications.

In the Tobin Bridge system in Boston, considerable effort is devoted to the disposal of the collected spent abrasive. To minimize this effort, it is suggested that the spent abrasive collected from the bottom of the enclosure be recycled after being treated in the same type of system that is used with vacuum blast machines (Fig. D-38). Finer material is pulled off to a dust collector, which in this case would be the wet scrubber. Heavier material falls onto a vibrating screen that traps larger debris for later removal. Good abrasive falls through the screen to the hopper and the pressure vessel for reuse. The pressure vessel is automatically refilled from the hopper whenever the blast nozzle is shut off. An abrasive with a low tendency to breakdown after impact would have to be used. Such abrasives include cast steel shot and grit, malleable iron shot and grit, chilled cast iron shot and grit, zircon, novaculite, copper slag, silicon carbide, and aluminum oxide (96).

One of the problems associated with the large blast enclosure used in Canada is the labor required to manually shovel the debris from the large floor area into the exit holes. A technique to overcome this problem centers on a special floor design (Fig. D-39). The floor is made up of a group of individual funnel-like units bolted

together to make up the total area from which debris is to be collected. The tops of the funnels are covered with perforated metal panels for walking. The funnel exits are equipped with flexible hoses leading to the debris container. (The same basic design could be used for open sand blasting and open wet blasting to collect some, if not all, of the debris and water runoff, by suspending the unit under the work area.)

Water Curtain

A significant improvement for collecting runoff (water and entrapped abrasive) from water curtains stems from a collection system concept (Fig. D-40) which entails the placement of troughs under the spray pattern to catch the water and sand mixture and divert it to an appropriate container, such as a tank truck for disposal. For low bridges the troughs can be placed on the ground. For high bridges, the troughs will be supported from the bridge structure. To minimize wind effects, porous cloth drapes can be used, extending from the blast area down to the troughs.

Wet Blasting

Present wet abrasive blasters mix the water with the abrasive prior to impact on the surface. This interaction may be one of the reasons the rate of surface cleaning is lower with present wet abrasive blasting than it is with dry abrasive blasting. A device, designed to minimize premixing of the water with the sandblast (Fig. D-41), is suggested which fits over the end of conventional abrasive blast nozzles. The two principal parts of the device are a swirl chamber and an exit nozzle. The swirl chamber is equipped with a tangential inlet to which the water line is connected. The incoming water swirls around the inside of the chamber and then out the exit nozzle. Centrifugal force causes the water to cling to the surface of the exit nozzle and produces a hollow cone of water. The angle of the water cone is controlled principally by the shape of the exit nozzle and centrifugal forces. The device is attached to the exit end of the abrasive blast nozzle with screws. The water hose is attached to the abrasive/air hose with tape or clamps. The switch used to open and close the abrasive/air line also actuates the water line so that both operate simultaneously.

This device is expected to be an improvement over existing wet abrasive blast devices. Existing devices introduce the water directly into the abrasive air stream, which may adversely affect the performance of the abrasive/air blast. The new water nozzle design provides a curtain of water around the abrasive/air stream; thus, the cleaning effectiveness of the abrasive/air stream should not be affected. The device is simple to install on and operate with conventional abrasive blast equipment.

New Techniques

Several new techniques for the removal and containment of paints and other coatings from structural steel surfaces are presently under development. These techniques include (1) cavitation blasting, (2) flash blasting, (3) strippable coatings, and (4) some proprietary techniques. Detailed descriptions of the nonproprietary techniques are given in Appendix D. Brief descriptions follow.

Cavitation Blasting

This is a new form of high-pressure water blasting in which bubbles are caused to form in the water jet. On impact with the surface the bubbles collapse, creating high local pressure reversals that cause erosion of the surface. This is known as cavitation erosion. A well-known example of uncontrolled cavitation erosion is the wear phenomenon experienced by ship propellers. Equipment is being developed to provide controlled cavitating jets for cleaning steel surfaces. Preliminary tests of cavitation blasters have been conducted on structural steel. A cavitation blaster with a containment and recovery system is presently under development for the Navy.

Flash Blasting

A new technique for cleaning painted surfaces is being developed based on the use of very intensive light pulses which vaporize the paint. Two types of light sources are being developed, xenon lamps and CO₂ lasers.

Strippable Coatings

A strippable coating for cleaning corroded metal surfaces has been developed and patented by the Navy. A chemical paste is brushed on the surface and allowed to dry. The hardened film, which contains the corrosion products, is then peeled from the surface like a strip of tape and disposed. The present formulation is effective only for rust, not paint. Several organizations are currently in the process of developing strippable coatings for removing paints from structural steel surfaces.

Proprietary Techniques

Several companies have advised us that they are in the process of developing new and improved techniques for removing bridge paints. However, because of the proprietary nature of these activities no information is available.

Evaluation of Techniques

Technical

Table 3 summarizes the technical evaluation of each of the removal, containment, and recovery systems included in this study. The characteristics covered are: (1) the effectiveness of the system in keeping the paint debris from getting into the air, on the ground, and into the water under the bridge; (2) the effect of the system on the paint removal rate; (3) the adaptability of the system to various bridge structures; and (4) the cost of each system. Insufficient quantitative data exist to evaluate in detail the technical effectiveness of each of the system characteristics; therefore, assignment of ratings (poor, fair, good, and superior) was accomplished subjectively. As can be seen from Table 3, the most effective existing system for removal, containment, and recovery of bridge paints is the Canadian blast enclosure. With improvements, the Boston blast enclosure system would be equally effective. Among the new systems, cavitation blasting is expected to provide the most effective removal, containment, and recovery. The systems that allow or provide the highest paint removal rates are open abrasive blasting, the Canadian blast enclosure,

Table 3. Technical evaluation of containment/recovery techniques.

○ = Poor ◐ = Fair ◑ = Good ● = Superior ⊙ = Unknown

SYSTEM	EFFECTIVENESS			Paint Removal Rate	Adaptability	Cost*
	Air	Ground	Water			
1. Ground/Water Covers	○	◐	◐	◑	◑	◑
2. Ground/Water Covers with Improvements	◐	◑	◑	◑	◑	◑
3. Water Screens	○	○	◐	●	◐	◑
4. Water Screens with Improvements	○	○	◑	●	◐	◑
5. Blast Enclosures						
a. California System	◐	◐	◐	◑	◑	●
b. Boston System	◑	◑	◑	◑	◐	◐
c. Boston System with Improvements	●	●	●	◑	◐	◐
d. Canadian System	●	●	●	●	◑	◑
e. Louisiana System	◐	◐	◐	◑	◑	●
6. Vacuum Blasters	◑	◑	◑	○	◑	◑
7. Drapes	◐	◐	◐	●	◑	◑
8. Water Curtains	◐	○	○	◑	◑	●
9. Water Curtains with Improvements	◐	◐	◐	●	◑	◑
10. Wet Blasters						
a. Wet Sandblasters	◐	○	○	◑	●	●
b. Wet Sandblasters with Improvements	◐	○	○	●	●	●
c. High Pressure Water	●	○	○	○	●	◑
d. High Pressure Water/Abrasive	◑	○	○	◑	●	●
e. Air/Water/Sand	◑	○	○	◑	●	◑
11. Centrifugal Blasters	◑	◑	◑	◑	⊙	^a
12. Vacuum-Shrouded Hand Tools	◑	◑	◑	◐	●	◑
13. Cavitation Blasting (w. recovery)	●	●	●	◐	◑	◐ ^b
14. Flash Blasting	◐	◐	◐	○	○	◐ ^b
15. Strippable Coatings	●	◑	◑	⊙	●	◐ ^b
16. Open Dry Abrasive Blasting	○	○	○	●	●	●

*From Tables 4 through 7.

^a No cost information for preparation of steel surfaces; but cost of preparation of other surfaces is low.

^b Systems have not been thoroughly tested on steel bridges; therefore, cost rating is from other steel surfaces

Table 4. Summary of cost estimates for existing systems.

Technique	Containment/Recovery (\$/ft ²)			Containment/Recovery and Paint Removal (\$/ft ²)		
	Low	Average	High	Low	Average	High
Ground/Water Covers	0.14	0.17	0.20	0.37	0.43	0.49
Water Screens	0.21	0.26	0.31	0.42	0.52	0.62
Blast Enclosures (Boston)	0.53	0.76	0.99	0.71	1.02	1.33
Blast Enclosures (California)	0.08	0.10	0.12	0.29	0.36	0.43
Blast Enclosures (Canada)	0.24	0.32	0.40	0.44	0.58	0.73
Vacuum Blasters				0.50	0.67	0.84
Water Curtains	0.10	0.13	0.16	0.31	0.39	0.47
Wet Blasters-Wet Sand				0.32	0.46	0.60
Wet Blasters-Water				0.55	0.78	1.01
Wet Blasters-Water/Air/Sand				0.41	0.69	0.99
Drapes-Barge	0.33	0.44	0.55	0.52	0.70	0.88
Drapes-Net	0.22	0.30	0.38	0.42	0.56	0.70

Source: Midwest Research Institute.

Table 5. Summary of cost estimates for existing systems not currently used on bridges.

Technique	Containment/Recovery and Paint Removal (\$/ft ²)		
	Low	Average	High
Vacuum-Shrouded Hand Tools	0.39	0.60	0.81
Centrifugal Blasters		> 0.10 ^a	

Source: Midwest Research Institute.

^a Estimates for road bed preparation not directly comparable to others.

Table 6. Summary of cost estimates for new systems.

Technique	Containment/Recovery and Paint Removal (\$/ft ²)		
	Low	Average	High
Cavitation Blasting	0.97	1.62	2.27
Flash Blasting	0.60	1.00	1.40
Strippable Coatings	2.40	4.00 ^a	5.60

Source: Midwest Research Institute.

^a Cost estimate for airplane preparation.

Table 7. Summary of cost estimates for suggested improvements to existing systems.

Technique	Containment/ Recovery (\$/ft ²)			Containment/Recovery and Paint Removal (\$/ft ²)		
	Low	Average	High	Low	Average	High
Ground/Water Covers w/Side Drapes	0.20	0.27	0.34	0.46	0.53	0.60
Water Screens w/Vacuum System	0.16	0.27	0.38	0.42	0.53	0.64
Blast Enclosures w/Seal (Boston)	0.46	0.77	1.08	0.72	1.03	1.34
Grit Recycling (Boston)				0.80	1.22	1.65
Waffle/Grating (Canada)	0.23	0.38	0.53	0.49	0.64	0.79
Louisiana	0.14	0.23	0.32	0.38	0.47	0.56
Water Curtains w/Catch	0.11	0.17	0.23	0.37	0.43	0.49
Catch/Recycling	0.30	0.46	0.62	0.56	0.72	0.88
Water Curtain Nozzle ^a					0.46	

Source: Midwest Research Institute.

^a Would add no additional costs to the existing wet sand system.

drapes, water screens, water curtains with suggested improvements, and wet abrasive blasters with suggested improvements. The existing systems that are most adaptable to various bridge structures are vacuum blasters, wet blasters, and vacuum-shrouded tools. Two of the new systems, cavitation blasting and strippable coatings, are expected to be adaptable to a large variety of bridge structures. The cost ratings are based on the "average" cost figure in Tables 4 through 7. A "superior" rating refers to a cost less than \$0.50/sq ft; "good," a cost of \$0.51 to \$0.80/sq ft; and "fair," a cost greater than \$0.80/sq ft. The rating of "poor" was not used. The cost ratings are also subjective and are based on comparison of relative costs among the techniques.

Costs

Table 4 gives the cost estimates for existing systems. Where segregation is possible the cost for the containment and recovery aspects is shown. The relative costs range from \$0.36/ft² to

\$1.06/ft². Table 5 gives the cost estimates for existing systems not presently used for bridges.

The cost estimates for new developmental paint containment systems are given in Table 6. All include paint removal as an inherent part of the system and all give some degree of protection to the total environment (e.g., protect the air, ground, and water).

Table 7 summarizes the cost estimates for improvements to existing paint containment and recovery systems. In most cases the improvements increase the type of protection afforded by the techniques, and in all cases they result in increased cost per square foot ranging from \$0.43/ft² to \$1.22/ft².

The cost estimates given in Tables 4, 5, 6, and 7 are designed to be comparative in nature and are not intended to represent the total costs to contractors. Standard assumptions regarding depreciation as well as the costs of labor, fuel, utilities, and supplies have been used. Costs for maintenance, final refuse disposal, overhead and profit margin have not been included. Details on the cost analysis are covered in Appendix E.

CHAPTER THREE

INTERPRETATION, APPRAISAL, AND APPLICATION

ENVIRONMENTAL POLLUTION AND TOXICITY

Although removal of lead-based bridge paints

has been performed in almost every state at one time or another, environmental and health concerns are greatest when operations are performed in or

near developed areas. If two similar bridge paint removal operations are compared, one in an urban setting and one in a rural setting, the extent of lead contamination of the environment is about the same. However, the urban setting would probably already have higher lead levels in its air, water, and soil; therefore, people could be approaching the threshold limit value for lead. Also, a greater risk of exposure to lead (and the other pollutants) associated with the removal operation would exist because of the proximity to people in the urban setting. Thus, the potential for environmental and health problems from these operations is greater in urban settings.

The bridge paint removal operations that present the greatest number of environmental problems are those that use abrasive blasting. Environmental pollution from this method of removal can be categorized as air pollution, water pollution, or soil contamination. Of the three, soil contamination probably poses the greatest threat to the environment and human health because of the long residence time for lead in soils maybe as long as several thousand years.

The dust from uncontrolled removal operations on lead-painted bridges contains large amounts of lead, and this dust will eventually be deposited on a nearby surface. Cleanup operations usually concentrate on the paint debris deposited on impervious surfaces such as sidewalks and roads. The dust on the soil surface, however, becomes part of the soil profile, and the lead concentration of the soil surface profile continues to increase with each new deposition, no matter what the lead source.

The lead on dust particles can be ingested by children playing in the soil; can be tracked into homes and buildings; and can be assimilated by plants growing in the contaminated soil. The dust particles can be resuspended and blown into homes and offices or inhaled by people in the area.

Air pollution created during bridge paint removal by abrasive blasting is a problem only in the immediate vicinity of the operation. Because the greatest concentration of particles will probably be deposited within 200 yd of the blasting operation, people living and working within this area (especially children) are the population at risk to the effects of absorption of lead-bearing particulate matter. Once the dust plume reaches 200 yd it will have become so dispersed that it probably will not be visible. However, because 50 percent of lead is likely to be transported beyond 200 yd, removal of lead paint from bridges via abrasive blasting could be considered a significant lead pollution source in many urban areas where soil and air lead concentrations are a problem. It might be possible to reduce the 10 percent of total particulates that are inhalable by using different types of abrasives, but deposition of lead on soil and other surfaces still would remain a problem.

It is difficult to determine how much of a threat inhalable lead particulates from an abrasive removal operation pose to human health. Granted, it is not nearly so great a threat as lead in soil. However, exposure to an additional lead source, no matter how minor, could be enough to initiate lead toxicity symptoms in a child already at its maximum permissible daily intake.

Deposition of lead paint residues in water produces one major result: the residues sink. Most particles sink immediately; some remain on the surface for awhile, but they eventually sink; some

reach the shore or bank and are deposited, only to be washed away when the water elevation changes with the next storm. The water solubility of the lead compounds in these residues is extremely low, and currently there is no indication that these residues are detrimental to fish and other aquatic life. Even if these compounds were soluble, the lead contribution to the water would probably not be enough to exceed state water lead standards, unless of course these compounds were deposited in urban streams where lead concentrations may already be approaching state standards.

The toxicity of lead has been well established. The problem is in determining what can be considered safe blood lead levels in children and adults. New data are being generated which show that subtle, negative health effects may occur below the CDC-recommended blood lead levels of 30 µg/dl for children and 40 µg/dl for adults. The main concern from the standpoint of children's exposure is the elimination of lead in their home surroundings, beginning with the contaminated outdoor play areas. Other potentially threatening areas are urban vegetable gardens, dust in the home, and of course lead-based paint on interior walls.

ENVIRONMENTAL REGULATIONS

Adequate regulations are now promulgated at the federal, state, and local levels to give environmental officials the necessary power to regulate bridge paint removal operations. However, much improvement is needed in the area of communication between environmental and transportation agencies. This study showed that there is a good deal of confusion in many transportation agencies as to what environmental restrictions apply to paint removal operations. Environmental agencies also had problems in getting paint contractors to abide by environmental regulations when the transportation agency had not stipulated in the contract with the paint contractor that any specific environmental controls be placed on the removal operations. When communication was found to be good between the environmental and transportation agencies, both sides showed that they understood each other's problems, and both worked to ensure that the contractor made best efforts to utilize good environmental controls on the paint removal operation.

PAINT REMOVAL, CONTAINMENT, AND RECOVERY TECHNIQUES

As stated in Chapter Two, a search of the literature related to bridge maintenance revealed only a small number of documents concerned with containment and recovery of paints from bridges. This is indicative of the general lack of past activity on the subject. Manufacturers of paint removal equipment indicated that they had not developed more equipment for containment and recovery of paints from bridges because they had not previously perceived a significant need or market for such equipment--although this situation now seems to be changing. Because of the lack of commercial equipment in this field, many of the existing techniques have been developed by bridge painting contractors, who generally do not publish technical papers on their activities.

In spite of the general lack of literature (or perhaps because of it), a wide variety of techniques have been used in attempts to contain and

recover the debris generated during removal of paint from bridges and other steel structures. Some are designed to minimize only airborne dust, while others are designed to keep the debris from falling on the ground or in the water under the bridge. A few are designed to minimize pollution of all three environments--air, ground, and water. Many of the systems have been custom-designed for a specific bridge or a portion of the bridge. As a consequence, there is presently a lack of commercially available techniques that can be used to contain and recover paint debris effectively from various types and sections of bridges.

The most technically advanced equipment for paint removal, containment, and recovery has been developed for use on large, flat surfaces such as ship decks, ship hulls, and storage tanks. This equipment includes centrifugal blasters, vacuum blasters, and other vacuum-shrouded tools. Unfortunately, such equipment is not directly applicable to bridges because bridges generally do not have large, flat surfaces.

Effective confinement and recovery of paint debris from bridges is a difficult task. There are numerous types and sizes of bridges, ranging from small, simple structures to large complex structures. Among the various types of steel construction used on bridges are longitudinal girders and supports under the deck (roadway), truss construction under the deck, trusses over the deck, and cable-supported bridges. Perhaps the most difficult construction from the standpoint of paint removal containment and recovery is the truss. Trusses are open lattice structures made up of numerous, comparatively small members that are either bolted, riveted, or welded together. This type of construction provides a challenge to the contractor who must remove the paint from each member of the truss with minimum pollution of the environment. Even nontruss bridge construction consists of relatively small surface areas, and many corners, overlays, and crevices that make containment and recovery of the paint debris difficult.

The paint containment and recovery techniques that are most applicable to a variety of bridge construction, including trusses, are blast enclosures, ground and water covers, vacuum blasters, drapes, and water curtains. For truss construction, the most effective technique is the large blast enclosures, such as used in Canada. This technique completely encloses large sections of the truss structure, capturing most, if not all, of the paint removal debris within the enclosure. Furthermore, many workers can operate simultaneously within the enclosure. The use of a special floor to automatically remove the debris from the enclosure, such as suggested in Appendix D, and the addition of a suction system to remove the airborne dust within the enclosure would be desirable improvements to the large blast enclosure.

The procedure of custom designing and fabrication of containment and recovery systems for various bridges and bridge sections is an expensive and time-consuming job. In general, there needs to be a concerted effort to minimize hand-crafted,

custom designs and to provide more universal commercial designs. This will require that the responsibility for the design, development, and fabrication of containment and recovery equipment be moved from the painting contractor to equipment manufacturers. Of course, the painting contractors should be consulted to assure that true field conditions are taken into account during the design and development of equipment.

Although it is desirable to avoid contamination of air, land, and water during bridge paint removal, minimization of contamination in just one of these areas has some benefit. For example, present wet blasting techniques minimize only airborne contamination. However, reduction of blast dust is desirable not only for environmental protection, but it also makes for better working conditions, avoiding the need for air hoods and providing better visibility.

As with other aspects of bridge painting, careful on-site inspections by the responsible enforcement agency of the paint containment and recovery system and operational techniques are imperative to assure maximum effectiveness. Unless there is close inspection, the tendency is to sacrifice environmental protection in favor of higher production.

Although they are beyond the scope of this study, techniques other than containment and recovery are being used to minimize potential pollution of the environment by lead-based and other toxic paints. One technique, being used in California on toll bridges, is to apply extra thick paint coatings to maximize the protective time, and to spot repaint, as necessary, to avoid major paint removal activities. Another obvious technique, now commonly used, is to apply nontoxic paint.

Generally, the estimated cost for blast enclosures (with the exception of the California type) is greater than the cost for all other existing paint containment and recovery systems or improved systems. Such systems as water curtains, ground and water covers, and drapes are lower in cost, while wet blasters are estimated to have moderate costs relative to other systems. Currently, the developing systems appear to be expensive, but performance tests are not yet complete to determine their cost effectiveness.

The estimated costs for containment and recovery systems are dominated by labor, capital costs, and fuel costs. In cases where baghouses and wet scrubbers are used, the cost of supplies are significant. The most important factor in the estimated cost per square foot of surface is the production rate (ft^2/hr).

It is important when reviewing these data to be aware of the type of protection afforded by each technique, the degree of protection, and the paint removal rate and adaptability. Tradeoffs are involved in selecting the technique to be used. For example, the estimated cost of a system might be selectively low, such as water screens, but the effectiveness is also low compared to other more expensive systems (e.g., blast enclosures).

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

1. Abrasive blast removal of lead-based bridge paint has a much greater impact on the environment and on human health when this operation is performed in urban environments than in rural environments. Consequently, environmental controls on abrasive removal should be more stringent when these operations are performed in or near population centers than in rural settings.

2. Contamination of soil by leaded debris is an often overlooked problem. Cleanup operations of paint debris should include surfaces other than sidewalks, streets, and streams.

3. Abrasives that produce the minimum of dust particles in the inhalable size range should be used when blasting in urban environments. This means that most dry silica sands would be unacceptable for bridge paint removal in urban areas.

4. Better communication is needed between state and local transportation agencies and environmental and public health agencies regarding bridge-paint removal operations. Existing environmental regulations are adequate to require the use of environmental controls on any bridge-paint removal operation, if necessary; the problem is knowing the capabilities of these controls to contain emissions from the removal operation. Requiring use of controls does not necessarily result in compliance with environmental regulations, and on-site transportation inspectors cannot be expected to make compliance or noncompliance decisions.

5. Paint removal debris is not routinely being checked to determine if it is hazardous under EPA's extraction procedure (EP) toxicity test. Current disposal practices, however, do not appear to be posing any problems to the environment or to human health.

6. The Canadian and Boston types of blast enclosures are very effective in containing abrasive blast emissions and would be adequate to meet any stringent urban emission control requirements.

7. Environmental controls specified in some paint contracts do not produce the desired containment results because they are inflexible and do not permit the contractor to use originality in complying with environmental regulations. Contract specifications that require the contractors to control all emissions, but leave the method up to them, seem to produce the best containment results.

SUGGESTED RESEARCH

Given the preceding conclusions, among the important items requiring additional consideration in areas that have environmental and health impacts are the following:

1. The best abrasives to use for paint removal, which also produce the minimum amount of inhalable leaded dust particles, need to be determined.

2. The long-term ecological consequences of introducing lead paint residues to water, particularly soft waters, need to be addressed.

3. Lead contamination of soils around lead-painted bridges needs to be studied further to determine the extent and seriousness of the problem.

4. Further work needs to be done in determining the amount of lead contributed to the body burden by any one lead source. Further work is also needed on the correlation between soil lead concentration and blood lead levels in children.

5. A data base needs to be generated that contains the results of EP toxicity tests on different lead-based paint residues. Most lead bridge paints will pass the test, but some are likely to fail. For those that fail, a review is needed of whether these wastes really must be disposed at a hazardous waste disposal facility, or whether conventional disposal is adequate.

The results of this project also suggest additional research in a number of areas of lead bridge-paint containment and recovery. These areas include the following:

1. Ideas were conceived during the course of this research to improve the performance and reduce the costs of existing techniques for containment and recovery of bridge paint debris. The improvements include: (1) side drapes to reduce the effect of crosswinds on ground and water covers, (2) a suction-equipped dam for more effective collection of floating paint debris, (3) flexible seals for better sealing of blast enclosures, (4) a recycling abrasive recovery system to minimize the costs of disposal of spent abrasives and paint debris, (5) a special floor design to reduce the time and labor required for removing debris from large enclosures, (6) a trough collection system for collecting runoff from water curtains, (7) a new water nozzle design for abrasive blasters, to increase production rates and minimize airborne dust. These concepts for improved performance or reduced cost should be developed and tested.

2. Additional engineering development and field evaluation of blast enclosures should be carried out. In particular, the Canadian type blast enclosure should be evaluated on a variety of truss bridges, and the Boston type blast enclosures should be adapted for a variety of handrail and walkway designs and for other parts of bridges.

3. The development of cavitation blasting for bridges should be continued with emphasis on (1) obtaining production rates comparable with sand-blasting, (2) evaluation of the performance of paints on surfaces cleaned by cavitation blasting, and (3) effective containment and recovery techniques.

4. Powered hand tools equipped with vacuum shrouds should be tested on bridges.

5. The need for cost-effective containment and recovery techniques for bridge paint removal should be publicized to encourage in-house development by equipment manufacturers.

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APPENDIX A

ENVIRONMENTAL POLLUTION AND TOXICITY

Appendix A discusses the environmental pollution and toxicity aspects of removal of lead-based bridge paints. Environmental pollution is reviewed in three sections: lead paint residues in air; lead paint residues in water; and lead paint residues in soil. The discussion of toxicity is restricted to the toxicity of lead in humans; lead toxicity in animals and vegetation is discussed briefly in the environmental sections. The three environmental sections and the toxicity section are each presented in two parts entitled, "Description of the Problem" and "Extent of the Problem."

The term "lead-based paint" encompasses a very large family of lead pigments or compounds. The

lead compounds most commonly used in bridge paints are red lead, basic lead silicochromate, basic lead chromate, basic lead sulfate, and basic lead carbonate. The first two compounds, red lead and basic lead silicochromate, are the most commonly used. Because chromium has the potential to cause environmental problems, it was originally thought that lead chromate compounds should also be addressed. However, the chromium in leaded paint is so unlikely to become biologically available and the environmental and toxicity problems of lead so outweigh those of chromium, it was decided that the environmental pollution and toxicity discussions would be limited to lead. Some of the environmental regulations

that pertain to chromium are discussed in Appendix B.

LEAD PAINT RESIDUES IN AIR

Description of the Problem

The primary means of introducing lead compounds to the atmosphere during paint removal operations is through abrasive blasting. The lead emitted to the atmosphere from these operations is in the inorganic particulate form. The particles are subject to gravitational settling, transport by wind, and dispersion by atmospheric turbulence (1, p. 48).

The size of the paint and abrasive particles created during blasting operations influences the length of time the particles remain airborne. Most of the particles fall within a few yards of the removal operation. However, many particles are small enough to be carried aloft and deposited at much greater distances from the work area. The horizontal distance that particles will be transported by the wind before reaching the earth's surface can be estimated from the release height, average wind speed, and particle terminal velocity. The terminal velocity of spherical particles is calculated from particle density and diameter.

The study by Bareford and Record (1, p. 50) presents the relationship between particle diameter and horizontal transport distance for three different wind speeds and release heights. Figure A-1 shows that relationship. The figure shows

The role played by atmospheric turbulence and wind speed on the behavior of particles introduced into the atmosphere is illustrated by Figure A-2 (2, p. 133). The area labeled "suspension" describes those particles which have the potential for long-range transport. The area labeled "unimpeded settling" represents particles with terminal velocities high enough to overcome the effects of turbulence. Particles in the "impeded settling" area are significantly affected by atmospheric motions during settling. It is clear then why abrasive blasting operations are required to cease work when wind speeds become "significant," a judgment which is made by the on-site engineer or inspector.

One factor that is important to determine is how much material is deposited in the immediate vicinity of the bridge. The GCA study estimated that of total particulate emissions from an uncontrolled sandblasting operation, as much as half of the sandblasted material consisted of particles greater than 65 μm in diameter. According to Figure A-1, a particle 65 μm in diameter released at a height of 65 ft in a 4-mph wind can be transported about 200 yd; and, in fact, the study found that the greatest concentration of debris was deposited within 200 yd of the generation point (1, pp. 24-29, 49). Only 7 percent of the particulate matter was less than 10 μm in diameter, but this size range is of concern because particles less than 15 μm are inhalable (3). Particles less than 10 μm in diameter diffuse much like a gas, following turbulent motions of the atmosphere.

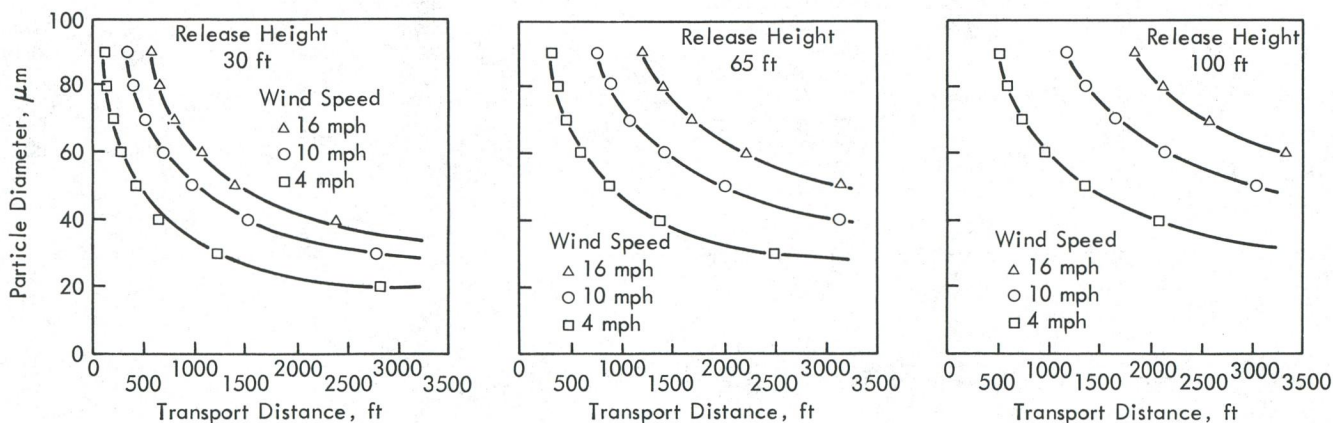


Figure A-1. Relationship between particle diameter and horizontal transport distance for three wind speeds and different release heights. Particles are assumed to be spherical and to have a density of 2.0 g/cm³.

that under worst case conditions, 100-ft release height and 16-mph wind speed, 75- μm diameter particles (silt or fine sand) can be carried about 2,500 ft. Paint particles would likely be in the form of chips and flakes rather than spheres, however, and could be expected to settle at a somewhat lower rate than spheres of equal density. Particles less than 10 μm in diameter follow the turbulent motions of the atmosphere and settle much more slowly. Downwind concentrations of these particles can be calculated using current meteorological data and standard Gaussian dispersion models. The settling time of a 5- μm particle in still air from a release height of 3 m has been calculated to be 50 min.

Figure A-3 shows that 50 percent of the lead is associated with particles in the size range of 50 μm and smaller (1, p. 35). A 50- μm particle will be transported nearly 1,000 ft; a 15- μm particle will probably be carried a mile or more (65-ft release height, 4-mph wind speed). Although the greatest concentration of lead will be deposited within 200 yd of the paint removal operation, over 50 percent of the lead will be deposited beyond this distance. However, because the dust plume from the abrasive blasting will be so dispersed beyond 200 yd, the deposition of lead will be extremely low at any one point in this area. In fact, in an urban environment it would be difficult to determine the

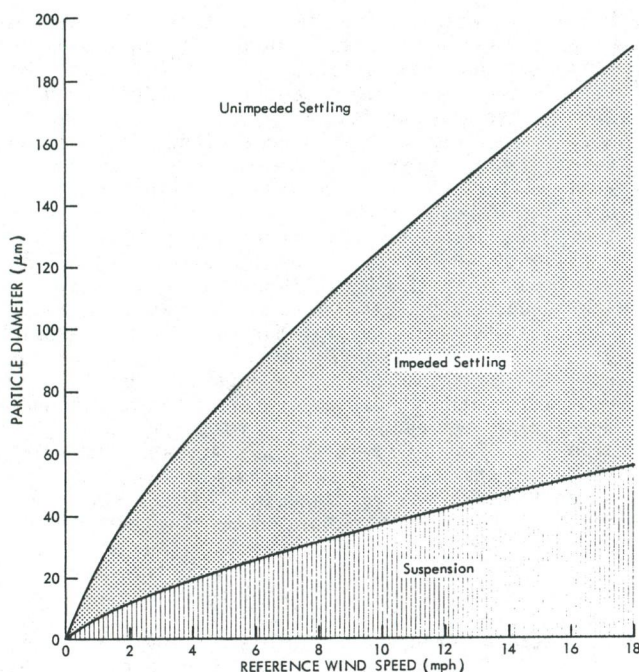


Figure A-2. Particle settling and suspension regimes.

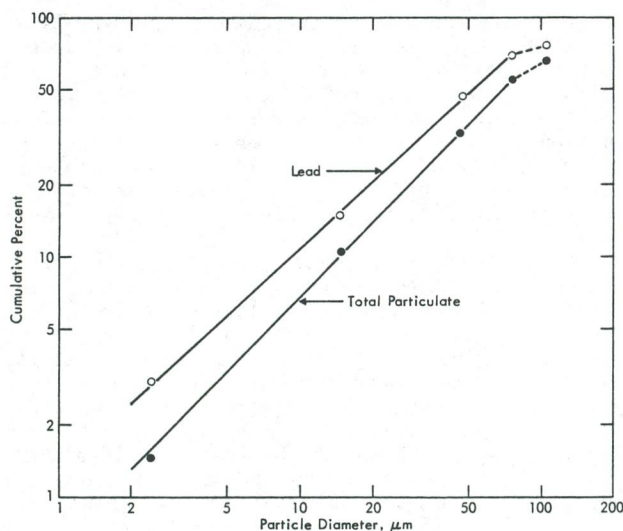


Figure A-3. Cumulative percent of lead and particulate by particle diameter.

source of the lead deposition at distances beyond 200 yd.

In the GCA study 11 percent of the total lead emitted was associated with the fraction that was less than 10 μm (1). About 10 percent of the particulates were of inhalable size, and these contained 16 percent of the lead. Only 1.6 percent of the particulates, containing 3 percent of the total lead emitted, were less than 2.5 μm in diameter. These findings support the assumption made

on the Tobin-Mystic River Bridge repainting project (4) that lead-containing particulates smaller than 3.5 μm came from vehicular exhaust. This assumption is further supported by Daines et al. (5), who found that 85 percent of the lead in the air between 30 and 1,750 ft from a highway consisted of particles under 4 μm.

The type of abrasive used influences the percentage of small particles created during paint removal operations. Some metropolitan ordinances will not allow the use of silica sand as an abrasive because the particles tend to shatter or break on impact and create more dust than do other abrasives such as Black Beauty, a crushed metal refining slag. There are also negative human health effects that can result from inhaling too much silica dust. The California Air Resources Board periodically checks abrasives used for paint removal to ensure that no more than 1.8 percent of the blast residue consists of particles less than 5 μm in diameter.

Extent of the Problem

Only two projects were found in which air emissions from the abrasive blasting of lead-based bridge paints were monitored: the GCA project (1) and Tobin-Mystic River Bridge project (4, 6). The GCA study monitored a spot removal sandblasting operation in which lead paint was removed from about 20 percent of the bridge. No emissions control was used during the operation. The height of the sandblasting ranged from 30 to 100 ft above the ground or water level. Typical wind speeds ranged from 4 to 16 mph.

The Tobin-Mystic River Bridge repainting project is an ongoing operation in which 100 percent of the lead paint is being removed on the outside girders, the handrails, and the walkway of the structure using grit blasting. Most of the operation is enclosed in a movable booth, and about 80 to 85 percent control of emissions is attained. The height of the grit blasting in the movable booth ranges from 0 to 150 ft above the ground. Typical wind speeds range from 0 to 10 mph.

The results of the GCA study showed that there was no exceeding of the federal ambient air lead standard, the annual total suspended particulate (TSP) standards, or the primary 24-hr TSP standard at any of five monitoring stations. The secondary 24-hr TSP standard was exceeded once at three of the sites, but the federal regulation would permit one exceedance per site. One other site had four exceedances of the secondary 24-hr TSP standard, which would have been a violation. This site was located 125 m downwind of the sandblasting operation. Discussion of the primary and secondary particulate standards can be found in Appendix B.

The results of the Tobin-Mystic River Bridge monitoring show that neither the lead standard nor the TSP standards are being exceeded by the abrasive blasting operation. Monitoring at this site is especially critical because the viaduct passes directly through urban residential neighborhoods where some houses are within 10 yd of the structure.

Studies (7-9) have shown that the mass median diameter of lead-bearing particles in the atmosphere is typically less than 1 μm. What few data are available for air monitoring of lead paint removal operations point to extremely low levels of particles of this size range being created by abrasive blasting. A reasonable conclusion is that the contribution of lead from abrasive blasting of

lead bridge paints to the total atmospheric load of lead is not significant. The air pollution concerns from removal operations should then focus on inhalation of lead compounds during operations and the ultimate fate of the particulates deposited in the area exposed to the abrasive blasting plume.

With respect to the first concern, even though the ambient lead standard may not appear to be violated, the fact that temporarily high concentrations of lead do occur in the dust plume during removal operations cannot be ignored. The attitude encountered by the MRI study team in a few metropolitan areas was: What is a little more dust in our already dirty city? The fact is, however, that adding more lead to an urban environment that already has high levels of lead can create adverse health effects, particularly in small children who may already be consuming the acceptable daily intake of lead. For this reason it is recommended that best efforts be made to contain emissions from lead-based paint removal operations conducted in urban settings. In a rural setting where people and animals may not be subjected to exposure to the dust plume, there is a decreased need for control measures. One needs only to compare rural to urban air lead levels to see why urban exposure to additional lead is of concern. Background levels of lead in remote areas have been found to be 8 to 10 ng/m³. On the other hand, background lead levels in urban environments range from 1,000 to 20,000 ng/m³ (10, p. 336). It is worth noting that natural prehistoric lead levels have been estimated to have been only 0.04 ng/m³.

The second air pollution concern is the ultimate fate of particulates deposited in the area exposed to the abrasive blasting plume. The deposition of lead compounds on soil, streets, sidewalks, and driveways as a result of air emissions from bridge paint removal has long-range consequences which cannot be overlooked and is probably the greatest environmental problem associated with lead-based paint removal. Lead particle resuspension may play an important role in the transport of lead (7). The leaded dust particles are apt to be resuspended and redeposited within the urban environment because of complex wind currents created by buildings and street canyons and because of vehicular traffic, resulting in a large buildup of lead in soil and dusts around buildings. The deposited particles can be picked up on feet, hands, clothing, pets, etc., and carried inside urban households and offices (11, p. 19). The dust can also enter directly through windows and doors to be deposited throughout the household or building, although this problem would normally occur only during warm weather. Dust deposited in children's outdoor play areas can enter the body via inhalation of resuspended particulates and ingestion of dirt. The leaded dust particles also deposit on vegetation. Some of the dust becomes fixed to the waxy cuticle of the leaves (18); often this embedded material cannot be removed by repeated washings. A more detailed explanation of lead deposition on soil is presented in the section entitled, "Lead Paint Residues in Soils."

LEAD PAINT RESIDUES IN WATER

Description of the Problem

Lead-based paint debris enters water when paint removal operations are performed on bridges over

bodies of water. The fate of this lead debris once it lands on the water surface depends on several factors: the size of the lead particle; the turbulence of the water; and the chemical form of the lead in the particle.

Upon landing on the water surface, most of the paint debris sinks immediately. Because it is more difficult for the smaller paint chips to overcome water surface tension, however, they often float for some time, creating a scum on the surface of the water. From the standpoint of water pollution, this scum is probably the most objectionable aspect of lead-based paint removal. The floating scum can last for some time on a calm water surface--a small lake, for instance--but will eventually break up and sink. On flowing bodies of water, the scum is carried some distance downstream before it settles to the bottom or is deposited on the shore of the stream. The distance it is carried downstream depends on the strength of the current in the stream. The stronger the current the greater the turbulence, and turbulence causes the debris to sink more quickly. On sluggish streams where turbulence is not significant, the scum will be carried farther downstream.

After the paint debris sinks below the surface, the particles are deposited on the bottom of the body of water or are carried along as part of a stream's sediment load to be deposited at some point downstream. Either way, the paint debris does not appear to pose an environmental problem for several reasons. First, the lead paint particles consist of insoluble compounds and thus contribute little dissolved lead to water. Second, even if all the lead in the paint debris were soluble, there are few instances when this would create a violation of drinking water standards. And finally, lead paint residues do not appear to affect aquatic organisms, based on available information. The aquatic environments most affected by lead-based paint removal operations are probably small lakes. The lead paint residues deposited on a lake are likely to remain where they were deposited.

Most of the data pertaining to lead pollution in water are based on dissolved lead and total recoverable lead. The total recoverable lead fraction includes such lead forms as the free ion and the hydroxide, carbonate, and sulfate salts. These forms are probably more toxic to aquatic life or can be converted to more toxic forms under natural conditions than lead associated with minerals, clays, and sands. However, the lead forms found in lead-based bridge paints are among the most water insoluble of all the lead compounds. Consequently, it is difficult to correlate the presence of these lead compounds in water to the data showing the effects of lead on aquatic biota. On the other hand, the addition of lead paint compounds to the bottom sediments of a stream or lake cannot be construed as beneficial and, as more research is performed, may be shown to be harmful.

Current information is that there is no biological magnification of lead in aquatic food chains. Aquatic biota in urban streams have many times higher lead concentrations than biota in rural streams, due almost exclusively to lead in urban stormwater runoff. Getz et al. determined that lead in aquatic organisms was related to the amount of contact with bottom sediments containing high lead concentrations (12). In other words, organisms at low trophic levels, which are associated with the benthic zone, have the highest lead

levels, while those at the top trophic level (fish) have the lowest. The amount of lead stored by the biota of a given segment of stream depends on the types and amount of habitat available, the community composition, and the lead concentration in the sediments (12, p. 132).

One useful characteristic of dissolved lead is its tendency to form compounds of low solubility with the common anions in natural water, e.g., sulfate and carbonate. The amount of lead that can remain in solution in water is a function of water pH and dissolved salt content. Studies show that lead content in natural water increases when the water is made more acid and that the increase is reversible on subsequent neutralization (11, p. 28). Equilibrium calculations show total lead solubility in soft water (low carbonates) to be 500 µg/L when pH is below 5.4; and in hard water, 30 µg/L when pH is above 5.4. Lead concentration in soft water is limited by the presence of lead sulfate. Above pH 5.4, lead carbonates limit the concentration (7, pp. 6-21). But solubilities of the lead-based paint compounds in water cannot be equated to these numbers that easily because these water solubilities are determined in deionized water. Thus, the anions that normally control lead solubility in natural waters, sulfate and carbonate, are not present. Even so, the two lead pigments predominantly used in bridge paints, lead tetraoxide (Pb_3O_4 , red lead) and basic lead silicochromate ($3 PbO \cdot SiO_2$, basic lead silicate, and $PbO \cdot PbCrO_4$, basic lead chromate), are considered insoluble in water for all practical purposes. For instance, lead tetraoxide has a solubility of only 0.0069 mg/100 ml; basic lead chromate has a solubility of only 0.0058 mg/100 ml (109). Two other less common lead compounds, blue basic lead sulfate (blue lead) and basic lead carbonate (white lead), are only slightly less insoluble (13). Blue lead consists of several lead compounds of varying solubilities (14, 15): basic lead sulfate ($PbSO_4 \cdot PbO$, 0.0044 g/100 ml); lead sulfide (PbS , 0.0124 g/100 ml); lead sulfite ($PbSO_3$, 0.124 g/100 ml). In most chemical handbooks white lead ($2 PbCO_3 \cdot Pb(OH)_2$) is listed as insoluble in water.

A long-term solubility study was recently completed in California (16). Samples of paint residue and spent abrasives containing red lead from the Middle River Bridge were placed in flasks of distilled water (pH 6.5) and flasks of river water and agitated daily. Aliquots of the waters analyzed 3 years later showed no discernible increases in lead and chromium.

While such studies show the insolubility of lead pigments in water, they do not address the long-term ecological consequences of introducing lead paint residues to water, particularly soft water or waters with a history of decreasing pH. The effects on solubility of lead in bridge paint residues caused by water becoming more acidic are uncertain, but the effects of these pH changes on the aquatic ecosystem can be drastic. Some lakes in the northeastern United States are showing a decline in productivity as a result of declining pH. These pH changes influence not only the biological balance, but also the chemical balance. It is not appropriate, however, to single out any one chemical change as the single menace to an aquatic ecosystem because changes in pH affect the solubilities of many different ionic species.

Extent of the Problem

Determining the extent of water pollution resulting from lead-based paint removal operations is a difficult problem. No documented cases of water pollution violations were found in the literature. In many state agencies that were contacted, there was someone who knew of a particular problem with water pollution from lead-based paint removal operations. The most frequently encountered anecdote was the "sick cow," but the fact that lead paint was the cause could never be substantiated. It does appear possible that livestock drinking downstream from a sandblasting operation could ingest floating paint chips and become sick. Another water pollution complaint had to do with paint scum accumulation on boat exteriors in a downstream marina.

State water resource agencies seem to be universally concerned about lead paint pollution and believe it is a serious problem that should be controlled. None of the information obtained during this project, however, justifies putting a greater emphasis on lead paint residues in water than on residues in air and soil. Most state fish and game agencies had had no complaints or problems with lead paint removal; the lead in lead shot was of greater concern.

A few states have a fish and game agency that has strict requirements for containment of abrasive blasting residues. The philosophy in these states is that the paint residues are harmful unless proven otherwise. The transportation people in these states reported having difficulty complying, for financial and technological reasons. A "zero discharge" requirement, in their opinion, is unreasonable and not supported by the available data. Based on the information gathered for this report it would seem that a zero discharge requirement is too stringent. However, the fact that lead is so persistent and toxic in the environment allows environmental agencies to err on the side of caution. A more reasonable approach might be to require "best efforts" to control paint debris, with close supervision of operations where environmentally sensitive areas are involved.

Thus, the main water pollution concern during a bridge paint removal operation is the debris that remains on the surface of the water, but it poses a health hazard only if it is ingested. The material is easily removed, however, by filtration during normal water treatment procedures. The debris does create aesthetic problems, particularly on streams and lakes with little turbulence. Almost all complaints to state agencies about water pollution are related to paint scum, because the debris is usually a quite visible red or orange color.

Based on available information, it appears that the deposition of lead paint residue on stream and lake bottoms is a secondary concern. No negative environmental impacts have specifically been identified, but long-term studies of this practice have not been performed. One would expect that deposition of large amounts of any foreign material in an aquatic ecosystem is bound to have some impact. Even though lead pigment solubilities are low, when these compounds are added to already high concentrations of lead in urban stream sediments, the result can only be further degradation

of the aquatic environment. Solubilities of some of the compounds, e.g., lead sulfide, will be more sensitive to the lowering of water pH, although the ramifications of changes in pH must be looked at from the overall perspective of changes in water chemistry and effects on the biotic community.

One concern that has not been addressed is how much of the lead paint residue that reaches water is not deposited on the stream bed but is carried in the stream in suspended particulate form. The size of particulate in this category would depend on the velocity of the stream, which is a measure of its sediment-load carrying capacity. Most lead in streams comes from runoff from land surfaces, and in urban environments the lead load in this runoff can be substantial. Consequently control of water pollution from lead-based bridge paint removal operations should be more stringent in urban areas than it is in rural areas.

LEAD PAINT RESIDUES IN SOIL

Description of the Problem

Soil contamination by lead-based bridge paints is the result of deposition of leaded paint chips and dust particles produced during bridge paint removal operations. The fate of this leaded material varies once it reaches the land surface: (1) it can remain in place in or on the soil surface profile; (2) some particulates can be resuspended by wind and transported away from the original place of deposition; (3) some particles can be carried away by surface runoff during rainfall; (4) some particles can be tracked into homes and offices by people and pets; and (5) some of the lead can eventually be assimilated by vegetation growing in the contaminated soil.

Very little information exists on residence time of lead in soils. What little is available indicates that lead in soils seems to have a residence time of a few thousand years (19, 20). Also, evidence is ample that a significant elevation of lead concentration above background level is not common below 10 cm from the soil surface (21). Because lead is not likely to leach once it enters the soil, a potentially severe lead contamination problem can occur in soils under and around bridges on which lead-based paint is used.

The lead compounds used in bridge paints are known to be chemically quite stable, and no information exists on their rate of breakdown in the soil ecosystem. However, if and when these lead compounds do release lead to the soil system, there is evidence that this lead will either be concentrated in the organic fraction of the soil or form an insoluble complex with anionic species in the surface horizon (7, 18, 22). In either case, the lead will remain near the surface of the soil. Soil properties that serve to keep lead immobilized in the surface profile are high clay content, high organic matter content, and high surface area (22). All are properties associated with cation exchange capacity. It stands to reason then that if movement of lead in a soil profile is to occur, it would occur on soils of low cation exchange capacity, such as in very sandy soils. However, this movement will probably not be significant.

The resuspension of lead particulates from soil is often overlooked and probably accounts for a significant portion of lead transport in the environment. Nriagu (21) implicated wind erosion as a

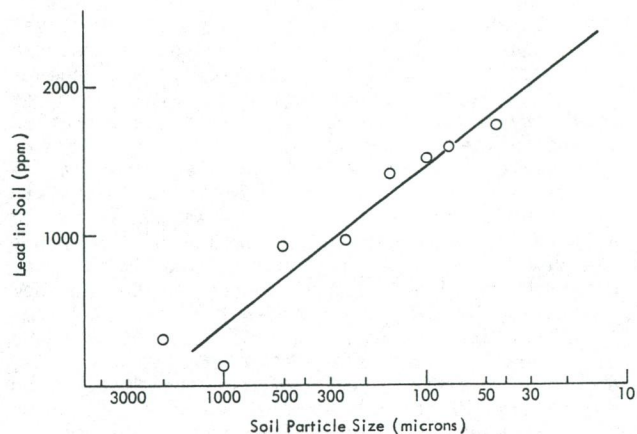


Figure A-4. Variation of playground soil lead concentration with soil particle size.

major factor in the dispersal of lead around contaminated soils. He estimated that from an anomalous soil containing 200 ppm lead, the annual loss of lead by wind erosion is approximately 3 lb/acre/hr. The smaller sized soil particles have been found to have the highest lead concentrations, as shown in Figure A-4 (23, p. 1208), and the smaller particles are the most susceptible to resuspension.

In the air pollution discussion, mention was made of the strong wind currents generated in urban environments, creating situations in which lead-based paint particles can be resuspended from soils and impervious surfaces. Because children are closer to the ground surface, they are more readily exposed to resuspended lead particles. This resuspension of dust is of concern only when soil lead concentrations are significantly above background levels, which, unfortunately, is often the case in urban environments. Studies have shown that significant lead concentrations are very common in urban environments, and the potential for increased ingestion certainly exists. The lead concentrations in dust are twice as high in indoor, urban nonresidential buildings as in indoor, urban residences. It should be remembered that the potential for increased ingestion of lead particulate matter exists in both well-maintained and rundown buildings (12).

Lead paint particles may leave the soil surface via surface water runoff from rainfall events. Nriagu (21) speculated that atmospherically supplied lead in soil profiles can be lost from the profile only by soil erosion. In urban environments, rainfall runoff is much higher in lead concentration than it is in rural areas. This is due primarily to the higher density of vehicular traffic in urban areas, as well as the greater amount of impervious area available for the deposition of leaded dust. A thorough cleanup of the streets, sidewalks, and driveways in the immediate area surrounding a bridge paint removal operation will eliminate much of the paint debris in urban surface runoff. However, debris will still be contributed from soil, vegetation, and rooftop runoff, which is why air emission

control on removal operations in urban areas is important.

Lead paint particles (or any lead particles) in soils and on other outdoor surfaces can be tracked into homes, offices, and shopping areas. Once in an interior environment they will be deposited on carpets or other floor surface. The more pedestrian traffic, the more lead carried inside. Because children frequently play on the floor, the likelihood of their ingesting or inhaling lead dust particles is greater than for adults.

The mechanisms of plant uptake of lead are not clearly understood and have been the subject of considerable debate. Since lead has not been proven to be essential for any living system, it has either no effect at all or only a harmful one. Most of the lead accumulated by plants remains in the roots. Some plant species are more sensitive than others to soil lead. Researchers have found evidence that the process of plant uptake of lead is nonmetabolic, i.e., passive uptake of lead through the roots (24). Major factors affecting uptake appear to be soil cation exchange capacity and soil pH (25). High cation exchange capacity and neutral-to-alkaline soil pH seem to reduce the availability of lead to the plant.

There is no information on the rate of breakdown of lead pigments in soil and availability of lead from this breakdown. However, research has shown that of the total lead in soils only 0.003 to 0.005 percent is available for plant uptake (26). This may appear to be an extremely low amount of lead, but it is enough to create significant lead accumulations in vegetables grown on lead-contaminated soils. High concentrations of lead have been recorded in leafy vegetables grown on lead-contaminated soils. Root crops seem to take up less lead than do leafy vegetables, and fruits take up less lead than do root crops (23). However, there really is no simple relationship between the metal content of vegetables and the soil in which they were grown. Each vegetable species has its own characteristic uptake. Even one vegetable can exhibit a wide range of lead concentrations depending on the type of soil on which it is grown (24). Therefore, it is impossible to predict lead uptake in vegetation based solely on the total lead content of soil. However, available information suggests that any vegetation that will be consumed by humans or animals and is grown on lead-contaminated soils should automatically be suspected of containing high levels of lead.

Extent of the Problem

Soil contamination by lead-based paint residues appears to be an underrated problem. Publicity has focused on the problem of lead paint in urban buildings and the hazards posed to children, but little publicity has focused on lead residues in soils around lead-painted bridges. Only one study was found in which soil around a bridge was examined for lead concentrations (27). Soil lead levels directly beneath the Tobin-Mystic River Bridge in Boston were found to range from 1,300 to 4,800 ppm, with an average of 2,700 ppm. A comparison of chromium-to-lead and bromine-to-lead ratios showed that the major source of this lead was the paint on the bridge, which consisted of red lead and basic lead chromate. (The major lead component of automotive exhaust has been shown to be lead bromochloride, hence the bromine and chromium comparison.) When these findings are compared to the average lead content of soils in the

United States, which is about 16 ppm (28), there appears to be a potentially severe lead contamination problem in soils under and around lead-painted bridges.

Children playing in areas of lead contamination are in the greatest danger of exposure. Even if lead-based paint on houses is eliminated, lead residues in soils will still pose a threat to human health. The problem is often ignored in urban areas. In most urban areas studied, the concern was more for public safety than for public health. The reason accumulations of debris on sidewalks and streets were cleaned up was so people would not slip and fall. No mention was made (except in Boston) of cleaning up leaded dust from a removal operation so that it would not be tracked into nearby buildings or homes.

The problem of lead in soils as it relates to the health of children is a source of much study (29-31). Because it is technically impossible to purify such soil, as can be done to a certain extent with air and water, it is of the utmost importance to prevent soil from being irreversibly contaminated. The only way to do this is to eliminate the sources of lead contamination. Consequently, control of emissions from lead paint removal operations on bridges and thorough cleanup of debris after the operation is finished are advisable practices in urban environments. These practices are not universally employed in metropolitan areas currently, and no information exists on the extent of lead contamination of soil around bridges. The overriding concern in most areas is the water pollution caused by removal operations, even though there is evidence that lead paints in soils are a much greater hazard to human health.

In rural areas, it is unlikely that lead in soils around bridges is a serious environmental problem because most of the lead contamination occurs within the highway right-of-way, a rather restricted environment. The buildup of lead in agricultural soils adjacent to the bridge is slow because of less auto traffic and tillage practices that disperse the lead throughout the plow layer. Animals feeding on vegetation close to these bridges might be exposed to a greater risk of lead poisoning, but it is doubtful that the risk would be any greater than for animals that eat vegetation near a roadway where leaded exhaust emissions have been deposited on the plants and soil.

It is the urban environments where control or recovery technologies are most needed on bridge paint removal operations. There is also a pressing need to educate the public and metropolitan public health agencies about the hazards of lead contamination of soils around homes, particularly soils that are used for gardening or that are part of children's play areas.

LEAD TOXICITY IN HUMANS

The amount of literature available on lead toxicity in humans is voluminous, and human health effects are undergoing constant revision as new data become available. Many studies try to pinpoint the source of lead creating the health problems in human subjects, and lead-based paints are frequently singled out as an important source. When considering human health effects of lead consumption, it is the source of the lead taken into the body that is of overriding concern and not the chemical composition of the lead contaminant. A statement in EPA's Ambient Water Quality Criteria for Lead should be kept in mind: "In reviewing the metabolism of lead in man, it is generally

assumed that all inorganic forms once absorbed behave in the same manner. There is no evidence to suggest that this assumption is erroneous" (17, p. C-16). Thus, there are no safe lead-based paint compounds where human health is concerned. This section will summarize the problems that lead-based paints on bridges can pose to human health.

Description of the Problem

The most important aspect of lead toxicity in humans is that children have been identified as the population most at risk to the health effects of low levels of lead. The difficulty in establishing levels of toxicity is that the minimum blood lead level at which there is an onset of recognizable symptoms is not established. Currently, the Center for Disease Control (CDC) has defined the safe childhood blood lead level as being below 30 µg/dl (32). The results of the second National Health and Nutrition Examination Survey conducted between 1976 and 1980 show that about 4 percent of children between 6 months and 5 years have lead levels above the CDC defined safe level (33), which is approximately 780,000 children. Many experts argue that even this level cannot be regarded as safe in light of new evidence suggesting subtle abnormalities at even lower levels (34-36). Blood levels in adults are considered elevated if they exceed 40 µg/dl (37).

Two means of absorption of lead by humans are applicable to lead paint removal operations: ingestion and inhalation. It has been estimated that on average approximately 8 percent of the normal dietary lead in adults is absorbed. However, the gastrointestinal absorption of lead in young children is considerably greater. Studies have shown that dietary lead absorption in children may be as high as 50 percent (17, p. C-16). The relationship between inhalation of lead compounds and levels of blood lead is not clearly defined. The data indicate a fairly narrow range of blood lead to air lead ratios, probably 1-4 µg/dl to 1 µg/m³. This ratio appears to be higher for children than for adults. Table A-1 displays the effect of various ambient air lead concentrations on blood lead levels of exposed populations. In making correlations between air and blood lead it is often difficult to know the lead input from other sources, such as food or water. A fact often given little consideration is that air lead concentrations vary inversely with altitude. One study found that lead concentration 20 m above the ground is twice what it is 1.5 m above the ground (38).

Absorbed lead is transported in the blood, and approximately 95 percent of it is bound to hemoglobin. Experiments have shown that blood lead peaks about 1 day after ingestion or inhalation. The time it takes for lead to clear the blood depends on the individual but can take anywhere from 5 days to 6 months. Soft tissue lead has a turnover rate of 30 to 40 days. The bones are the largest repository of lead, accounting for 95 percent of the total body burden in adults and about 70 percent in young children. Residence time in bone is at least 30 years (35).

There are many metabolic functions which lead disrupts once it gets into the body. The levels of blood lead required to create various toxicity symptoms are not germane to this report but can be found in several reports that summarize lead toxicity (7, 17, 18, 39). However, it should be

Table A-1. Estimated percentage of population exceeding a specific blood level in relation to ambient air lead exposure.

Air Lead (µg/m ³)	Percentage Exceeding Blood Lead Level of:		
	20.0 (µg/dl)	30.0 (µg/dl)	40.0 (µg/dl)
0.4	15.22	0.59	0.02
1.0	26.20	1.67	0.07
1.5	34.12	2.88	0.16
2.0	40.23	4.12	0.26
2.5	45.15	5.35	0.38
3.0	49.23	6.57	0.51
3.5	52.69	7.75	0.66
4.0	55.67	8.90	0.81
4.5	58.27	10.01	0.97
5.0	60.57	11.09	1.14
6.0	64.45	13.16	1.48
7.0	67.63	15.10	1.83
8.0	70.28	16.92	2.20

Source: U.S. Environmental Protection Agency, "Air Quality Criteria for Lead." Office of Research and Development, Washington, D.C. NTIS Document No. PB 280-411 (December 1977) 299 pp.

noted that a blood lead level that elicits a response in one individual may not elicit any response in another. Susceptibility to lead depends on a variety of dietary factors including intake of calcium, iron, protein, vitamin D, ascorbic acid (vitamin C), and nicotinic acid (vitamin B₃) (40, 41). Deficiencies in any of the foregoing nutrients, particularly calcium (42, p. 160), can bring about increased susceptibility to the toxic effects of lead.

The biological effects of lead on humans are numerous and can be categorized as follows: hematological effects; neurobehavioral effects; reproductive and developmental effects; and renal effects. Of the hematological effects, anemia is one of the classical manifestations of clinical lead intoxication and occurs because of decreased production of hemoglobin and destruction of red blood cells. Lead also affects the synthesis of heme and globin. One study showed that blood levels as low as 20 µg/dl can affect globin synthesis (7).

Among the most deleterious effects of lead poisoning are those associated with central nervous system damage. The acute effects of high lead exposure levels include symptoms such as irritability, stupor, convulsions, and/or coma, and the symptoms may progress to death within 48 hr. It is widely accepted that irreversible neural damage occurs as one of the sequelae of nonfatal encephalopathy episodes. The symptoms of such permanent damage can range from behavioral changes, such as hyperactivity in children, to severe mental retardation or continuing mental incompetence (7, 43). The central nervous system of a child below the age of 6 is most susceptible to low level lead exposure because the central nervous system is still developing. There is some evidence that blood lead levels below 30 µg/dl may affect the mental development of small children (44). The

problem is that children with "abnormal" blood levels have often been reported as asymptomatic. But symptoms from low-level lead intake may have been overlooked because clinicians did not know what to look for (45). Also, in identifying subtle neuropsychological deficits it is difficult to distinguish between the effects of lead and the influence of sociocultural factors.

It should be noted that at the upper end of the range of blood levels at which subtle neurobehavioral effects have been reported to occur, the shift from subtle to severe neural symptoms may be abrupt, due to differences in individual susceptibility. The neurobehavioral deficits that have been observed at lower exposure levels do not appear in a discrete, stepwise fashion as particular threshold blood lead levels are reached. What probably occurs is a shift from no-effect levels to levels at which fairly well substantiated neurobehavioral effects have been found to occur, i.e., around 50 to 60 $\mu\text{g}/\text{dl}$. Above this point, however, further increases in relative levels of neural damage occur in a smoothly ascending fashion in relation to increasing blood lead levels, as indicated by increasingly severe neurological or behavioral deficits (7, p. 13-7).

The effects of lead on reproduction and development fall into two categories: (1) the effects on spermatogenesis and ovarian function, and (2) the effects on postconception events through delivery. Lancranjan et al. (46) found that workers with moderately increased lead absorption (blood lead of about 50 $\mu\text{g}/\text{dl}$) demonstrated spermatocidal alterations. It is also possible that the ovarian cycle may be disturbed in women 20 to 25 years old who are exposed to air lead levels around 7 $\mu\text{g}/\text{m}^3$ (7). There is general agreement that the fetus is vulnerable to the toxic effects of lead. Studies have established that lead crosses the placenta of pregnant women and enters the fetal tissues. Lead levels in the umbilical cord blood correlate highly with those of the mother's blood. The question remains whether prenatal exposure to lead may adversely affect growth and development in utero or later in life. Prenatal lead exposure is suspected in children who exhibit signs of permanent damage to the central nervous system when they have been only moderately exposed to lead and who show no overt symptoms of toxicity. The effects on these children include hyperactivity, difficulty in task performance, deficiency in IQ, and nerve conduction deficits (43, p. 271).

The kidney was identified as a particularly important target organ for lead effects during OSHA (Occupational Safety and Health Administration) lead hearings (43, p. 270). Most of the evidence on adverse effects suggests that nephritis is found in workers with a history of lead exposure with a corresponding blood lead level of about 70 $\mu\text{g}/\text{dl}$. Because kidney damage results only after prolonged or repeated exposure, it is difficult to reconstruct exposure history; consequently, no exposure threshold for this effect can be determined (7, p. 13-18).

The question of carcinogenicity of lead in

humans has not been answered. Studies in experimental animals suggest that lead may be carcinogenic, especially in the kidneys, but there is no convincing evidence of carcinogenicity from the human studies that have been conducted (43).

Extent of the Problem

Studies of the daily intake of lead in adults do not provide a consensus on average daily intake. Rates range from 100 to 250 $\mu\text{g}/\text{day}$ (7, 49), with the average absorption far lower. Because it is common practice for small children to suck their dirty fingers, to eat with unclean hands, to consume food dropped on the ground, and to mouth toys or other objects containing dust or dirt, they are at greater risk to exposure. Children's absorption of ingested lead is also several times greater than that of adults. For those children who live or play in an environment where dust and dirt have a high lead content, it is likely that the maximum daily permissible intake of lead is frequently exceeded (38). A child playing in a soil with 30 ppm lead would have to consume 10 g (about two teaspoonsful) daily to exceed a maximum permissible daily lead intake of 300 μg . However, if soil lead were 3,000 ppm (not unusual in many urban areas or around lead-based painted homes), the child would need to consume only 100 mg (fifty times this dose would be about one teaspoon) daily to exceed the permissible intake (30). Of course, 300 $\mu\text{g}/\text{day}$ may be too high for a maximum permissible intake; if so, it would take less lead-contaminated soil to exceed the permissible level.

The problem in evaluating exposure of children and adults to lead is that there is no way to determine the amount of lead contributed to the body burden by any one lead source. But it does appear that lead in soil and house dust carries a greater potential for ingestion than does lead paint on walls. Sayre et al. (51) studied children in the inner city of Rochester and concluded that elevated blood levels could not all be accounted for by eating paint chips. They estimated that only one child in eight might be expected both to have pica (craving for unnatural food) and to be in an environment with available lead-based paint. Thus, they concluded that household dust and soil appear to be the major sources of lead intake to the body.

The mean lead concentration in 10 surface soil samples obtained within 100 ft of the Tobin-Mystic River Bridge, where grit blasting of lead-based paint was being performed was 3,272 ppm (50). In an area where no grit blasting had occurred, soil lead concentration within 100 ft of the bridge averaged about 1,000 ppm. The study found elevated blood lead levels, but whether the abrasive blasting of lead-based bridge paint was the major cause could not be determined. It stands to reason, however, that cleanup and containment of all environmental lead pollution, no matter what the source, can only serve to decrease body lead burdens in urban areas.

APPENDIX B

ENVIRONMENTAL REGULATIONS

Appendix B discusses environmental regulations that may be applicable to various aspects of bridge lead-based paint removal operations. There are no environmental regulations directed specifically toward bridge paint removal, but there are various air and water quality standards as well as waste disposal, human health, and nuisance regulations that, in their general coverage, impact on this type of operation. Each of these areas of regulations will be discussed and an assessment made as to the likelihood of a paint removal operation violating these regulations.

In addition to discussing regulations in this appendix, specifications of some of the state transportation and highway departments will be covered. These are not regulations in that they are not state or federal laws; rather, they are clauses or specifications included in some of the contracts let by the states for paint removal operations. These contractual obligations are used to "regulate" environmental aspects of the operations.

RELEVANT AIR REGULATIONS

Federal Level

On the federal level there are regulations that are potentially applicable to lead-based paint removal operations on bridges. First are the national primary and secondary air quality standards for lead and its compounds. Currently they are the same and are set at $1.5 \mu\text{g}/\text{m}^3$ figured as the arithmetic mean averaged over a calendar quarter (40 CFR 50.12). High level emissions of lead compounds over a short period would not violate the standard as long as the emissions averaged over a quarter did not exceed the $1.5 \mu\text{g}/\text{m}^3$ level.

Next are the national primary and secondary air quality standards for particulate matter. The primary standard is $75 \mu\text{g}/\text{m}^3$ (annual geometric mean), and $260 \mu\text{g}/\text{m}^3$ is the maximum 24-hr concentration not to be exceeded more than once per year. This primary standard became effective December 31, 1982. The secondary standard is $60 \mu\text{g}/\text{m}^3$ (annual geometric mean), with $150 \mu\text{g}/\text{m}^3$ as the maximum 24-hr concentration not to be exceeded more than once per year (40 CFR 50.6.7). The secondary standard is in effect at the discretion of the states. Fugitive dust from sandblasting or other operations could potentially violate these standards.

The air quality standards for particulate matter are under review by EPA and may be revised soon.

State Level

None of the states have specific air regulations applicable to bridge paint removal, but some states regulate sandblasting, particularly sandblasting on buildings. In conversations with officials in these states it was learned that these sandblasting regulations are usually not applied to bridge paint removal operations.

California regulates abrasive blasting by setting opacity standards for the emissions. Discharges into the air are not to be as dark as or darker than No. 1 on the Ringelmann Chart (published by the U.S. Bureau of Mines) for more than 3 min in any 1-hr period. Measurements for unconfined blasting are taken at the densest point of emission after a major portion of the spent abrasive has fallen out at a point between 5 and 25 ft from the source. With confined blasting, readings are taken at the densest point after the air contaminant leaves the enclosure (California Title 17, Chapter 1, subchapter 6, articles 2 and 3). Utah has a similar regulation for sandblasting based on opacity measurement. Both California and Utah require that the abrasive used be certified as to size. Not more than 1 percent by weight of the abrasive should be able to pass through a No. 70 U.S. standard sieve, and after blasting not more than 1.8 percent by weight should be $5 \mu\text{m}$ or smaller (Section 92520 of Subchapter 6, Title 17, California Administration Code; Utah Title 26, Chapter 13, Part 4.10). The California Air Resources Board also publishes a list of abrasives certified for use in dry unconfined blasting. These two states, California and Utah, appear to have the most detailed regulations covering abrasive blasting. Arizona and Texas have sandblasting regulations that require measures be taken to prevent or minimize dust emissions (Arizona Title 9, Chapter 3, Article 5, R9-3-526, and Texas Title 31, Chapter 111.41). In Texas the regulation applies only to nonattainment areas as designated by government action under the Federal Clean Air Act.

This is the case in a number of states that have nonattainment areas. These states are attempting to bring nonattainment areas into compliance with the National Ambient Air Quality Standard. In these areas, various emissions such as fugitive dust and abrasive blasting might be more restricted than they are in other parts of the state. These nonattainment areas are subject to change, so restrictions must be determined on an individual case basis.

Other states have general particulate emission standards and fugitive dust and opacity restrictions that could be applied to bridge paint removal operations. For example, in Nevada the restriction on fugitive dust reads:

No person shall cause or permit the handling, transporting, or storing of any material in a manner which allows, or may allow, controllable particulate matter to become airborne. (Title 40, Chapter 445, Article 7.3),

and in Pennsylvania the opacity limit reads:

No person shall cause, suffer, or permit the emission into the outdoor atmosphere of visible air contaminants in such a manner that the opacity of the emission is:

- (1) Equal to or greater than 20 percent for a period or periods aggregating more than 3 minutes in any one hour; or
- (2) Equal to or greater than 60 percent at any time. (Title 25, Part 1, Chapter 123).

Most states have similar general air quality regulations, or at least they have a general nuisance law such as this one from Vermont:

A person shall not discharge, cause, suffer, allow, or permit from any source whatsoever such quantities of air contaminants or other material which will cause injury, detriment, nuisance or annoyance to any considerable number of people or to the public or which endangers the comfort, repose, health or safety of any such persons or the public or which causes or has a natural tendency to cause injury or damage to business property. (Title 10, Chapter 5-241).

In conversations with state officials it was learned that bridge paint removal operations usually receive very little attention and, therefore, little regulatory enforcement. Most states function on a complaint-received basis, and most officials contacted stressed that their first response would be to seek the cooperation of the contractor and/or transportation officials involved. If this route failed to produce results, they would then enforce the regulation and force compliance. Air pollution violations were not found to be very common, probably because conflicts are either resolved quickly (e.g., stopping when wind is too high or from the wrong direction) or are never resolved (e.g., the job is completed before the bureaucracy can act on the problem). On average, there is generally a poor line of communication between state highway departments and state environmental agencies.

Local Level

In a limited survey of 10 large metropolitan areas (see Chapter One), no specific air pollution ordinances were found that specifically regulate bridge paint removal, but a number of local ordinances do affect the operations. Most of the cities regulate abrasive blasting operations. They may specify that either wet blasting or enclosures be used, and they may regulate the kind of abrasives that can be used. Some require permits to perform abrasive blasting; this permitting process may also include filing a pollution control plan. Local governments have various fugitive and nuisance dust ordinances that an abrasive blasting operation might violate. Local officials seemed to be more aware of environmental problems from abrasive blasting paint removal than state officials; in fact some had taken action such as issuing citations to the contractor or transportation agency conducting a removal operation. They also seemed to be aware of the difficulties in developing and utilizing effective controls.

RELEVANT WATER REGULATION

Federal Level

No water regulations are directly applicable to bridge lead-based paint removal operations, but

there are regulations which apply to water quality that must be considered. First would be the lead and chromium water standards. The chromium standards are included in this discussion because lead chromate is often a component of lead bridge paint. The only standards currently in effect are for drinking water, with the maximum level of lead and chromium set at 0.05 mg/l for each chemical (40 CFR 141.11). This is 0.05 mg/l dissolved lead or chromium. Although paint debris can get into surface waters which serve as a drinking water source, it is very unlikely that these standards would ever be exceeded because the lead and chromium compounds in the debris are nearly insoluble. Also, lead and chromium are easily removed by normal water treatment procedures.

There are national ambient water quality criteria for lead and chromium. For human health, the lead criterion is identical to the drinking water standard, 50 µg/l; for aquatic life, the criterion is based on water hardness. For example, at hardness of 50, 100, and 200 µg/l as CaCO₃ the criteria are 0.75, 3.8, and 20 µg/l, respectively, as 24-hr averages; and the concentration of lead should not exceed 74, 170, and 400 µg/l, respectively, at any time (17). The chromium III criterion for human health is 170 µg/l; for freshwater aquatic life the criterion is based on water hardness. For example, at hardnesses of 50, 100, and 200 µg/l as CaCO₃, levels should not exceed 2,200, 4,700, and 9,900 µg/l, respectively, at any time. The chromium VI criterion for human health is 50 µg/l; for freshwater aquatic life the criterion is 0.29 µg/l as a 24-hr average, and concentration should not exceed 21 µg/l at any time (52). These criteria are not likely to be exceeded as a result of bridge paint removal operations because of the insolubility of the lead and chromium compounds in the residues.

Other federal water regulations that must be considered are the various requirements of the Federal Water Pollution Control Act, which is the federal law that addresses surface water pollution. This Act does not set national water quality standards, but requires the individual states to establish their own water quality standards and pollution regulations to prevent further deterioration of natural water systems and to clean up those waters already polluted. These standards and regulations vary from state to state and will be reviewed in the following section on state-level regulations.

A part of the Federal Water Pollution Control Act is the requirement that the states and federal government establish a permit system to reduce effluent discharged into water, the National Pollutant Discharge Elimination System known as the NPDES permits. NPDES permits are required by all point source discharges. Although point source is defined broadly enough to include concentrated animal feeding operations, it is generally confined to describing a municipal or industrial discharge. During the course of this study, all regulatory officials questioned considered a bridge paint removal operation a nonpoint source and no case of a decision to require an NPDES permit was found. Therefore, it is assumed the NPDES permit system and its stringent control requirements do not apply to bridge paint removal operations.

State Level

State and water regulations are varied and of two general types: regulations developed to comply with the Federal Water Pollution Control Act

and regulations addressing other water quality and pollution concerns in each state. No state has any water regulations directed specifically toward removal of lead-based bridge paints, but existing water regulations are potentially applicable to these operations.

Under the Federal Water Pollution Control Act (this includes provisions of the original Water Quality Act and the Clean Water Act), the states have been required to classify their rivers, streams, lakes, etc., as to their uses and quality. They also have had to develop means to control further degradation in water quality as well as clean up water found to be below minimum water quality standards. The federal law has suggested general standards, but these are only guidelines for the states to follow, so the states have adopted differing standards for various pollutants. State water quality standards for lead and chromium vary for each water classification, from Class A water (a drinking water source) to Class E water (source for agricultural irrigation). (Classification schemes also vary from state to state.) Some states have adopted the federal lead and chromium ambient water criteria as standards, some have modified them, and others have set no lead and chromium standards. Consequently, state lead and chromium standards cannot be easily summarized. The standards that have been set, however, are for dissolved lead and chromium; therefore, it is unlikely they would be exceeded by bridge paint debris entering the water. A summary of state water classifications and standards has been published (53, 54).

Besides dissolved chemical pollutants, the federal act requires the states to deal with "man-caused paint or nonpaint source discharges in concentrations that settle to form objectionable deposits or float as debris, scum, oil, or other matter to form nuisances." Some states have adopted this or similar language into a regulation prohibiting the addition of such material to bodies of water. For example, in South Dakota the law states:

There shall not be discharged or caused to be discharged into any lake or stream any raw or treated sewage, garbage, municipal wastes, industrial wastes, or agricultural wastes which produce floating solids, scum, oil slicks, material discoloration, visible gassing, sludge deposits, slimes, fungus growth, or other offensive effects (South Dakota Title 73, Article 3:02:13).

In addition to water regulations related to the Federal Water Pollution Control Act, states have two other areas of regulations potentially applicable to bridge paint removal operations: general or nuisance water pollution laws and permit and reporting requirements. Most states have very general or vague "Thou shall not pollute the water" regulations that cover situations not specifically mentioned in the regulations but which are causing pollution or creating a public nuisance. In conversations with state water pollution officials this type of regulation was cited almost exclusively as the authority under which they could take legal action against a bridge paint removal operation. Kentucky has such a law, for example, and it states:

It shall be unlawful for any person or municipality to put or place into any of

the waters of the Commonwealth, or allow or permit to be discharged from property owned or occupied by such person or municipality into any of the waters of the Commonwealth, any substance of any kind or character resulting in pollution as herein defined. Any such discharge is hereby declared to be a nuisance (Kentucky Title 35, Chapter 5, Article IV).

A summary of these state water quality criteria has been published (55).

The subject of permits and reporting requirements is also a difficult one to summarize. Many states require anyone causing water pollution to get a state permit or to file a report with the appropriate state agency. For example, in Florida the law states, "Any person intending to discharge wastes into the waters of the state shall make application to the department for an operation permit" (Florida Title 26, Chapter 413, Section 403.0883(3)(a)). Some states have provisions for temporary permits or short-term exemptions, but they still require that notification or application be made. In conversations with state officials, only the state transportation departments of Arkansas, California, Pennsylvania, and Wisconsin (or their contractors) were actually being required to get permits or to file pollution reports. This is an area where existing regulations could be more rigorously enforced in the future, thus requiring bridge paint removal operations to apply for a state permit and/or to file pollution reports. An integral part of the permit process in most states is the requirement to take measures to minimize water pollution.

Local Level

In a limited survey of city ordinances, no water regulations were found that are directed toward bridge paint removal operations, although some cities require that a permit be obtained to sandblast over water. Officials in charge of bridges in several cities reported using booms, barges, and tarps to catch material rather than letting it fall into the water. These efforts seemed to be in response to state rather than local regulations.

HAZARDOUS WASTE REGULATIONS

Disposal of solid waste, including hazardous waste, is regulated by authority of the Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976. The hazardous waste management regulations contain criteria for identifying characteristics of hazardous waste and possible hazardous waste, and for listing hazardous waste. The question is whether the paint material removed from a bridge is a hazardous waste because of its lead or its chromium content. If it is considered a hazardous waste under these regulations, special handling and disposal methods are required. These requirements would add considerable cost to bridge paint removal operations.

Waste material can be declared hazardous if the material has been placed on the list of designated, hazardous wastes; lead-based paint wastes are not on that list. Waste material may also be declared hazardous if it fails any one of four tests; materials containing lead, chromium, or their compounds are in this second category. The

first three tests, ignitability, corrosivity, and reactivity, do not apply to lead-based paint debris. The fourth test is the extraction procedure (EP) toxicity test, a method of determining the solubility of potentially toxic components of a waste. Paint chips and related waste from a bridge-cleaning operation must pass the EP toxicity test in order to be declared nonhazardous. It is the responsibility of the waste generator to see that the EP test is performed on the paint removal debris.

The EP toxicity test procedures are contained in 40 CFR 261, Appendix II, and are described briefly here. A representative sample of the waste to be tested (minimum size 100 g) should be obtained and separated into its component liquid and solid phases. The solid material is then evaluated for particle size; it must pass through a 9.5-mm (0.375 in.) sieve or else be crushed or ground until it is the acceptable size. This material is then weighed and placed in an extractor with 16 times its weight of deionized water. The extractor must agitate this mixture enough to prevent stratification for 24 hr. During that time pH must be maintained at 5.0 ± 0.2 , with 0.5 N acetic acid, but the amount of acid added should not exceed 4 ml of acid per gram of solid. Temperature is maintained at 20 to 40°C. At the end of the 24-hr extraction period, deionized water should be added to the extractor in the amount of

$$V = 20(W) - 16(W) - A$$

where V = ml of deionized water to be added

W = weight in grams of solids used

A = ml of acetic acid added to adjust pH

The material in the extractor should be separated into its component liquid and solid phases. The liquid is combined with the liquid obtained at the beginning of the test when the solids were separated out for extraction. This combined liquid must be analyzed for the presence of lead and chromium using EPA methods of atomic absorption. Full details on the methods are given in the EPA document, "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods," SW-846. If the level of lead or chromium in the extract exceeds 5.0 µg/l, the material is a hazardous waste (40 CFR 261).

If lead-based paint residue fails the EP toxicity test for lead or chromium, the residue will be classified as a hazardous waste and must be disposed of in accordance with hazardous waste regulations. Apparently most states do not consider these residues to be hazardous; however, this question was not specifically asked of the states during this study. Massachusetts requires disposal in an EPA approved hazardous waste disposal facility, which means the wastes must be sent out of the State (at great expense) because there is no in-state disposal facility; California allows disposal in what they call a Class II disposal facility, defined as a facility which may overlie or be adjacent to usable groundwater. Class I facilities in California are defined as facilities which are designed so there is no possibility of pollutant discharge to usable waters from them. Usable groundwater may underlie the site, but only under extreme cases where geologic conditions prevent waste movement to the water.

There are very few data showing results of EP toxicity tests run on lead paint residues, which probably means the tests are not commonly run.

Because it is the responsibility of the generator to have the tests run, it seems that the generators (1) have chosen to assume that the residues are not hazardous or (2) have not considered the question because they have been given no guidance by the state. If the wastes are found to be hazardous by EPA standards, it becomes costly to dispose of them, and the repainting job also becomes costlier to the state (or local) transportation agency.

The only EP toxicity test data received during conduct of the study were from Massachusetts. Ten bridges in the state under the authority of the Massachusetts Department of Public Works (MDPW) and two under the Massachusetts Port Authority (Massport) had their lead paint residues tested using the EPA extraction procedure for solid wastes. Residues from the 10 MDPW bridges and one Massport bridge failed to meet the 5-ppm allowance for lead in the extract (56, 57). However, residues from Massport's Tobin-Mystic Bridge passed the EP toxicity test. Many people contacted during this study said they had run EP toxicity tests on lead residues but had no data. Based on these conversations, on the Tobin bridge results, and on the MDPW data, it is possible that whether the paint residues pass or fail the EP toxicity test may depend on the type of lead-based paint contained in the residues. It is possible that residues with only lead tetraoxide, or red lead, and possibly basic lead chromate can pass the test, but other lead compounds cannot. The paints on the 10 MDPW bridges contained red lead and blue lead (lead sulfide). On the one Massport bridge, the lead compounds were unknown, but it was speculated that the 60-year-old structure had "everything" on it, including basic lead carbonate (white lead), red lead, and basic lead chromate.

There are not enough data available to conclude whether any one particular lead paint residue is a hazardous waste or not according to the EPA definition of hazardous wastes. It is safe to say that each residue should be tested separately. If the lead paint composition of each residue is known, a body of data will eventually be accumulated which will permit a decision to be made about whether a bridge paint is hazardous before it is removed from the bridge.

California has adopted its own extraction procedure for solid wastes, and it is more rigorous than the EPA procedure. Extraction is performed with citric acid buffered to pH 4 (58). Because lead is very soluble in citric acid, any lead paint residue extracted using this procedure will exhibit a large amount of lead, even if red lead is the lead compound in the residue.

It should be noted that lead is nearly immobile in soil; and, even if paint residues fail the extraction tests, it is very unlikely that lead leached from buried residues will move into the groundwater. Free lead forms insoluble precipitates with carbonate and sulfate anions and can also be strongly adsorbed to clay particles.

OCCUPATIONAL EXPOSURE REGULATIONS

Federal Level

Several regulations of the Occupational Safety and Health Administration (OSHA) to limit worker exposure to silica and inert dust would apply to bridge paint removal operations. The limits have been set as:

Silica

Quartz (respirable) - $(10 \text{ mg/m}^3) \div (\% \text{ SiO}_2 + 2)$

Quartz (total dust) - $(30 \text{ mg/m}^3) \div (\% \text{ SiO}_2 + 2)$

Inert or nuisance dust

Respirable fraction - 5 mg/m³

Total dust - 15 mg/m³

These values are the 8-hr time weighted average limits for a worker in any 8-hr work shift of a 40-hr week (29 CFR 1910). The silica limit is used when the dust contains greater than 1 percent quartz; otherwise the inert or nuisance dust limit applies. In the case of paint removal from a bridge using dry sandblasting, worker exposure is likely to exceed these limits and respiratory protection is required.

State Level

States are free to set their own stricter standards, but many have adopted the federal OSHA exposure limit values. State occupational exposure regulations were not investigated in this study.

SPECIFICATIONS AND RELATED STATE TRANSPORTATION DEPARTMENT POLICIES

Even though there are no federal or state environmental regulations specifically directed at bridge lead-based paint removal, the environmental aspects of these operations have not been ignored by state and local transportation officials. Several state transportation departments have developed specifications to address environmental issues surrounding bridge paint removal operations. These are not official regulations however; instead, they are clauses included in contracts let by the states for paint removal that require the contractor to follow certain procedures to reduce pollution. They are enforceable to the extent that they are part of a legally binding contract, and payment is usually dependent on the contractor meeting all the contract specifications. In a survey of the states, four were found to have developed specifications that are routinely included in their bridge painting contracts. The four states are Wisconsin, Iowa, Minnesota, and Indiana, the states in the first category shown in Table B-1. All of them require that controls be used in an attempt to reduce water pollution. The first three require the use of drop cloths under the bridge, and all four require the use of floating booms.

In Wisconsin, contractors must make a reasonable effort to contain paint chips and sand. Indiscriminate dropping or shoveling of spent cleaning material into the water or onto the ground below is prohibited. No blasting or cleaning is allowed if wind is in excess of 15 mph. A cover material must be put over the ground, extending 5 ft beyond the side of the bridge. When over water, a cover must be suspended at a 45-degree angle sloping to the bank and extending 12 ft in length and 5 ft beyond the bridge sides. When the upper trusswork is being cleaned, a platform at curb level with side deflection devices must be constructed to catch falling material. Water booms are required to contain the scum and floating debris in water. Spent material on the floor of the bridge, covers, and the water booms must be removed daily, or more frequently if necessary, and it must be disposed in an approved manner.

Iowa's specifications were patterned after those of Wisconsin with the added proviso that special abrasives may be required in urban or sensitive areas. A copy of Iowa's specifications is included as Figure B-1.

Minnesota's specifications require the use of drop cloths, curtains, and water booms, to contain paint overspray, paint pails, and rags, as well as to catch as much sand and as many paint chips as are readily recoverable. Catchment systems are to be emptied as often as necessary to maintain their structural integrity. Work must be suspended during unfavorable weather conditions that would reduce the effectiveness of controls. All sand and paint chips on the bridge deck and stream bank must be cleaned up. All spent cleaning materials must be disposed of in an approved manner.

In Indiana the specifications state, "The contractor shall retain paint particles resulting from cleaning and blasting operations over waterways. He shall employ the use of booms and skimmers in order to prevent any paint particles from floating downstream." The main concern seems to be for floating paint chips. Waste material is to be removed from the water and booms prior to settling and disposed of in an approved manner. Blasting and cleaning are not to be performed in the vicinity of the stream on days when the wind velocity is such that it prevents the retention of paint particles.

The second category of specifications in Table B-1 contains 10 states that require contractors to take steps to prevent pollution and comply with general pollution regulations but do not specify how this is to be performed. Some require contractors to officially notify the state environmental departments of their activities (e.g., Arkansas, Connecticut), but others leave the full responsibility of controlling emissions with the contractor. In the latter approach, inconsistent levels of control can result within a given state. In some states, compliance with regulations is closely supervised. California, for example, requires contractors to control all emissions from bridge paint removal operations instead of requiring the use of certain control procedures.

The third category of specifications in the table contains states that require controls only as the situation dictates. Most transportation department officials contacted were aware of the environmental problems posed by bridge paint removal. Some have a policy of cooperating with state pollution, health, and wildlife agencies. If they receive complaints from another state agency or if the work is being done in a sensitive area, e.g., in a trout spawning area or an urban residential area, they may require the use of tarps, water booms, or other controls. But this is strictly an informal, situational use of control measures.

The fourth category of specifications in Table B-1 lists states that currently have no specific policy related to bridge paint removal controls. In most of these states, environmental problems associated with bridge paint removal operations have not been an issue.

Some local governments include contract specifications similar to those found in state contracts (see Table B-2). In a limited survey of 10 cities, 4 cities (Boston, Chicago, Cleveland, and Philadelphia) were found to have specifications that require the control of emissions from abrasive blasting on bridges, but they do not specify the type of control. In Washington, D.C.,

IOWA DEPARTMENT OF TRANSPORTATION
Ames, Iowa



SPECIAL PROVISIONS
FOR
REPAINTING BRIDGES
(Environmental Protection)

February 16, 1982

THE STANDARD SPECIFICATIONS, SERIES OF 1977, ARE AMENDED BY THE FOLLOWING ADDITIONS. THESE ARE SPECIAL PROVISIONS AND SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

390.01 GENERAL. The contractor shall make a reasonable effort to contain old paint chips, corrosion residues, and spent abrasives, herein referred to as waste materials, resulting from blasting and other cleaning operations. Caution shall be exercised to avoid depositing or dropping waste materials into water and onto the ground or roadways below the structure outside the specified containment areas.

Blasting or other cleaning operations shall not be performed when the direction or velocity of prevailing winds prevents reasonable containment of waste materials or, in the opinion of the engineer, causes a pollution problem. If wind or other factors prevent reasonable containment where containment is specified, drapes may be utilized to minimize drift beyond all containment areas.

390.02 CONTAINMENT. Specific containment procedures may be specified on the proposal as "Regular Containment" and "Special Containment." When specified, the contractor shall follow the specified procedure.

A. Regular Containment shall consist of the following:

1. **Ground and Roadway Coverage.** The contractor shall provide coverage on or over the ground and roadways under the structure in the work area, capable of catching and holding waste materials. A highway pavement and paved shoulder under a structure, from which wastes may be collected and removed by sweeping, may be used as the containment cover for that area; such containment shall be on lanes and shoulders closed to public traffic. Containment on railways under the structure shall be limited to areas outside the railroad track clearance line, and no containment is required on the railway roadbeds. The cover shall include all ground areas within the streambed that are above the existing water line and sustain vegetation. The length of the cover shall be determined by the length of the work area, and the width shall be at least 5 feet greater than each side of the area directly under the steel to be cleaned. Edges of the cover shall be turned upward to minimize loss of waste materials. Covers on or over roadways shall not present a hazard of any kind and shall not remain in place overnight.

2. **Waterway Coverage.** The contractor shall provide a cover that laps and continues from the ground cover provided and extends upward over the water at an angle of about 45 degrees. The cover shall be capable of holding and deflecting the waste materials towards the waterway-bank and shall be at least 12 feet in length and at least 5 feet wider than each side of the area directly under the steel to be cleaned. The cover shall be anchored at the waterway-bank with the end over the water suspended from the structure. If an obstruction is encountered, such as a pier in the water near the shoreline, the cover shall extend from the bank to the obstruction. Outside edges of the cover shall be turned upward to minimize loss of waste materials. The cover shall not remain in place overnight if it presents a hazard of any kind.

3. **Floating Waste Materials.** The scum that forms on the water, from waste materials that do not sink in place, shall be contained from moving upstream or downstream by use of straw dams or floating boom devices. If the scum tends to collect at the containing device, it shall be contained, collected daily, and not allowed to travel beyond the device. The straw used for damming shall be replaced with clean straw weekly or as needed.

4. **Disposal of Waste Materials.** The contained waste materials that remain on the bridge deck, on the ground covers, and on the waterway covers shall be removed at least once a day or more frequently, if required. No waste materials shall remain on the bridge deck or containment covers overnight. Waste materials shall not be removed through floor drains or by throwing them over the side of the bridge. The contained waste materials and used straw from dam devices shall be disposed of at a legal disposal site.

The contractor may use other methods or modifications, subject to approval of the engineer, that will accomplish the results intended by this specification.

B. Special Containment shall consist of the same measures required for regular containment, except for waterway coverage, where the contractor shall provide cover over the waterways in the work area, capable of catching and holding waste materials. The cover shall meet the requirements specified for regular containment over ground and roadways.

When the bridge location and characteristics or the surrounding topography do not lend themselves to the specified control measures, modifications may be approved by the engineer or specific control measures may be specified in the special provisions.

390.03 SPECIAL ABRASIVE. The quality of abrasive for normal work is specified in the General Supplemental Specifications. Use of a special abrasive may be required by a note on the proposal, generally when the work is in an urban or other sensitive area.

When special abrasive is required, blast cleaning shall be with a material approved by the engineer as a special abrasive for this use, in accord with I.M. 482.03. The material shall be a silica sand or approved equivalent. The following brands and sources are currently approved.

Granusil: Unimin Corp., Le Sueur, Minnesota.

Flint-Shot: Ottawa Silica Co., Ottawa, Illinois.

Clayton washed and dried sand #410: Martin-Marietta, Clayton, Iowa.

Various grades of abrasive may be available from these sources. The contractor should select the grade best suited for his operation.

390.04 BASIS OF PAYMENT. Add the following to the second paragraph of 2508.12:

Figure B-1. Sample copy of Iowa specifications.

Table B-2. Status of bridge paint removal controls and paints used in 10 large metropolitan areas.

		METROPOLITAN AREA									
		Boston	Chicago	Cleveland	Detroit	Houston	Miami	New York	Philadelphia	St. Louis	Washington D.C.
Status of Paint Removal Controls	Specific Control Techniques Required										
	Control Required, But Techniques Not Specified	•	•	•							•
	Controls Used Only As Situation Dictates				•			•	•	•	
	Currently No Specific Policy Related to Control					•	1				
Permit or Notification Required		•	•	•							•
Type of Control Measures Used	Tarps	•	•	•	•			•	•	•	
	Water Booms								•		
	Boats and Barges				•						
	Other	2	3								4
Common Removal Methods Used	Abrasive Blasting	•	•	•	•			•	•	•	•
	Power Tool			•		•	•	•			•
	Hand Clean		•	•		•	•	•			•
	Other										
Paints Currently Used	Red Lead	•	•	•							
	Basic Lead Silicochromate	•	•		•		•	•	•	•	
	Zinc Rich	•		•	•		•	•			•
	Other (Iron Oxide, Aluminum, etc.)	•	•	•		•	•	•			

1. Abrasive blasting not allowed because they are in aquatic preserve area. They also have drawbridges whose mechanisms can be fouled by blast grit.
2. Total enclosure specially constructed for Tabin -Mystic River Bridge.
3. Chicago Transit Authority has used a movable enclosure that consists of a large room with tarps for walls.
4. Requirement to contain emissions has only recently been enforced; no control methods have been designated yet.

the Bureau of Construction and Maintenance was in the process of changing its contract specifications to bring bridge repainting operations into compliance with city environmental restrictions. These restrictions require that all blasting in Washington, D.C., be enclosed. Four other cities require the use of controls as the situation dictates.

SUMMARY OF REGULATIONS

There are numerous federal, state, and local regulations that might be applicable to various aspects of bridge paint removal operations. On the federal level are ambient air, drinking water, occupational exposure, and hazardous waste regulations. From the states there are general regulations of air and water pollution, permitting and

reporting processes, and contract specifications. On the local level there may be ordinances similar to state regulations but differing in their specific requirements.

In most jurisdictions, these regulations and requirements are only loosely enforced with respect to bridge paint removal operations. Most enforcement action originates as the result of complaints filed with the cognizant agency. If officials choose to enforce regulations on their books, the regulations in place at most jurisdictional levels in the country are sufficient to require environmental controls on any paint removal operation.

Contractors and those responsible for bridge paint removal operations should be familiar with the potentially applicable regulations for each site. These regulations vary from location to

Table B-3. Environmental regulations that may have an impact on bridge paint removal operations.

Environmental Regulation	Comment
National ambient standard for lead	1.5 $\mu\text{g}/\text{m}^3$ averaged over calendar quarter
National ambient standard for particulate matter	
Primary (effective Dec. 31, 1982)	75 $\mu\text{g}/\text{m}^3$ annual mean
Secondary	260 $\mu\text{g}/\text{m}^3$ max 24 hr
	60 $\mu\text{g}/\text{m}^3$ annual mean
	150 $\mu\text{g}/\text{m}^3$ max 24 hr
National drinking water standard for lead	0.05 mg/l dissolved lead
National drinking water standard for chromium	0.05 mg/l dissolved chromium
State abrasive blasting regulations	Usually applied only to buildings
State nonattainment area restrictions	Vary from site to site
State particulate emission standards, fugitive dust or opacity restrictions	Each state has at least one of these to cover dust levels
State water classification and restrictions	Restrictions vary with use classification
State ambient lead and chromium standards	Pertains to dissolved form, residues unlikely to exceed
State permit and reporting requirements (air and/or water)	May have to get permit or report activities
State prohibition of floating debris, etc.	Most states have general water regulations
Hazardous waste status from EP test	If fails, special disposal required
State waste disposal restrictions	Disposal restrictions vary with state
Federal OSHA standards for silica	Vary with quartz level and size
Quartz (respirable)	10 mg/m ³ divided by % SiO ₂ + 2
Quartz (total dust)	30 mg/m ³ divided by % SiO ₂ + 2
Federal OSHA standard for inert or nuisance dust	Applies if quartz \leq 1% of dust
Respirable fraction	5 mg/m ³
Total dust	15 mg/m ³
State contract specification	More effective than regulation when used

location. Table B-3 provides a list of the regulatory areas that should be investigated, as well as the general federal standards in effect.

POTENTIAL FOR REGULATORY VIOLATIONS

This section examines the potential for bridge paint removal to violate existing regulations. Because abrasive removal is potentially the most environmentally damaging and the most common of the removal practices, it is the method used in this discussion to demonstrate how violations of regulations can occur.

National Ambient Standard for Lead

It is unlikely that this standard will be exceeded by an operation that has some type of emission controls. For uncontrolled operations, it depends on where air monitors are located. It is possible, but not too likely, to exceed the standard in the immediate vicinity, because values are averaged over a calendar quarter. Also, the large majority of lead particles fall through the air very quickly and are deposited on surfaces below.

National Ambient Standard for Particulate Matter

Because the standard (both primary and secondary) is an annual mean, it is unlikely that it will be exceeded by a temporary operation such as abrasive blasting of bridges. The 24-hr maximum standard might be exceeded if air monitors are located close to the operation and if wind direction is towards the monitors. The majority of the

particulates will fall very quickly to the surface beneath, however.

National Drinking Water Standard for Lead

This will not be a factor because the compounds in the residues are nearly insoluble and because standard water treatment methods precipitate lead from drinking water.

National Drinking Water Standard for Chromium

The same reasoning would apply for chromium as with lead.

State and Local Abrasive Blasting Regulations

These are usually applied only to buildings, but in some places (e.g., California and Washington, D.C.) approval or permits are required before operations begin. With approval may come restrictions (e.g., hours of operation, type of grit, shrouding). It is not uncommon for the transportation agency or environmental agency, or both, to use discretion by not applying these regulations because bridge structural integrity is given priority and because controls are costly and extremely difficult to apply to the operation.

State Nonattainment Area Restrictions

The bridge may be in a nonattainment area, and abrasive blasting may even be prohibited or require stringent emission controls; or the nonattainment area may be for a pollutant that is not

produced during abrasive blasting, in which case there may be no restrictions applied to removal operations.

State Particulate Emission Standard, Fugitive Dust or Opacity Restrictions

These standards and restrictions are usually not applied to bridge paint removal operations but can be if complaints are received about dust levels across property boundaries. Opacity standards are usually applied to smoke, but California and possibly other states or cities also use opacity readings on dust plumes from abrasive blasting.

State Water Classifications and Restrictions

A bridge may be over a stream or body of water that has been given a specific classification by a state agency. This classification might restrict what can be placed in the stream; for example, a stream might have been identified as an excellent trout stream and classified accordingly, and restrictions on this classification might state that no abrasive blasting debris of any kind could fall into the stream. Each state classifies its streams differently (55), and restrictions on what can be placed in the water vary from state to state and from classification to classification. The restrictions might even suggest types of controls that paint contractors should use to control debris (e.g., tarps or floating booms).

State Ambient Water Lead and Chromium Standards

The states develop their standards for lead and chromium based on the national ambient water quality criteria. These criteria pertain to dissolved lead and chromium in water. It is highly unlikely that residues entering water will create problems that violate state standards. The most recent compilation of state standards by EPA is dated July 1980 (56, 57).

State and Local Air and Water Permits and Reporting Requirements

A number of metropolitan areas and a few states require that an abrasive paint removal operation obtain a permit or other clearance from the appropriate agencies that oversee air and water quality. It is the responsibility of the contractor to do this and to comply with the terms of the permit. The requirement of a permit to sand blast is loosely interpreted in some locales and strictly enforced in others. Sometimes a letter of notification of the sand blast operation is all that is required. Each locale is different, and the contractor cannot rely on the transportation agency to know the proper procedure because the line of communication between these agencies is often weak.

State Prohibition of Floating Material

All states have a provision covering floating

debris, scum, etc. (required by the Clean Water Act), and it is this provision that is most often applied to bridge paint removal operations. Most states apply the provision only on a complaint-received basis; others are more vigorous in their enforcement. Small paint chips can float on water for some time and thus are relatively obvious as environmental degradation.

Hazardous Waste Status from EP Test

It is the contractor's responsibility to have an EP toxicity test performed on the residues. The fact that this test is not commonly done might indicate that the states do not perceive the wastes to be hazardous or that they are influenced by the costs of disposing of the material. Current disposal practices do not appear to be creating environmental problems as long as the debris is not left where it can be resuspended or ingested by animals or humans. Burial of the debris appears to be safe practice; however, if the debris is determined to be hazardous, this practice needs to be reviewed.

State Waste Disposal Restrictions

State disposal restrictions vary; and if waste is declared hazardous by the state, disposal options are both limited and costly.

Federal OSHA Standards for Silica and for Inert or Nuisance Dust

The contractor must abide by OSHA standards for particulates when doing abrasive blasting. One problem often overlooked by many contractors is that the OSHA standard for silica is applied if the dust contains greater than 1 percent silica. The silica content of the abrasive should be known before using it for blasting. The wearing of hoods with an independent air supply solves this problem, but workers near the abrasive blasting operation should also take precautions.

State Contract Specifications

Contract specifications can be more effective than environmental regulations because they can be tailored to a specific job and supervision of compliance is easily accomplished by the on-site transportation agency inspector. There is incentive for compliance because a violation of specifications can be costly to the contractor. On the other hand, if an inspector sees that a contractor is making best efforts to comply with the specifications of the contract but is having problems, the inspector can decide to overlook the problems. One drawback to this scenario is that inspectors are not in a position to decide if environmental regulations are being violated. The inspector's job is to ensure that the paint job is done efficiently and properly. Environmental concerns are not a top priority with inspectors, and violations could result in even greater costs to the transportation agency.

APPENDIX C

METHODS FOR ANALYZING LEAD IN ENVIRONMENTAL SAMPLES

This review of environmental testing methods will concentrate on analytical methods already developed and being used to analyze lead in a range of environmental samples: airborne particulate matter, soil, plant tissues, surface or ground water, aquatic life, human fluids and tissues, and solid waste leachates. These methods and their analytical suitability for environmental sampling, cost-effectiveness, and current acceptability among government regulatory agencies will be described.

It is worthwhile noting that the entire field of analytical chemistry is rapidly changing, fueled by increasing analysis requirements and the continuing evolution of more sophisticated computer-controlled instrumentation (59-62). As appropriate, mention will be made of some relatively new analysis methods, although truly novel analytical schemes for measuring lead that are not commercially available will be left for future reviews.

Any of a number of instrumented analysis methods can be employed to measure lead in a range of environmental samples and at a range of levels, from high levels in paint chip particulates to quite low levels in natural waters. A specific sample preparation scheme is employed to permit optimum use of any one of these methods. The sample preparation method is a function of the sample type, lead concentrations anticipated, and the instrumental analysis methods available for use. In most cases more than one instrumental analysis technique will be available. One typically matches up instrumental analysis capabilities with the environmental type and lead concentration. Then a sample preparation and instrumental analysis method is used that satisfies the technical and cost requirements of the environmental study.

For example, two types of samples, unfiltered water and sediment, are collected to measure the amount of lead available to biota in a given pond. The unfiltered water is expected to have a total lead concentration less than 5 $\mu\text{g/l}$, while the sediment concentration for lead is perhaps 10 $\mu\text{g/g}$ sediment. The following types of instrumental analysis equipment are available: flame or furnace atomic absorption spectrophotometer, anodic stripping voltammetry (ASV) analyzer, and inductively coupled plasma (ICP) emission spectrometer. The low level water samples are acidified to a $\text{pH} < 2$ since total lead concentration is sought. Two instrumental analysis methods have sufficient sensitivity to detect lead in the water: ASV analysis or furnace atomic absorption spectrophotometry (AAS). Furnace AAS is considered more reliable and is less expensive.

The sediment samples need to be dried to provide an accurate basis for quantitative analysis. A nitric acid wet digestion is selected to solubilize all the lead from the sediment. The solubilization will result in a 100-fold concentration dilution of lead in the nitric acid digest versus the sediment. Because only lead concentrations are desired, it is not cost effective to use the

more expensive multi-elemental ICP emission spectrometric method. The most rational approach is first to analyze the samples by flame AAS, which is reliable and much less expensive than either the ASV or furnace AAS method. Those sediment digestions with lead concentrations below the flame AAS detection limits will then be reanalyzed by furnace AAS.

The purpose of this review is to equip the readers with enough general knowledge of available analytical methods for lead in environmental samples to permit them to begin the selection process for the optimum method for analyzing lead in a particular study.

This review first discusses sampling methods and preparation methods separately. Then each instrumental analysis method is reviewed. This organizational approach was done primarily because many of the instrumental methods can be applied to most sample types provided an appropriate preparation method is used and detection limits and interferences are considered.

SAMPLING AND SAMPLE PREPARATION

Air Particulates

The accepted method for sampling airborne particulates containing lead is collection with a high-volume (hi-vol) sampler. The high volume method is summarized in the U.S. Environmental Protection Agency (EPA) Quality Assurance Handbook for Air Pollution Measurement Systems (63) as follows:

Air is drawn into a covered housing and through a filter by means of a high-flow-rate blower at a flow rate (1.13 to 1.70 m^3/min ; 40 to 60 ft^3/min) that allows suspended particles having diameters of less than 100 μm (Stokes equivalent diameter) to collect on the filter surface. Particles within the size range of 100 to 0.1 μm diameter are ordinarily collected on glass fiber filters. The mass concentration of suspended particulates in the ambient air ($\mu\text{g}/\text{m}^3$) is computed by measuring the mass of collected particulates and the volume of air sampled.

This method is applicable to measurement of the mass concentration of suspended particulates in ambient air. The size of the sample collected is usually adequate for other analyses.

When the sampler is operated at an average flow rate of 1.70 m^3/min (60 ft^3/min) for 24 hr, an adequate sample will be obtained even in an atmosphere having concentrations of suspended particulates as low as 1 $\mu\text{g}/\text{m}^3$.

Based upon collaborative testing, the relative standard deviation for single analyst variation (repeatability of the

method) is 3.9%. The corresponding value for multilaboratory variation (reproducibility of the method) is 5.6%.

The use of hi-vols for sampling emissions from abrasive bridge paint removal operations in urban areas has some limitations. Beyond 200 yd from the bridge, it is very difficult to locate the dust plume because buildings create tricky wind shifts and because the plume is so widely dispersed at this distance. It is also impossible to eliminate contributions from other lead pollutant sources or distinguish between two different sources.

The EPA-approved reference method for lead analysis of air particulates (64) calls for leaching of the lead from the filter particulates with hot 3M nitric acid.

Other fiber substrates can be used. Two procedures for airborne lead approved by the National Institute for Occupational Safety and Health (NIOSH) (65, 66) use a 37-mm diameter 0.8- μ m cellulose ester filter that is ashed with concentrated nitric acid and diluted with deionized water. Cellulose ester filters have two advantages over glass fiber filters with regard to sample preparation. First, the cellulose ester wet ashing procedure is more vigorous than the glass fiber filter leaching procedure, so there is no doubt that all lead present on the cellulose ester filters is solubilized for chemical analysis. Second, work at Midwest Research Institute (MRI) has indicated that the trace metal filter blank concentrations are lower for cellulose ester than for glass fiber filters (Table C-1).

Soil

A variety of procedures have been used to determine the lead content of soils, but they fall into two major categories. First are the soil leaching procedures used for agricultural purposes (67). These consist of aqueous buffers and chelator media used to extract the biologically available or mobile fraction of lead and other cationic species in the soils. Second are the vigorous wet ashing techniques designed to analyze the total lead content of the soil. These methods use combinations of concentrated nitric, sulfuric, hydrochloric, and occasionally perchloric acid in heated open or sealed containers.

The procedure most suitable for a given study will dictate which method is most appropriate.

Plant Tissues

After plants have been carefully collected, washed, and dried, a vigorous ashing procedure is needed to determine total lead content. The preferred scheme is wet ashing using combinations of concentrated nitric, sulfuric, or hydrochloric acid and heat. Another approach commonly used for some metals in organic material is dry ashing, i.e., heating the tissues at 500°C, followed by the dissolution of the nonorganic residue with acid. By this method, however, lead and several other elements are lost because of volatilization (68). Therefore, even though some sample contamination occurs due to lead in the concentrated acids, wet digestion is the predominant means of preparing plant tissues.

Table C-1. Comparison of blank filter elemental analyses for spectrograde glass fiber and cellulose ester* 8-inch by 10-inch filters (total micrograms).

Element	Glass Fiber ^a	Cellulose Ester ^b
Ag	< 6.8	< 4.8
Al	2,800 \pm 500	< 17
As	< 74	20 \pm 8
B	3	43 \pm 12
Ba	141 \pm 34	0.77 \pm 0.67
Be	< 0.81	< 1.1
Ca	4,200 \pm 800	250 \pm 160
Cd	< 2.7	< 1.1
Co	< 6.1	< 2.6
Cr	< 8.5	< 3.7
Cu	< 2.4	< 2.1
Fe	34	8.2 \pm 7.7
Hg	< 27	< 17
K	510 \pm 170	< 48
Mg	1,700 \pm 500	39 \pm 16
Mn	< 14	< 0.53
Mo	< 10	< 2.1
Na	8,700 \pm 1,200	260 \pm 73
Ni	< 8.8	< 4.8
P	< 68	23 \pm 15
Pb	< 51	< 22
Sb	< 47	< 25
Se	< 223	< 26
Sn	< 37	23 \pm 5
Ti	< 14	< 1.6
Tl	< 68	< 26
Y	< 1.7	< 1.6
Zn	109 \pm 26	32 \pm 8

* Cellulose ester filters measuring 8 in. x 10 in. were not available. Therefore, 37-mm diameter filters were used and the mass multiplied by 48 for the correction to 8 in. x 10 in. size.

^a Means of preparation and analysis of three samples. Due to high amounts of Al, Ca, and Na, greater sample dilution was necessary for the glass fiber filters.

^b B not quantitatively determined since H₂BO₃ was added to the HNO₃/HF digestion to neutralize the excess F.

Surface and Ground Waters

Accurate chemical analysis of lead at levels less than 10 μ g/l in natural waters requires special care during sampling, sample handling, and instrumental analysis (69). Very pure water and acids must be used. All plastic and glassware must be rigorously acid washed and rinsed, and stored in plastic bags to prevent contamination.

No sample preparation is required for measurement of total lead in surface or ground water other than acidification to a pH < 2 with double-distilled HNO₃.

Aquatic Life

Fish, shellfish, and other aquatic life to be monitored for lead uptake and accumulation need to be collected in cleaned plastic equipment rinsed with deionized water, and wrapped in clean plastic before immediate freezing. A variety of

subsequent homogenization techniques can be employed for determining lead per total sample mass. Likewise, some studies require sampling of specific tissues in an organism. In all cases, lead contamination must be monitored and quantified. As with plants, wet ashing is the preferred dissolution technique for aquatic animal tissues. Stronger oxidation is required for animal tissues. Therefore, sulfuric or perchloric acid is often used with nitric acid to complete sample digestion (68).

Human Fluids and Tissues

Human blood and urine are frequently analyzed for total lead. An acid digestion is usually performed on the fluids prior to instrumental analysis, although some methods have been developed for blood that require only water dilution (70).

Human tissues are prepared analogously to other animal tissues, with a wet oxidation of nitric acid and either sulfuric or perchloric acid as needed.

Solid Waste Leachates

With the implementation in 1980 of EPA's final regulations under the Resource Conservation and Recovery Act (RCRA), solid waste must be tested to determine if harmful amounts of lead and other hazardous metals or compounds would leach from the waste if it were placed in a landfill. The test is called the extraction procedure (EP) toxicity test, and a description of the method is given in the Hazardous Waste Regulations section of Appendix B of this report.

This test is a laboratory 24-hr leaching experiment using acetic acid. The leachate is then directly instrumentally analyzed for lead. The maximum contamination limit below which the waste is not hazardous for lead is 5.0 mg/l leachate.

STANDARD REFERENCE MATERIALS

An essential part of the chemical analysis of unknown environmental samples for lead is analysis of standard reference materials (SRMs) that contain known amounts of lead. The two major sources of environmental reference materials are the National Bureau of Standards and the Environmental Protection Agency. Table C-2 summarizes the available SRMs and their certified lead concentrations.

In addition, some environmental research studies generate and archive additional subsamples that might be available if one inquired of the researchers in charge.

COLORIMETRIC SPECTROPHOTOMETRY

Description and Ease of Use

Diphenylthiocarbazone (dithizone) quantitatively forms an intensely colored chelate with lead and 16 other metals (71). The lead dithizone compound absorbs light at a 510-nm wavelength; therefore, the concentration of lead as the chelate can be determined with a spectrophotometer. Formulation of metal chelates is pH dependent; lead dithizone formation requires a pH between 8.5 and 9.0. Citrate must be added to prevent precipitation of alkaline earth and transition metal

Table C-2. NBS and EPA standard reference materials containing lead.

Source	SRM I.D. Code	Pb (µg/g)
NBS ^a	1632a Bituminous Coal	12.4
	1633a Coal Fly Ash	72.4
	1635 Subbituminous Coal	1.9
	1643 Water	0.027
	1645 River Sediment	714.
	1646 Estuarine Sediment	In preparation
	1648 Urban Particulate	6,550.
	1579 Powered Lead Base Paint	118,700.
	1570 Spinach	1.2
	1571 Orchard Leaves	45.
	1573 Tomato Leaves	6.3
	1575 Pine Needles	10.8
	1577 Bovine Liver	0.34
	2676a Metals on Filter Media	6.94-29.6 µg/filter
EPA ^b	WS378 2 Drinking Waters	0.022, 0.038
	WP475 3 Wastewaters	0.080, 0.018, 0.250
	WP476E 3 Wastewaters	0.030, 0.383, 0.113
	WP976 Municipal Digested Sludge	519.

^a National Bureau of Standards, Office of Standard Reference Materials, Room B311, Chemistry Building, Washington, D.C. 20234. Phone: (301) 921-2045

^b U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory-Cincinnati, Cincinnati, Ohio 45268. Phone: (513) 684-7325

hydroxides and phosphates. Cyanide is added to prevent formation of copper, zinc, and other transition metal dithizone chelates. Lastly, a reducing agent is added to prevent oxidation of the dithizone.

This method is well developed and simple, and the equipment required is inexpensive. However, it is labor intensive compared to many other methods, prone to solution phase interferences, and has a detection limit of 0.08 µg/ml.

Costs

The reagent chemical and instrument costs of colorimetric spectrophotometry are low compared to other methods. However, the labor costs to perform the sample preparation, manual instrumental analysis, and analysis data evaluation and reduction are high compared to those of more automated instrumental analysis methods such as atomic absorption spectrophotometry.

Frequency of Use

Because of the rather high detection limits and labor expenses associated with this method, other analysis techniques, particularly atomic absorption spectrophotometry, have replaced the dithizone colorimetric method for routine lead analyses

in many cases.

Acceptability by Regulatory Agencies

Both the Association of Official Analytical Chemists (73) and the American Public Health Association (72, p. 206) have approved methods for lead analysis by dithizone colorimetry.

ATOMIC ABSORPTION SPECTROPHOTOMETRY

Description and Ease of Use

Since the mid-1960s, atomic absorption spectrophotometry (AAS) has grown in popularity to become one of the most widely used instrumental analysis techniques for lead and other trace elements in environmental samples. The determination of lead or other analytes in a liquid (usually) or solid begins by quantitatively atomizing the sample to release gaseous ground state analyte atoms to appear in the path of an intense monochromatic light source. The wavelength of the light source is selected to permit absorption of the light by the gaseous analyte atoms by an amount proportional to the concentration analyte in the sample. This relationship is called Beer's law:

$$\log \frac{I_0}{I} \epsilon bc = A$$

where log = base 10 log

I_0 = light intensity of the light with no absorption

I = light intensity of the light with sample absorption

ϵ = molar absorptivity of the element

b = thickness of the path through the sample

c = concentration of the element

A = absorbance

There are currently two principal ways by which samples are atomized for lead analysis:

1. Flame atomization consists of aspirating a liquid sample into a flame. The lamp light passes through a selected portion of the flame where the most abundant element atoms exist. This technique is rapid and, for lead, possesses few interferences. A detection limit of 0.1 µg/g is achievable.

2. Furnace atomization consists of placing a small liquid aliquot or solid in a graphite tube or cup that is in the path of the lamp. In progressive steps, the sample is dried, charred, and finally atomized by increasing the electrical power through the graphite. This technique is much more sensitive than flame atomization. A detection limit of 1.0 µg/g is achievable. However, furnace atomization should be used only when very low detection limits are necessary. In comparison to flame atomization, the method is much slower, more difficult, and prone to more sample matrix interferences (71, pp. 50-52).

An additional consideration regarding the two atomization techniques is that flame AAS requires a significantly less trained and experienced operator. A laboratory performing furnace AAS must have a knowledgeable and experienced atomic spectroscopist in residence.

Both techniques have been significantly automated in recent years.

Reliability and Repeatability

For an EPA interlaboratory study six synthetic standards containing Al, Cd, Cr, Cu, Fe, Mn, Pb, and Zn were analyzed by at least 60 laboratories (74). The true concentrations for lead were 0.025 to 0.367 µg/ml with corresponding standard deviations of 0.022 to 0.128 µg/ml and relative errors of 25.7 to 0.2 percent.

A single EPA laboratory analysis of Ohio River water fortified at 0.025, 0.050, and 0.100 µg/ml Pb gave standard deviations of 0.0013 to 0.0037 µg/ml and recovery values of 88 to 95 percent (74).

Costs

A new atomic absorption spectrophotometer equipped for automated flame atomization analysis costs approximately \$20,000. Another \$2,500 for lamps and supplies is required. A trained laboratory technician can perform most routine lead analyses under the supervision of a more experienced degreed chemist.

A new atomic absorption spectrophotometer equipped for automated furnace atomization analysis requires better optics; stable, faster electronic detection; and more sophisticated analysis data handling. The current costs for such an instrument system range between \$35,000 and \$45,000. Another \$3,000 for lamps, furnace tubes, and supplies is required. A trained technician can perform routine analysis by furnace AAS. However, a degreed chemist with several years' experience in furnace atomization and ultra-trace metal analysis must be available for technical supervision. The operating costs for either technique are approximately \$6/hr, excluding labor costs.

Most testing laboratories now offer inexpensive and reasonably reliable flame atomic absorption spectrophotometric analyses. The fees are typically \$12 to \$14 per sample per element. However, many of the smaller laboratories do not have sufficient in-house staff to oversee low-level furnace AAS analyses. The quality of the work should be checked using blind duplicate field samples and check standards. Fees are typically \$20 to \$25 per sample per element.

Frequency of Use

Atomic absorption spectrophotometry, with either flame or furnace atomization, is the most widely used and available instrumental analysis technique for lead in all types of environmental samples.

Acceptability by Regulatory Agencies

EPA has a flame AAS method (Method 239.1) and furnace AAS method (Method 239.2) for water and wastewater analyses (74). The EPA also has approved a flame AAS method (64, 75) and a flameless AAS method (75) for lead on air filters.

NIOSH has two flame AAS methods for lead on cellulose ester air filters--Method 173 (65) and Method S341 (66).

The current "Standard Methods for the Examination of Water and Wastewater" edition issued by the American Public Health Association, American

Water Works Association, and Water Pollution Control Federation also has approved a flame AAS method (Method 129A) (72, p. 147).

ATOMIC EMISSION AND FLUORESCENCE SPECTROMETRY

Description and Ease of Use

A family of instrumental analysis techniques related to atomic absorption spectrophotometry methods is the emission spectrometric methods (68, pp. 123-181). The principal operation of these methods first requires that analyte elements in the sample be atomized to ground state gaseous atoms. Atomic emission spectrometry consists of thermally exciting the gaseous analyte atoms. When the excited analyte atoms relax back to the ground state configurations, light is emitted whose wavelengths are characteristic of the analytes present and whose intensities are proportional to the concentration of the analytes. Atomic fluorescence consists of exciting atoms with an intense external monochromatic light. When the excited analyte atoms again relax to their ground states, light is emitted by characteristic wavelengths and intensities. Primarily because of the opportunity to measure a large number of elements very rapidly in a given sample, a great deal of equipment and method development is occurring in this area (59, 60, 76).

Atomic fluorescence spectrometry appears to be a sensitive and ideal method for multi-elemental analysis which would include lead. However, continued development is needed to produce reliable, commercially available equipment that is cost competitive with other techniques (77). In 1982 the first commercially available atomic fluorescence multi-element spectrometer became available (78).

Atomic emission spectrometry has been invading the environmental trace metal analysis field over the last 4 yr. The primary reasons are improved instrumentation that provides sensitivities comparable to flame AAS and rapid, cost-effective multi-elemental analysis capability. With regard to sensitivities, a new thermal excitation source has been developed and field tested for several years that is superior in many cases to the conventional flame or high energy arc/spark sources. This is the inductively coupled plasma (ICP).

The ICP is created and sustained by a 27-MHz alternating 1- to 3-kW electromagnetic field in copper load coils located at the end of a quartz torch. A plasma (hot ionized medium) is initiated by adding ions and electrons via a Tesla coil into the argon flow while the electromagnetic field is energized. Ions are induced to flow in closed annular directions by the alternating electromagnetic field. The charged particles meet resistance to flow, which generates heat and causes additional ionization of the argon. As more argon enters the newly formed plasma, it is also heated and ionized. With appropriate argon flow design, electromagnetic power, and impedance matching between the power supply and energy-consuming plasma, a stable flame-like plasma is sustained above the torch. A sample aerosol is then injected into the center of the plasma.

The temperature inside the plasma near the load coil is about 10,000°K. Intense continuum emission from ion recombination processes and bremsstrahlung emission occurs, making this region unsuitable for analytical use. However, 13 to 20 mm

above the load coil, this background emission is greatly diminished. Intense line emission from individual elements is present. This area is highly suitable for observing analyte emission.

Compared to other sources, spectral interferences for the ICP are minimal. It is hot enough to facilitate analyte emission, yet the sustained argon plasma has fewer of the interferences associated with emission spectroscopy. The background in the region with most of the sensitive emission lines for many elements (190 to 300 nm) has relatively few interference emissions.

For flame emission spectrometry, a good quality atomic absorption spectrophotometer is used. For the arc or spark excitation and the ICP excitation sources, more complex spectrometers with better optical characteristics and much more complex electronics are used. Two basic multi-elemental analysis instrument options exist for the ICP source. First is a simultaneous system, which features a fixed grating that disperses emission light along a focal curve to a discrete detector for each element. The arc or spark sources also use this configuration. Second is a sequential system, which features a computer-programmed scanning monochromator with a single photomultiplier tube that rapidly selects each element to be analyzed.

The relative instrumental detection limits for an uncomplicated lead standard are: DC arc, 10 µg/ml; flame, 0.2 µg/ml; and ICP, 0.05 µg/ml.

Flame emission spectrometry can be performed by an experienced and trained technician. Arc/spark or ICP emission spectrometry generally requires an experienced degreed chemist with a senior spectroscopist available for consultation.

Reliability and Repeatability

An EPA interlaboratory study (79) using seven laboratories produced the following precision and accuracy data for ICP emission spectrometric analysis of synthetic standards:

Lead Concentration (µg/l)	Mean Recovery (%)	Relative Standard Deviation (%)
24	125	32
80	100	14
250	94	16

The NIOSH ICP emission spectrometric analysis method (Method 351 (80)) reported:

Lead Concentration (µg/filter)	Mean Recovery (%)	Relative Standard Deviation (%)
2.5	105	6.0
1,000	95	1.1

The accuracy and precision would not be expected to be any better for flame emission spectrometry than for ICP emission spectrometry due to more severe gas phase molecular emission and other matrix effects. Precision and accuracy are poorer for arc or spark emission spectrometry. For example, precision relative standard deviations less than 20 percent are difficult to obtain (68, pp. 123-181).

Costs

Flame emission spectrometry equipment costs the same as atomic absorption spectrophotometric instrumentation, i.e., \$30,000 to \$40,000 for a good quality instrument. A typical arc or spark simultaneous emission spectrometer costs approximately \$125,000. ICP emission spectrometers range in cost from approximately \$60,000 for sequential instruments to over \$200,000 for simultaneous instruments with 40 to 50 channels and large computers.

Most service laboratories offer flame emission spectrometric analysis of samples for lead for \$12 to \$14 per sample. Many larger laboratories now offer ICP multi-elemental analyses with the costs ranging from \$10 per sample for large groups of similar samples to \$100 per sample for batches of less than 10 samples.

Frequency of Use

Flame emission spectrometric analysis for lead in many environmental samples is not used because atomic absorption spectrophotometric analysis is more sensitive and similar in cost. Likewise, arc or spark emission spectrometry is not used.

ICP emission spectrometry is now gaining wide acceptance.

Acceptability by Regulatory Agencies

The EPA has recently added its ICP emission spectrometric method (Method 200.7) to its reprinted and updated manual, "Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020 (81). The EPA has also approved ICP emission spectrometry for analysis of air particulate for lead (19). NIOSH has proposed an ICP emission spectrometric analysis technique for lead and other elements on filter media (80). Flame and arc/spark emission spectrometric techniques are not approved methods by these two organizations.

X-RAY FLUORESCENCE SPECTROMETRY

Description and Ease of Use

Another family of sophisticated instrumental analysis systems consists of those based on either absorption or fluorescence of x-rays. Of these two types, x-ray fluorescence has become a multi-elemental method suitable for measurement of lead and other elements in environmental samples (82-84).

The principle for instrumental analysis involves irradiation of analyte atoms in a sample with a high energy photon or charged particle. This causes ejection of inner electrons from the sample atoms. Outer electrons fall into the vacancies in the electron shells, which causes emission of x-rays characteristic for each analyte element undergoing electron transfers. Various sources have been used to induce x-ray fluorescence: x-ray tubes, electron beams, radioactive isotopes, and protons (7, p. 4-10).

Detecting circuitry is both complex and expensive for low-level applications. For the best available laboratory instrumentation, highly skilled chemists are needed. However, portable x-ray fluorescence spectrometers have been developed and field tested for analysis of lead in

paints (85).

Reliability and Repeatability

No large amount of interlaboratory study data is readily available concerning reliability and repeatability.

Costs

There is considerable x-ray fluorescence equipment available, ranging in cost from as little as \$10,000 to more than \$200,000. Few contract laboratories have x-ray fluorescence analysis capabilities at this time. One well-known laboratory that offers a range of inorganic analysis capabilities charges \$144 for a general qualitative analysis. It charges \$49 per sample for the first element and \$14 per sample for each additional element. In addition, it charges \$1,250 to \$3,000 for development of a unique method for a new sample type.

Frequency of Use

Although an excellent choice for lead analysis in some cases, x-ray fluorescence methods are not widely used at this time because of the expense and personnel expertise required.

Acceptability by Regulatory Agencies

No approved standard methods have been issued by major government regulatory agencies for the use of x-ray fluorescence spectrometry.

MASS SPECTROMETRY

Various mass spectrometric analysis techniques are used for inorganic analyses in a research environment (71). These techniques require considerable expertise and are not widely used at this time.

NEUTRON ACTIVATION ANALYSIS

The requirement for a nuclear reactor for neutron activation analysis has precluded widespread use of these methods (71).

ELECTROCHEMICAL METHODS

Although excellent for specialized environmental research and monitoring studies (86, 87), these methods require far more time and personnel expertise than do several of the spectroscopic techniques. Therefore, these methods are not widely used.

SUMMARY

A range of analytical methods are available to environmental research concerned with lead concentrations. Continuous improvements are being made in the area of lead analysis in environmental samples. For air particulate matter and high lead level solid sample analysis, x-ray fluorescence spectrometry looks promising. At this time, flame atomic absorption spectrophotometry (AAS) and ICP emission spectrometry appear to be the methods of choice for analysis of most environmental samples for lead. In addition, furnace AAS is the method of choice for analysis of very low-level samples.

APPENDIX D

PAINT REMOVAL, CONTAINMENT, AND RECOVERY TECHNIQUES

EXISTING TECHNIQUES

The following techniques have been used to remove, contain, and recover the debris generated during paint removal from bridges and other steel structures. These techniques are designed to reduce the amount of debris that becomes airborne or falls on the ground or water in the vicinity of the bridge or other structures being cleaned.

Ground and Water Covers

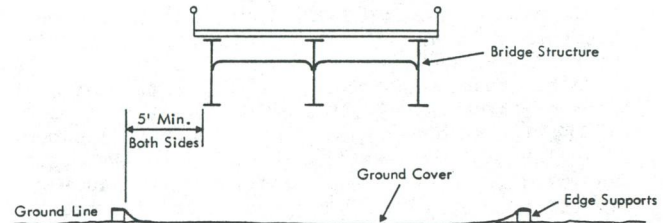
The ground and water cover technique, shown in Figures D-1 and D-2, consists of sheets of canvas, plastic, or other appropriate material spread on or over the ground or the water under the bridge structure to catch and hold the waste materials. Pavement under the structure (closed to public traffic) from which wastes can be collected and removed by sweeping may be used as cover. When suspended from the bridge structure, the covers are placed as close as possible to the underside of the bridge structure to minimize the effects of wind. The length of the cover is determined by the length of the work area, and the width is at least 5 ft wider than each side directly under the steel being cleaned. The edges of the cover are turned upward to minimize loss of waste material. The waste material is removed from the covers at least once a day, more frequently if required, and disposed of at a legal disposal site.

The advantages of this technique are that (1) the equipment is relatively inexpensive, (2) it is easily installed, when laid on the ground, and (3) it does not reduce the production rate of the blasting operation.

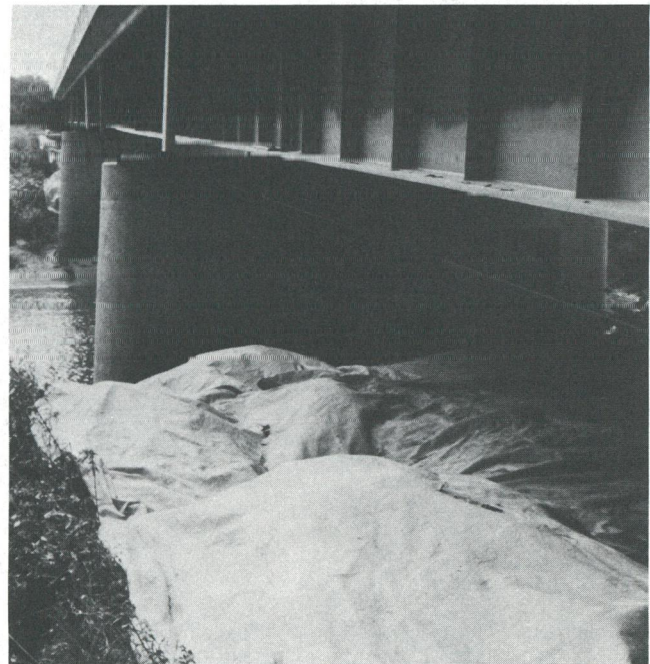
The disadvantages of this technique are that (1) it is not very effective when the wind blows, (2) the covers are rather difficult to install when they must be suspended from the bridge structure, and (3) retrieval of the debris from the covers is awkward and labor intensive. Care must be taken to ensure that the covers are in good condition, that they are installed properly, and that the paint removal process is stopped when the wind increases to the point where it carries the debris beyond the covers.

Water Screens

A water screen technique, shown in Figure D-3, is used in several states to collect the bridge paint debris that falls into the water under bridges during the paint removal process and floats on the water. A straw dam is suspended across the waterway to trap the floating debris. If the waterway is nonflowing, such as a lake, dams are placed on both sides of the bridge. If the waterway is flowing, such as a stream or river, the dam is placed on the downstream side of the bridge. The dam is constructed from wire mesh covered on the bridge side with straw or similar material. Floats, such as inflated tire tubes, are used to keep the dam at the water surface.



(a) Diagram of Technique

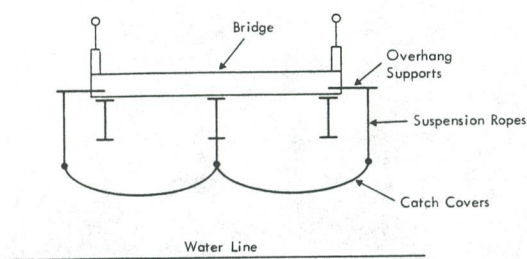


(b) Field Installation

Figure D-1. Ground cover technique.

Cables are used to anchor the dam to the shoreline. The floating debris contained in the dam is removed daily, and the old straw is periodically replaced with clean straw.

The advantage of this technique is that it is a relatively inexpensive method for trapping much of the floating debris. However, it is not practical to use this system on large bodies of water or on those with water traffic. Also, the system is not very effective if the water flow is fast or turbulent. It is somewhat difficult to keep the straw in place without gaps. Finally, it is awkward and time consuming to gather the trapped debris for disposal and to replace the straw.

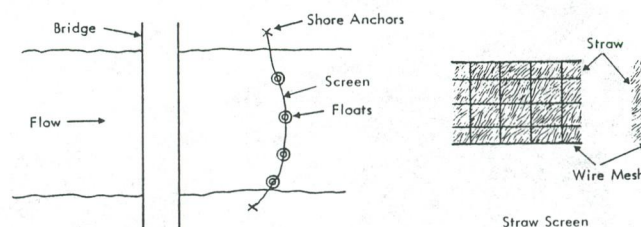


(a) Diagram of Technique

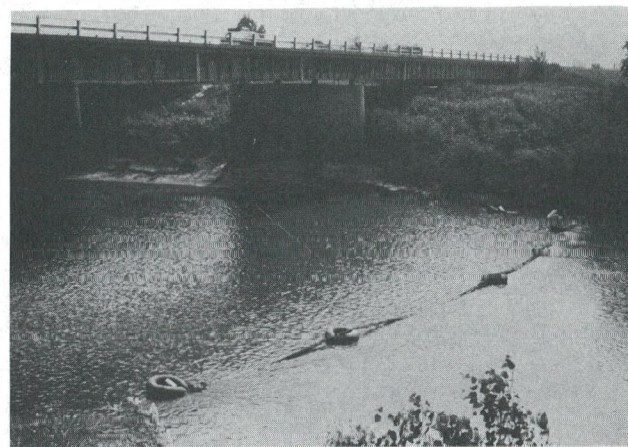


(b) Field Installation

Figure D-2. Water cover technique.



(a) Diagram



(b) River Installation

Figure D-3. Water screen installed on river.

Blast Enclosures

Special blast enclosures, shown in Figure D-4, have been developed and used on parts of the Tobin-Mystic River bridge in Boston. The enclosures are rigid structures designed to enclose the handrails, the walkway, and the beams that project beyond the longitudinal girders. The original paint (which includes a lead-based primer) is being removed in these areas to near-white in preparation for repainting. The enclosure is designed to accommodate one blaster. It is about 6 ft x 6 ft x 6 ft and is mounted on two wheels which ride on the top of the handrail, as shown in Figure D-5. The bottom of the booth is tapered to catch the blast debris and funnel it through a flexible tube to a covered truck positioned under the bridge, as shown in Figures D-6 and D-7. A suction system draws the dust from inside the booth through a special portable wet scrubber to remove the dust from the air stream (Fig. D-8). The residue is deposited in a sealed, truck-mounted container for disposal.

The blaster works inside the booth, which is illuminated by electric lamps. The outside of the booth is covered with rigid plastic to reduce sound transmission. The booth is periodically moved along the handrail as the work area progresses.

This recovery system is reported to capture 80 to 85 percent of the airborne dust and lead, and virtually all the blasting grit (88).

One of the limitations of these booths is that the present unit is designed for a specific section (handrail area) of the Tobin bridge. Although it could be redesigned for other bridge handrail areas, it is not readily adaptable to other parts of bridges. There is presently some leakage from the gaps between the booth and the bridge structure, particularly when the blast is directed into these areas.

Another, less sophisticated, moveable blast enclosure technique has been used in California (89). In this design a burlap funnel encloses the blaster's scaffold. The bottom of the funnel is equipped with a cylindrical snorkel extending to the ground. The snorkel is normally closed at the bottom. An overall view of the technique is shown in Figure D-9. The snorkels, shown in Figure D-10, are used to contain the debris from the blast enclosure. To empty the unit the bottom of the snorkel is opened.

Another enclosure technique to confine and collect the debris from sandblasting has been used on a large bridge near Burlington, Canada (Figs. D-11 through D-14). The bridge construction is a truss structure about 30 ft deep and 60 ft wide underneath the multi-lane roadway. The entire structure is being sandblasted and repainted. During the blasting and repainting operation, an entire truss section (approximately 30 ft x 60 ft x 160 ft) is enclosed with a plywood floor and reinforced transparent plastic sheets on the sides and ends. The floor is supported by a steel

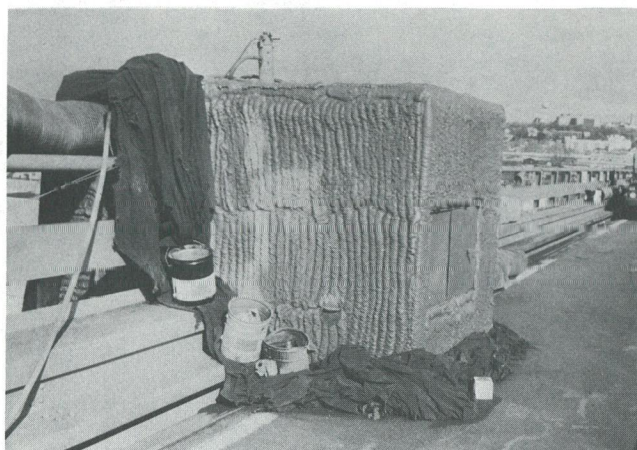


Figure D-4. Boston blast enclosure.

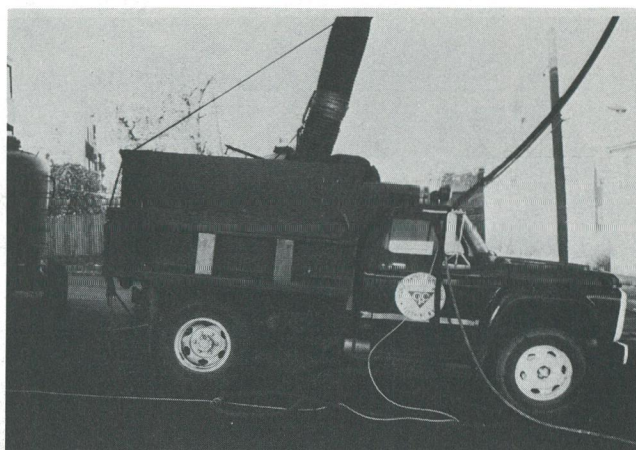


Figure D-7. Enclosed truck for debris.

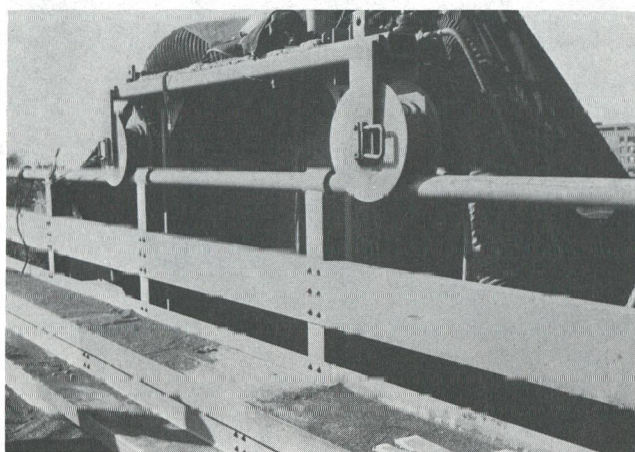


Figure D-5. Method of mounting blast enclosure.

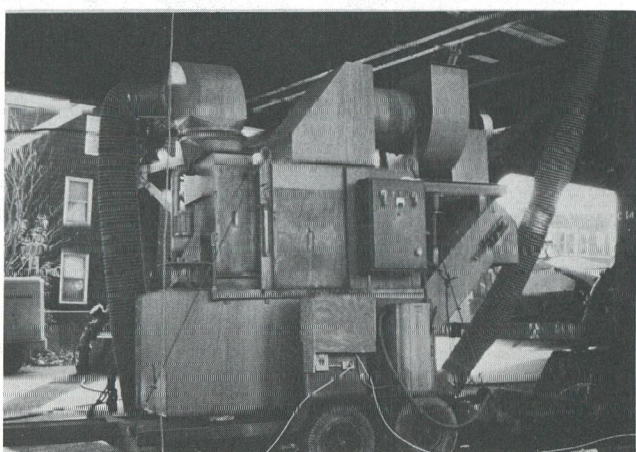


Figure D-8. Wet scrubber used to wash dust from enclosure.

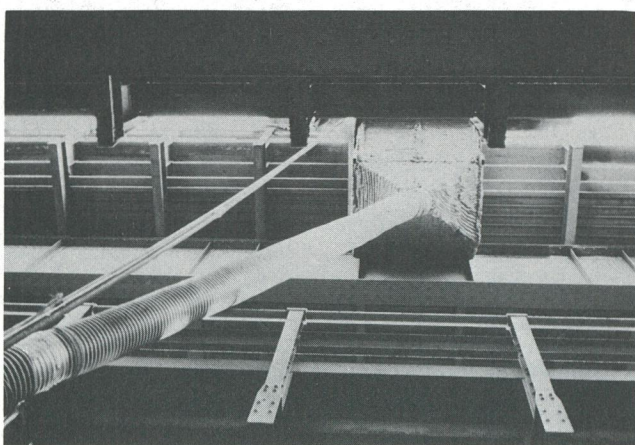


Figure D-6. Discharge system from bottom of enclosure.

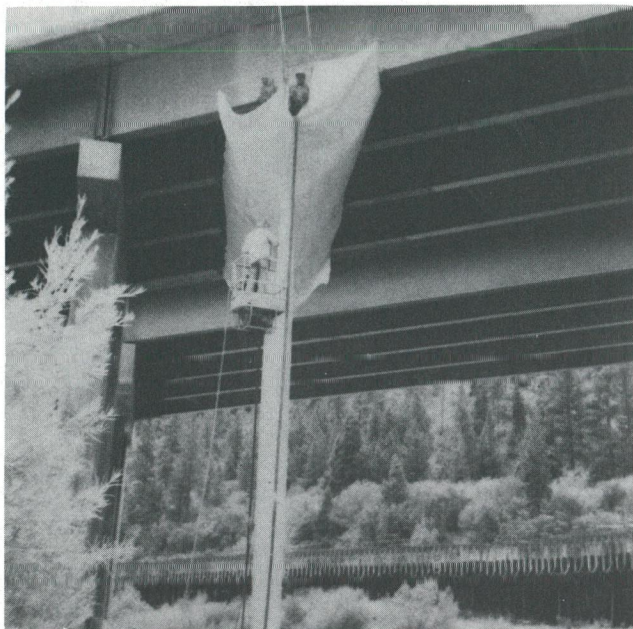


Figure D-9. Burlap enclosure used to contain the blast debris from bridge understructure, with snorkel-like container suspended from enclosure to the ground. (Courtesy: California Department of Transportation)

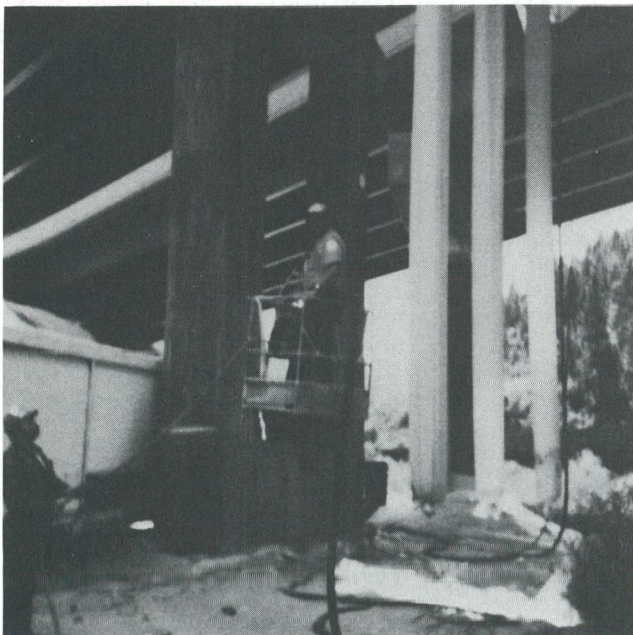


Figure D-10. Close-up of snorkels used to contain debris from blast enclosures; pile of debris removed from snorkels shown behind. (Courtesy: California Department of Transportation)

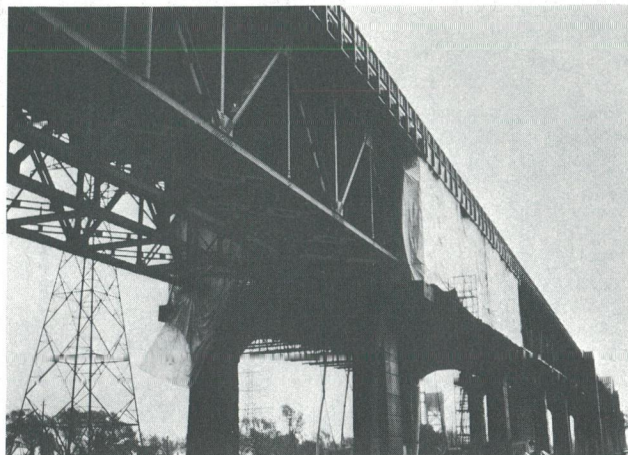


Figure D-11. Overall view of Canadian blast enclosure.

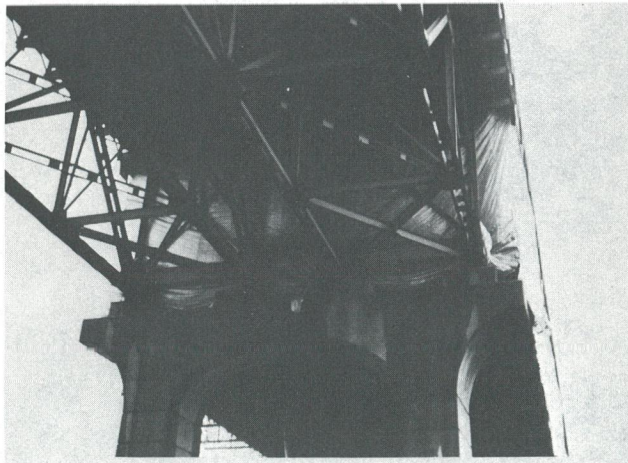


Figure D-12. End of blast enclosure.

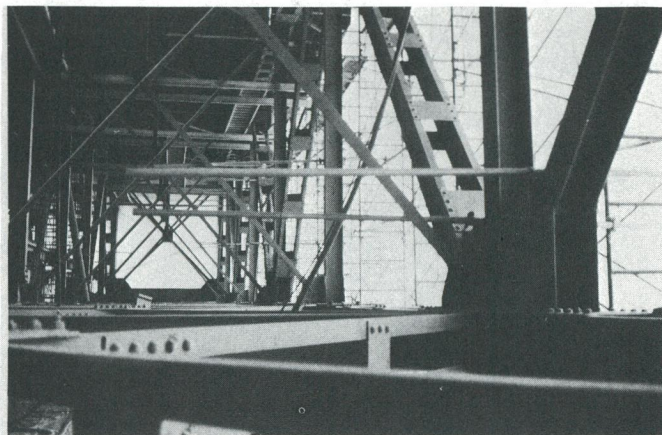


Figure D-13. Inside view of blast enclosure.

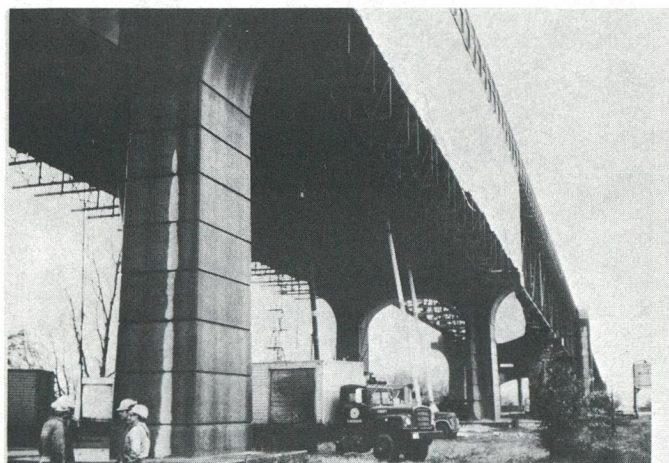


Figure D-14. Discharge from enclosure floor to disposal trucks.

framework and is cable-suspended from the bridge structure. The floor has several large holes and is equipped with flexible tubes leading to trucks below the bridge. Twelve blast operators work simultaneously within the enclosure. The sand-blast debris that collects on the floor of the enclosure is shoveled through the floor holes and funneled into the trucks below for disposal. When work is completed on each bridge section, the enclosure is moved to the next section. Cranes are used to move the flooring.

The principal advantage of this enclosure system is that large sections of the bridge truss structure are enclosed, permitting many blasters to work simultaneously within the enclosure. The disadvantages are that cranes and considerable labor are required to move the enclosure, not to mention the labor required to move the debris from the floor into the exit holes.

Several versions of blast enclosures have been proposed by the Louisiana Department of Transportation and Development (90). Figure D-15 shows a technique for cleaning highway bridges over land. The enclosure covers the work area and extends down to the ground. A truck-mounted vacuum pump with a snorkel is used to remove the debris collected at the bottom of the enclosure. Figure D-16 shows a proposed enclosure for use over water. A version of the curtain enclosure technique that would be applicable over both land and water is shown in Figure D-17. The work platform is fully enclosed, and the debris falls to the bottom of the enclosure. A truck-mounted vacuum pump removes the accumulated debris from the bottom of the enclosure.

Among the anticipated problems with these proposed designs is blowing of the structure by the wind and the blast, and it will be difficult to find a cover material that allows ventilation and still does not permit escape of fine particles. Furthermore, a considerable amount of dust will be created within the enclosure, which will make visibility and other working conditions difficult. An improvement in these designs would be to add a suction system to the upper part of the enclosure to remove the airborne dust for ventilation and better visibility within the enclosure.

Vacuum Blasters

Vacuum blasters are designed to remove paint and other surface contaminants by simultaneously blasting the surface with an abrasive and recovering the spent abrasive and paint debris with a suction system surrounding the blast nozzle. The suction system moves the spent abrasive and debris to a reclamation system that removes the reusable abrasive and returns it to the blast supply. There are two types of vacuum blasters, pressure blasters and suction blasters. In the pressure blast system, the abrasive falls by gravity from a pressurized container into a line carrying compressed air. The abrasive is carried by the compressed air to and out the blast nozzle. In suction blasters, an air ejector draws the abrasive to the blast head where it is mixed with a compressed air supply and discharged from the nozzle.

In both cases, the blast nozzle is surrounded by a shroud equipped with a suction hose, as shown in Figure D-18. The periphery of the shroud is equipped with a brush to allow air to enter between the shroud and the surface being cleaned.

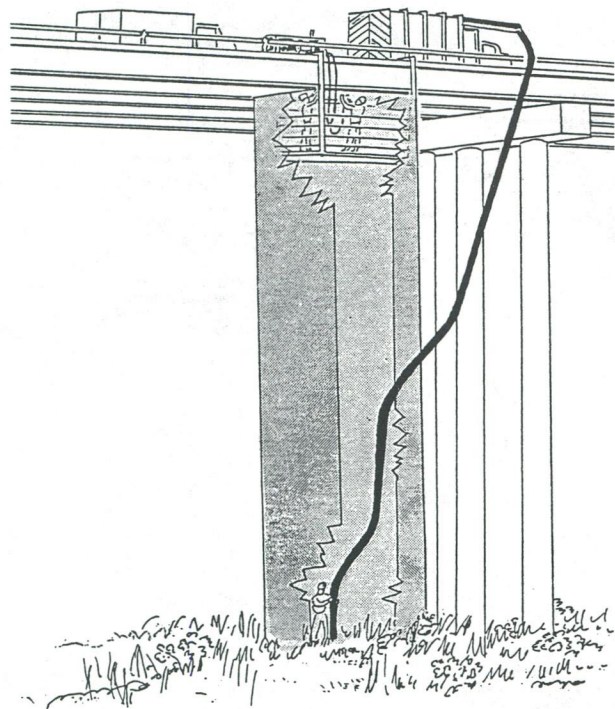


Figure D-15. A land operation of cleaning or painting a highway structure utilizing a full curtain made up of material for ventilation and confinement of debris. This is provided to contain the sand-blast debris and excess paint generated during the cleaning and painting operations and at the same time provide adequate ventilation for the workmen. Also being utilized is a truck-mounted vacuum pump with a snorkel for removal of residue. (Courtesy: Louisiana Department of Transportation)

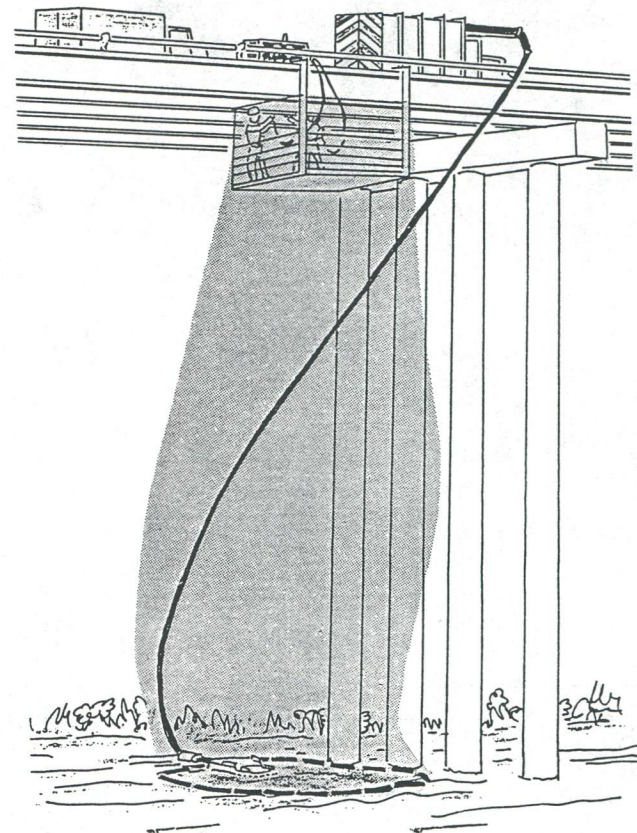


Figure D-16. An over-the-water operation of cleaning and painting a highway structure utilizing a full curtain made up of material for ventilation and confinement of debris. In addition, a pollution boom similar to Sea Sentry by Goodyear and an adjustable weir-type skimmer similar to Slurp by Seaward International, Inc., is being utilized. (Courtesy: Louisiana Department of Transportation)

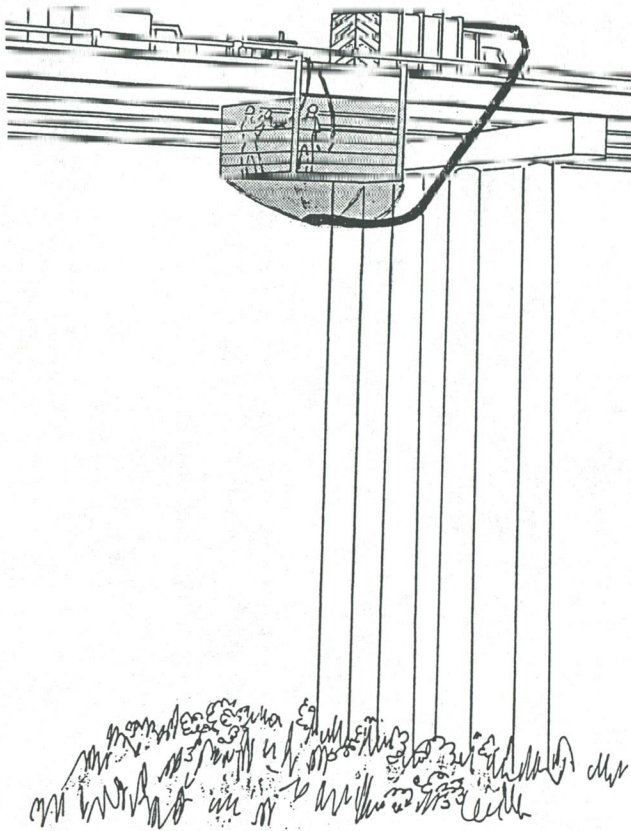
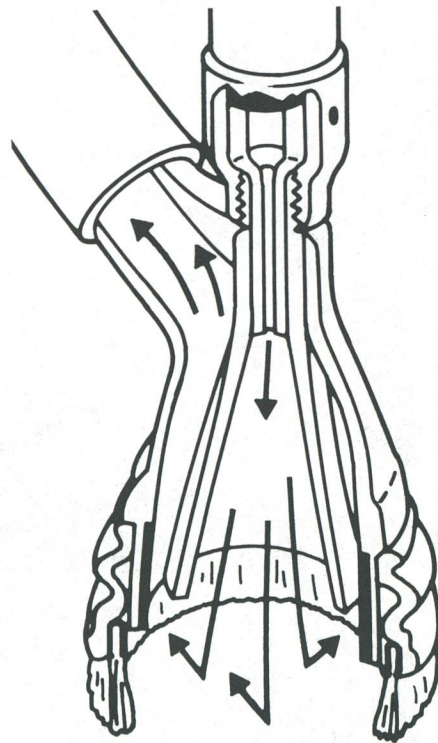


Figure D-17. A work platform with fully enclosed curtain made up of material for ventilation and confinement of debris. Debris generated by the cleaning and painting operation is removed by a truck-mounted vacuum pump equipped with a snorkel. (Courtesy: Louisiana Department of Transportation)



(a) Vacuum Blaster in Operation



(b) Diagram of Vacuum/Blast Head

Figure D-18. Vacuum blaster. (Courtesy: Vacu-Blast International)

The suction draws the blast debris through the suction line to the separation system, shown in Figure D-19, which consists of a cyclone separator, dust collector, and a vibrating screen. The heavy particles are separated from the lighter particles by centrifugal force in the cyclone separator. The light particles are drawn into and deposited in a bag filter. The heavy particles are screened to separate out oversize particles, and the remaining usable abrasive drops through the screen and into the storage container for reuse. The blast heads are made in a variety of sizes, the larger units being mounted on casters. Special shroud adapters are designed for use in corners and over edges.

The principal advantages of vacuum blasters are: the blast head is equipped with a recovery shroud that collects the debris before it can get into the environment; the abrasive is recycled; and a minimum amount of debris must be disposed. The disadvantages are: the production rate for hand-held units is low; the heads are heavy, making it fatiguing for the operator; and the abrasive is expensive.

Drapes

Drapes were used on each side of the Middle River Bridge near Stockton, California, to collect the waste material from the sandblasting operation (91). The bridge, shown in Figure D-20(a), is about 550 ft long and consists of a steel truss approach span and a through truss swing span with a concrete two-lane deck. The tops of the drapes were attached by cables near the top of the bridge superstructure, as shown in Figure D-20(b). The bottoms of the drapes were placed in a small barge floating in the river, shown in Figure D-20(c). Initially, the drapes were made from nonporous material, which billowed extensively because of the blasting operation and wind. The billowing also

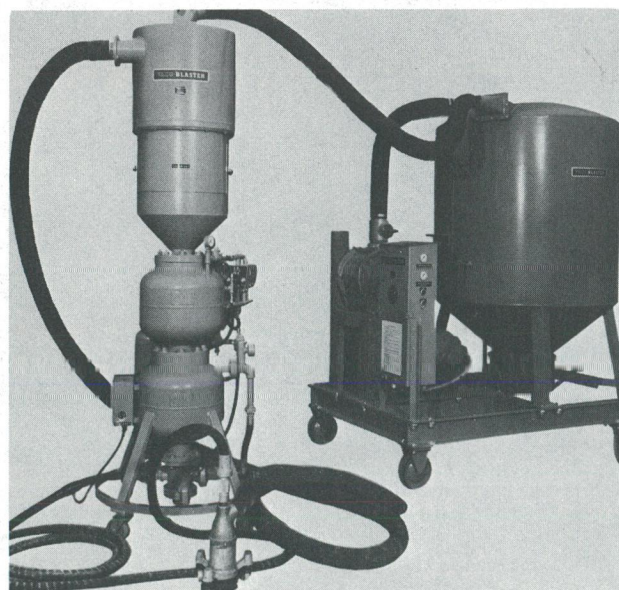


Figure D-19. Vacuum blast system. (Courtesy: Vacu-Blast Corporation)

allowed the waste material to be dumped into the river instead of onto the barge. A porous material was then used which reduced the billowing but allowed some waste particles to pass and fall into the river. Although measurements were not made, it was estimated that 50 to 75 percent of all waste material was recovered on the bridge deck or in the barge.

In a later modification of the drape technique, plastic lined cargo nets were suspended under the bridge structure, as shown in Figure D-21, to catch the debris. A vacuum system was used to remove the accumulated debris from the cargo nets, as shown in Figure D-22.

The advantages of the drape technique are that the equipment is relatively inexpensive, and the technique is adaptable to a variety of bridge designs, including truss structures. The disadvantages are the difficulties in installing the drapes and catch nets, the adverse effect of wind, and the relatively low collection efficiency.

Water Curtains

Water curtains are designed to minimize the amount of airborne debris from grit-blasting steel structures. One type of water curtain, used on bridges in California (89), is shown in Figure D-23. A water line equipped with a series of spray nozzles along its length is laid along the edge of the bridge deck, outside the railing. The water spray is directed downward. When the blasters work on the steel structure under the bridge, the curtain of water interacts with the dust, washing it down to the ground under the bridge, as shown in Figure D-24. A photograph of the dust cloud without the water curtain is shown in Figure D-25.

The advantages of the water curtain technique are the relatively low cost of the equipment, ease of installation, and its adaptability to a variety of bridge structures. The principal disadvantages are contamination of the ground and water under the bridge.

Wet Blasting

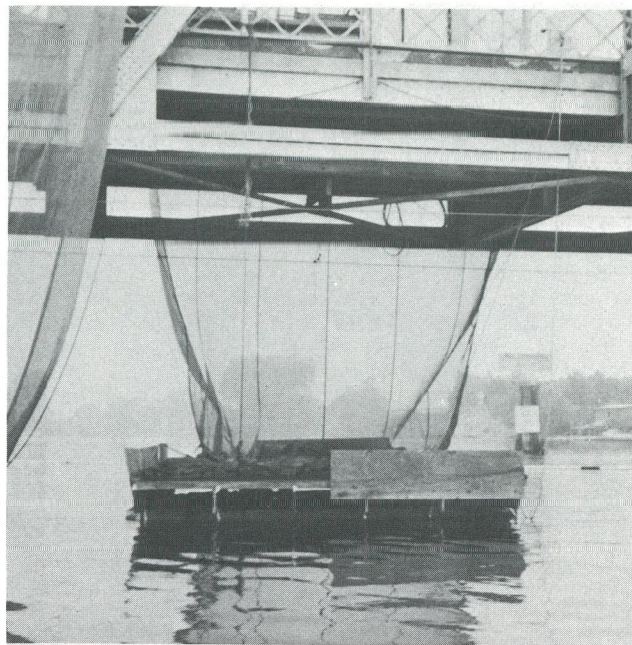
There is a variety of wet blasting techniques used to remove paint from structural steel, including wet abrasive blasting, high-pressure water blasting, high-pressure water and abrasive blasting, and air and water and abrasive blasting. A special category of high-pressure water blasting called "cavitation blasting" is covered in a separate section. Although present wet blasters are not usually designed to recover the removed paint, they are of interest to this study because they minimize the amount of dust and resulting airborne contamination encountered with conventional (dry) abrasive blasting. Furthermore, the collection of the debris would be easier than with open dry blasting.

Wet Abrasive Blasting

In wet abrasive blasting, conventional abrasive blast nozzles are equipped with devices that introduce rust-inhibited water into the sandblast stream. An example of such a device is shown in Figures D-26(a) and D-26(b). The device is attached to the end of a conventional dry sandblast nozzle. A series of small water jets impinge on the abrasive blast stream as it emerges from the



(a) Middle River Bridge During Repainting Operations



(c) The Lower Ends of the Drapes Were Placed on a Small Barge Floating in the River

Figure D-20. Drape containment and recovery technique. (Courtesy: California Department of Transportation)



(b) One End of the Drapes Attached to Cables Near the Top of the Superstructure



Figure D-21. Side drapes and lined cargo nets. (Courtesy: California Department of Transportation)



Figure D-22. Vacuum removal of debris from lined cargo net containers. (Courtesy: California Department of Transportation)

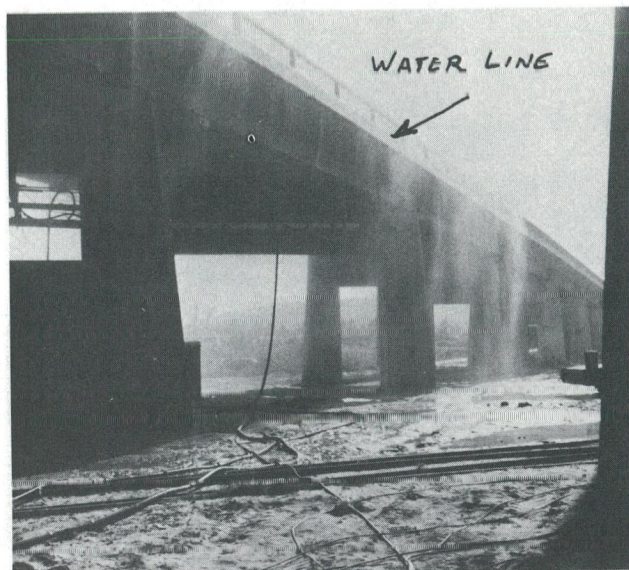


Figure D-24. Water curtain in operation during grit blasting on underside of bridge. (Courtesy: California Department of Transportation)

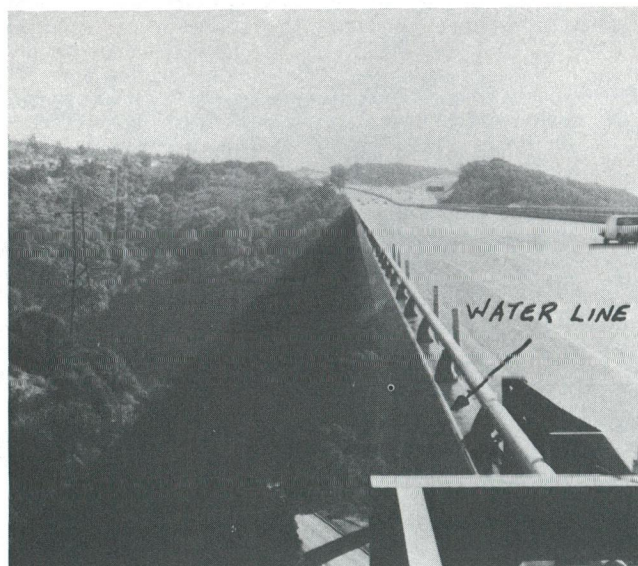
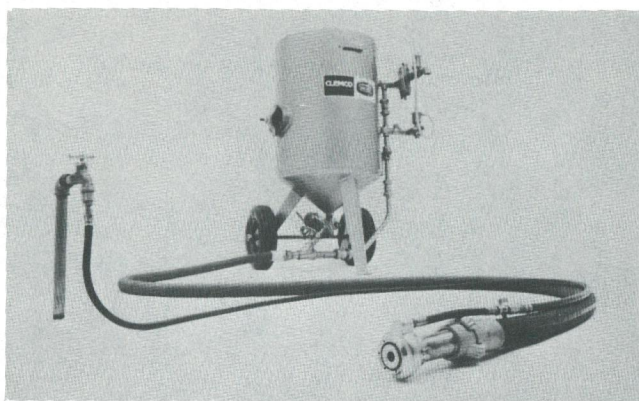


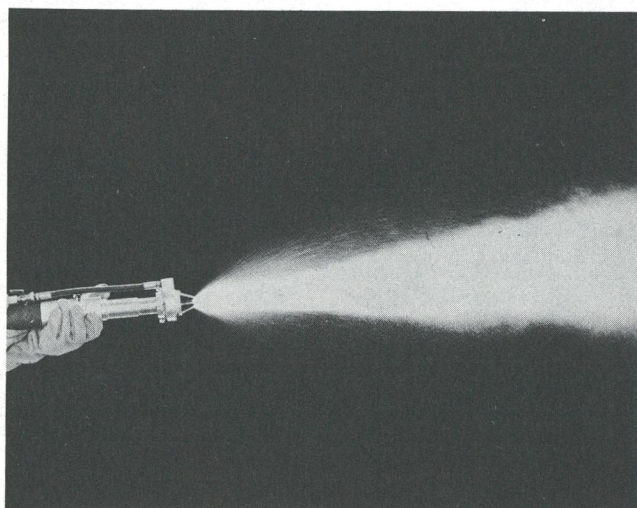
Figure D-23. Water curtain technique; water line outside the bridge handrail. (Courtesy: California Department of Transportation)



Figure D-25. Dust cloud during abrasive blasting without water curtain. (Courtesy: California Department of Transportation)



(a) Water Injection Device Attached to Conventional (dry) Abrasive Blast Nozzle



(b) Blast Pattern

Figure D-26. Wet blast system. (Source: Reference 108)

nozzle. Water pressures of 30 to 60 psi are acceptable. Rust inhibitor, such as sodium nitrite, sodium/potassium dichromate, and ammonium phosphate, is introduced into the water to prevent rusting of the cleaned steel prior to repainting.

Reported (92) test results of a wet abrasive blast system indicated that the blast dust formation is reduced by at least 50 percent. The cleaning rate was 90 ft²/hr to obtain a near white (SSPC-SP10) (93, p. 47) surface (Table D-1), as compared to 210 ft²/hr obtained with dry blast. The decrease in cleaning rate was attributed, at least in part, to the problem of keeping the face shield of the sandblaster's hood free of damp particles during the wet blast cleaning.

High-Pressure Water Blasting

Equipment is commercially available to produce

Table D-1. Wet sandblasting.

Cleaning Grade	Surface Area Cleaning Rate (ft ² /hr)	Sand Usage (lb/ft ²)
Brush blast	385	2.03
Commercial blast	183	4.29
Near white blast	90	8.83

Source: Ref. 92.

Nozzle pressure: 80 to 100 psi.

Water (with rust inhibitor) rate: 0.156 gal/min.

high-velocity jets of water at pressures ranging from 2,000 to 10,000 psi. In the lower range of pressures (2,000 to 5,000 psi) loose paints and rust can be removed. In the upper range of pressures (5,000 to 10,000 psi) bonded paint, tight rust, and mill scale can be removed from structural steel to commercial blast (SSPC-SP6) (93, p. 41). A typical high-velocity water jet is shown in Figure D-27. The equipment includes an engine-driven high-pressure pump, high-pressure hose, and a gun equipped with nozzles capable of producing either round or flat sprays.

Tests of high-pressure water blasting on bridge structures were conducted by the Florida Department of Transportation, the Texas State Department of Highways, and the New Jersey Department of Transportation. A summary report (92) of these tests indicates that the average cleaning rate for a near white blast was 25 ft²/hr, as shown in Table D-2. Rust inhibitors were found to be necessary and effective. When not used, flash rusting was exhibited as early as 90 sec after the cleaning. When the inhibitor was used, oxidation products were not discernible to the unaided eye for as much as 48 hr or more.

Table D-2. Water blasting.

Cleaning Grade	Surface Area Cleaning Rate (ft ² /hr)	Water Usage (gal/ft ²)
Brush blast (SSPC-SP7)	110	2.7
Near white blast (SSPC-SP10)	25	9.2

Source: Ref. 93.

Water pressure: 9,500 psi.

The advantages of high-pressure water blasting are the virtual elimination of air pollution and confinement of the debris to the immediate area. The main disadvantages are the relatively low cleaning rate, the lack of surface profiling, and the high rearward force of the nozzle.



Figure D-27. High-pressure water jet. (Courtesy: Butterworth, Inc.)

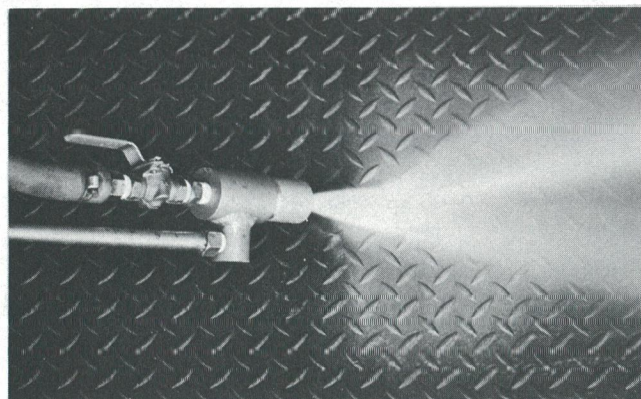


Figure D-28. Apparatus for adding abrasives to high-pressure water jet. (Courtesy: Butterworth, Inc.)

High-Pressure Water and Abrasive Blasting

A system for introducing abrasives into high-pressure water jets is shown in Figure D-28. An accessory attaches to the water jet gun converting it into a high-pressure water and abrasive blasting system. Abrasives are pressure- or suction-fed into the gun. A valve permits the operator to turn the sand flow on or off for alternate water or water and abrasive blasting. A metering device permits injection of a rust inhibitor into the water stream.

The addition of abrasive to high-pressure water jets significantly increases the cleaning rate and provides profiling of the surface. Near white

cleaning rates of 150 ft²/hr are reported (92). Production rates for other surface cleanliness and sand usage are given in Table D-3. After water and abrasive blast cleaning, it is necessary to use water or compressed air to remove the residue of sand which remains on the surface. Operator fatigue and safety are concerns with the high-pressure water and abrasive blasting system because of the relatively high backward thrust of the gun.

Table D-3. Water blast with abrasive.

Cleaning Grade	Surface Area Cleaning Rate (ft ² /hr)	Sand Usage (lb/ft ²)
Brush blast (pipe)	90	1.4
Commercial blast (pipe)	53	2.9
Near white blast (venturi)	150	2.0 (1.4 gal water/ft ²)

Source: Ref. 92.

Air/Water/Abrasive Blasting

Air/water/abrasive blasting systems have been developed both in England and the United States. The English system is illustrated in Figure D-29. The system consists of a 1,080-gal water tank, a 40-gal inhibitor tank, a 26-gal air-powered mixing drum, an abrasive hopper with a capacity of 7 tons, two pressure vessels, an engine-driven air compressor, inhibitor pump, pneumatically driven water pump, a covered controller position, communication system, storage space for blast hoses and communication equipment, hoses, a control panel and indicators. All equipment is permanently mounted on a semitrailer truck. The working pressure at the nozzle is variable over a range of 15 to 95 psi. The flow rates of the three media--air, abrasive, and water--are independently adjustable.

Test reports (94) of this system indicate that the system is more versatile than other wet blast systems, but it is not without some problems. No difficulties were experienced in getting down to white metal. The pressure levels are relatively low, so there is comparatively little back pressure and therefore minimum operator fatigue. The cleaning rate on heavily coated steel was 90 ft²/hr. There is little splashback or overspray usage because of the low pressure and relatively small amounts of water (about 2 gal/min). One of the problems with this system is the accumulation of abrasive sludge in and around the work area.

An air/water/abrasive system developed in the United States is similar to the British system (95). However, the U.S. system operates at about 1,000-psi water pressure. The operator can vary the mix ratio of the three elements at the nozzle, whereas in the British system the control orders are verbally communicated to the controller.

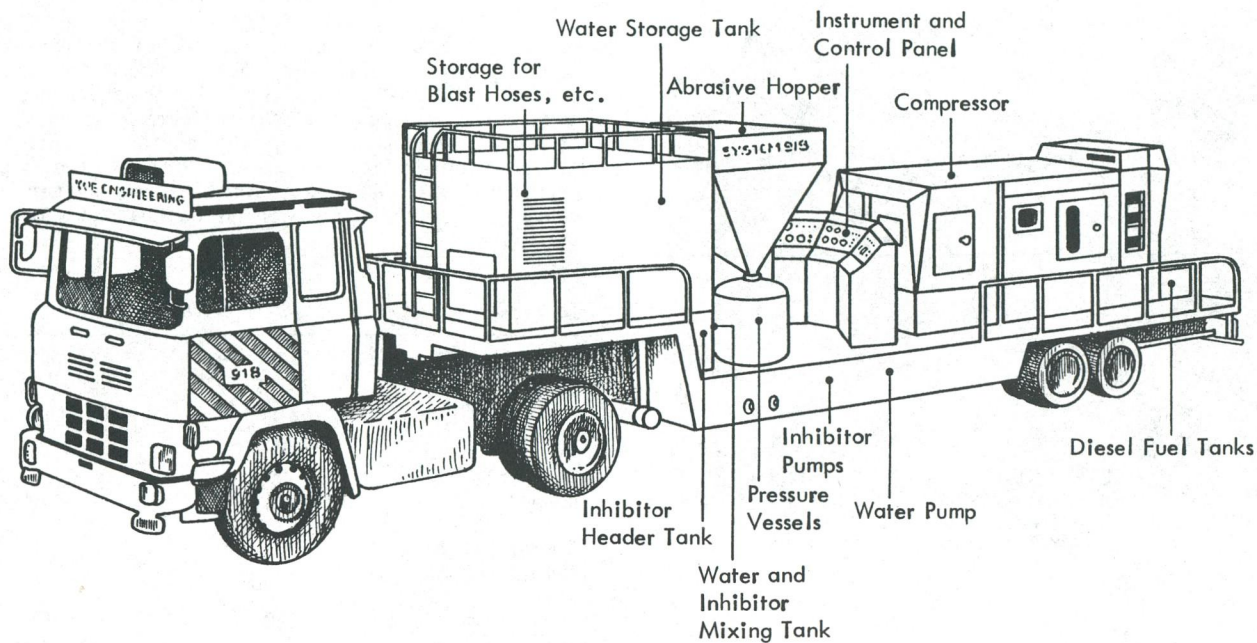


Figure D-29. Air/water/sand system. (Courtesy: KUE Engineering, Ltd.)

Centrifugal Blasters

Centrifugal blast cleaning machines, shown in Figures D-30 and D-31, use high-speed rotating blades to propel abrasives against the surface to be cleaned. For cleaning structural steel, the abrasive consists of particles of alloy steel that resist fracturing despite repeated impacts on the surface. The abrasive is fed to the inner section of the rotating blades and slides along the blade to the outer edges. As the abrasive particles move along the blade they are accelerated by centrifugal force and hurled at high speed against the surface in a fan-like pattern. The particles are projected at an angle to the surface so that the abrasive particles rebound from the surface and are returned through a return duct to the abrasive storage bin. Light particles consisting of paint chips and other debris are drawn by suction into a dust collector.

Present portable centrifugal blast machines are particularly suited to cleaning large, flat horizontal surfaces such as ship decks. Custom-designed systems have been developed for cleaning the sides of ships (Fig. D-32) and tanks (Fig. D-33). Small units are being developed to clean small areas, vertical surfaces, and weld seams (96, p. 30; 97).

The advantages of centrifugal blasters are that they are very effective in cleaning structural steel, they capture most of the spent abrasive and debris, and the abrasive is reused. Unfortunately, present centrifugal blasters are not designed for the comparatively small, irregular shapes of surfaces commonly found on bridges.

Vacuum-Shrouded Hand Tools

A variety of hand-held power tools, including rotary and impact types, are used to remove paint, rust, and other surface contaminants from steel

structures. The rotary tools are often equipped with shrouds to protect the operator from flying debris. Some manufacturers offer, as an accessory, a vacuum system attached to the existing shroud or special shrouds to capture the debris. An example of a vacuum-shrouded power tool is shown in Figure D-34.

Vacuum-shrouded hand tools are available and used in various industries, but they have generally not been used for bridge paint removal. Hand tools without debris recovery features, nevertheless, are commonly used. The reason for this may be the present general lack of emphasis on paint debris containment and recovery in bridge maintenance.

IMPROVEMENTS FOR EXISTING TECHNIQUES

The following concepts are designed to improve the performance of existing techniques for containment and recovery of paints from bridges. These design concepts have not been field tested.

Ground and Water Covers

To reduce the detrimental effect of crosswinds on ground and water covers, side curtains should be added, as shown in Figure D-35. The side curtains should be hung on each side of the bridge and should extend from the bridge deck to the ground. The bottoms should be anchored to the ground. In those cases where the covers are suspended from the bridge structure, the side curtains should be anchored to the covers. The curtain should be made from porous material to minimize the wind force.

Water Screens

To reduce the difficulty of gathering the floating debris, it is suggested that a floating

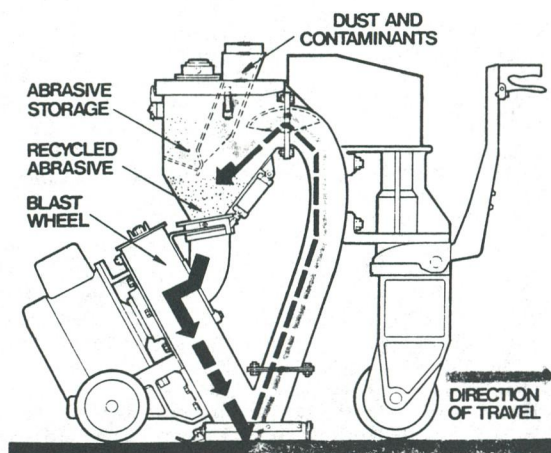


Figure D-30. Portable blast cleaning system (operational schematic). (Source: Reference 96, p. 29)



Figure D-32. Centrifugal blaster cleaning ship sides. (Courtesy: Nelco Manufacturing Company)

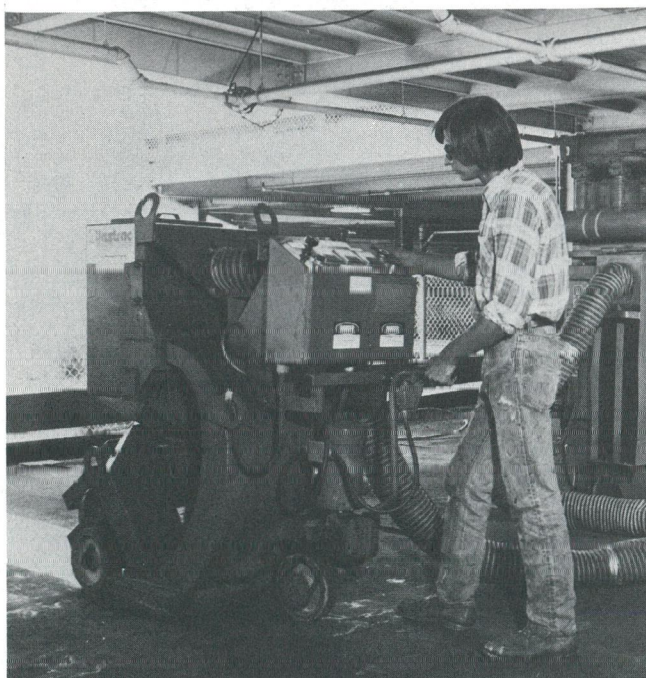


Figure D-31. Portable cleaning system with auxiliary dust collector (steel surface parking deck). (Source: Reference 96, p. 29)

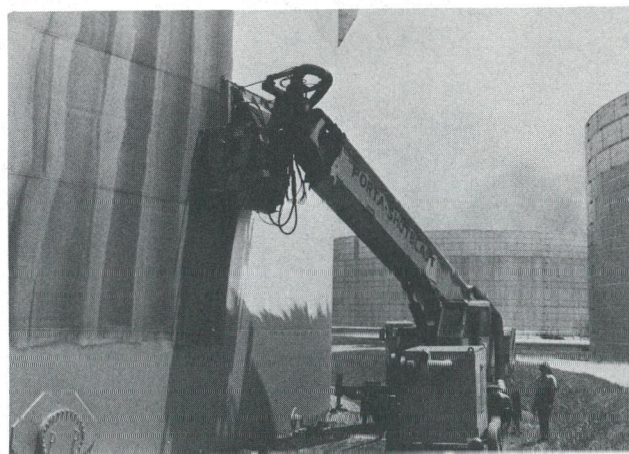


Figure D-33. Centrifugal blaster cleaning storage tank. (Courtesy: Nelco Manufacturing Company)



Figure D-34. Vacuum-shrouded vertical sander. (Courtesy: ARO Corporation)

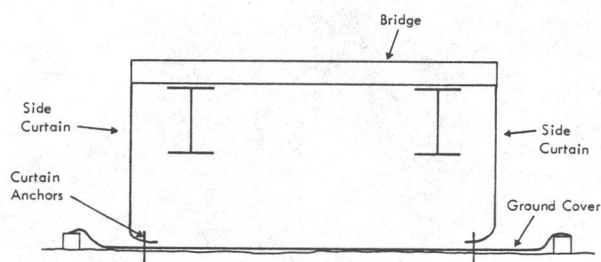


Figure D-35. Ground cover with side curtains.

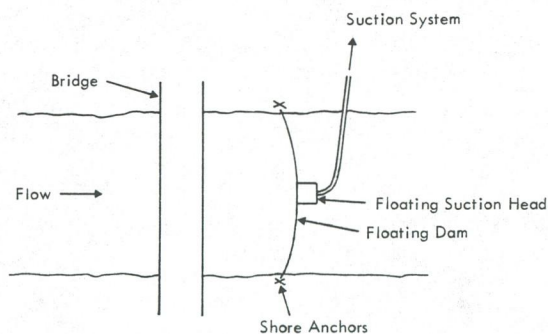


Figure D-36. Floating dam with suction system.

suction system be used as shown in Figure D-36. Such systems are used to recover oil spills on bodies of water. This technique would be useful for both stationary and flowing water. For flowing water, only one dam (downstream) would be required. For stationary water, two suction dams would be required, one on each side of the bridge.

Blast Enclosures

Some leakage of abrasive and paint debris at the joints between the blast enclosure and the bridge structure currently occurs in the Tobin Bridge paint debris containment and recovery system. An attempt is being made to seal the joints with canvas, but this is not very effective, particularly when the blast is directed into these areas. A suggested method to minimize leakage from the joints is shown in Figure D-37. A flexible seal made from rubber, plastic, or thin metal is fastened to the inside edges of the enclosure walls. The end of the flexible seal rests on the bridge structure. This technique is similar to that commonly used to prevent air leakage under house doors, to prevent lubricant leakage around automobile axles, and for other similar applications.

In the Tobin Bridge system, considerable effort is devoted to the disposal of the collected spent abrasive. To minimize this effort, it is suggested that the spent abrasive collected from the bottom of the enclosure be recycled after being treated in the same type of system that is used with vacuum blast machines. Abrasive with a low tendency to breakdown after impact would have to be used. Such abrasives include cast steel shot and grit, malleable iron shot and grit, chilled cast iron shot and grit, zircon, novaculite, copper slag, silicon carbide, and aluminum oxide (96, pp. 32-51). A typical abrasive recovery system is shown in Figure D-38. Finer material is pulled off to a dust collector, which in this case would be the wet scrubber. Heavier material falls onto a vibrating screen that traps larger debris for later removal. Good abrasive falls through the screen to the hopper and the pressure vessel for reuse. The pressure vessel is automatically re-filled from the hopper whenever the blast nozzle is shut off.

One of the problems associated with the large blast enclosure used in Canada is the labor required to manually shovel the debris from the large floor area into the exit holes. A technique to overcome this problem is shown in Figure D-39. The floor is made up of a group of individual funnel-like units bolted together to make up the total area from which debris is to be collected. The tops of the funnels are covered with perforated metal panels for walking. The funnel exits would be equipped with flexible hoses leading to the debris container. (The same basic design could be used for open dry abrasive blasting and open wet abrasive blasting to collect some, if not all, of the debris and water runoff, by suspending the unit under the work area.)

Water Curtains

A significant improvement for the water curtain technique would be to provide a method to collect the water and entrapped abrasive. A collection system concept is shown in Figure D-40. Troughs are placed under the spray pattern to catch the

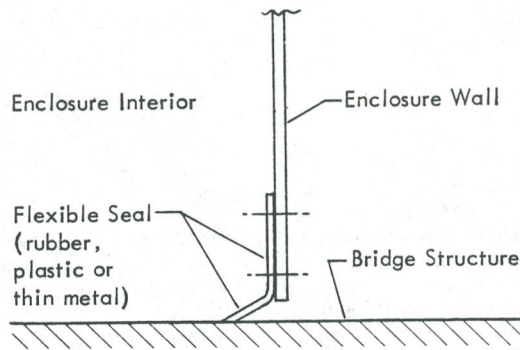


Figure D-37. Blast enclosure seal technique.

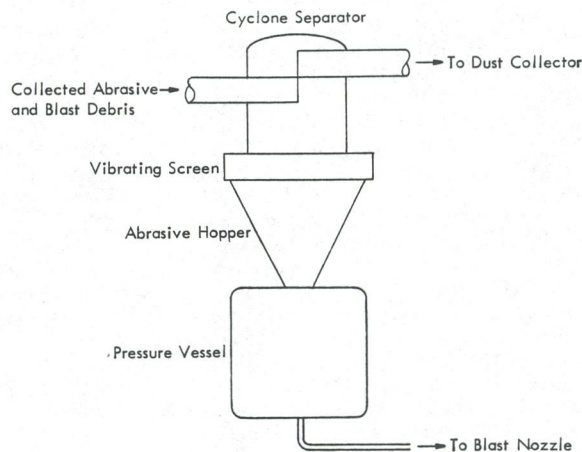


Figure D-38. Abrasive reclaimer.

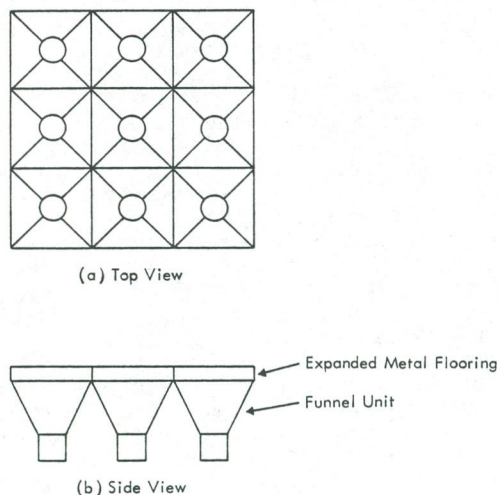


Figure D-39. Funnel flooring for large blast enclosures.

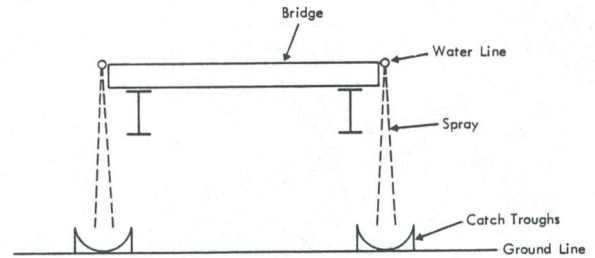


Figure D-40. Technique for containment of water curtain runoff.

water and abrasive mixture and divert it to an appropriate container, such as a tank truck for disposal. For low bridges the troughs can be placed on the ground. For high bridges, the troughs will be supported from the bridge structure. To minimize wind effects, porous cloth drapes can be used, extending from the blast area down to the troughs.

Wet Blasting

Present wet abrasive blasters mix the water with the abrasive prior to impact on the surface. This interaction may be one of the reasons the rate of surface cleaning with present wet abrasive blasters is lower than for dry abrasive blasting. A device designed to minimize premixing of the water with the sandblast is shown in Figure D-41. The device is designed to fit over the end of conventional abrasive blast nozzles. The two principal parts of the device, as shown on the figure, are the swirl chamber (A) and the exit nozzle (B). The swirl chamber is equipped with a tangential inlet (C) to which the water line (D) is connected. The incoming water swirls around the inside of the chamber and then out the exit nozzle. Centrifugal force causes the water to cling to the surface of the exit nozzle and produces a hollow cone of water. The angle of the water cone is controlled principally by the shape of the exit nozzle and centrifugal forces. The device is attached to the exit end of the sandblast nozzle with screws (E). The water hose is attached to the abrasive/air hose with tape or clamps. The switch used to open and close the abrasive/air line also actuates the water line so that both operate simultaneously.

This device is expected to be an improvement over existing wet abrasive blast devices. Existing devices introduce the water directly into the abrasive/air stream, which may adversely affect the performance of the abrasive/air blast. The device provides a curtain of water around the abrasive/air stream; thus, the cleaning effectiveness of the abrasive/air stream should not be affected. The device is simple to install on and operate with conventional abrasive blast equipment.

NEW TECHNIQUES

Cavitation Blasting

A liquid is said to cavitate when vapor bubbles form and grow as a result of a reduction in pressure. When these bubbles impact against a surface, the increased pressure causes the bubbles to

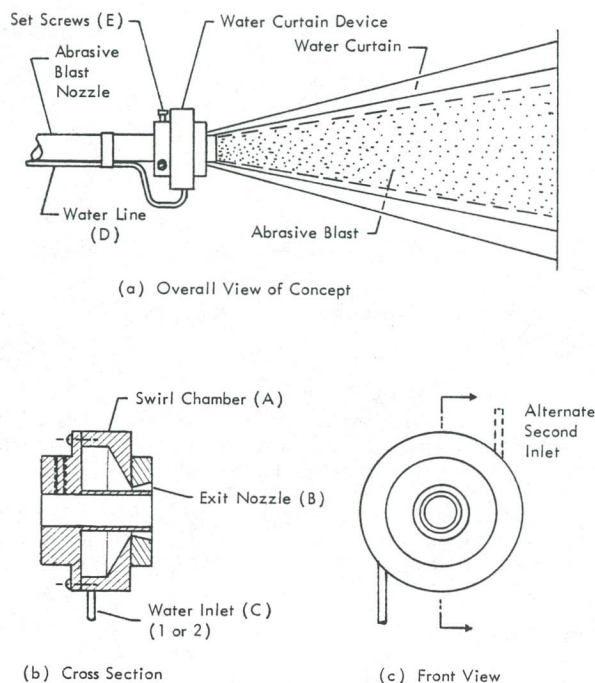


Figure D-41. Water curtain device for abrasive blast nozzles.

collapse as the vapor within them condenses. As large numbers of these bubbles collapse, the impact of opposing masses of liquid produces high local pressure reversals that are imposed on the surface and result in erosion of the surface. The process is illustrated in Figure D-42. A well-known example of erosion caused by cavitation is the wear phenomenon experienced by ship propellers.

Equipment has been developed to provide controlled cavitation in high-pressure water jets for use in cleaning steel surfaces. These systems have been used to remove marine growths from ship hulls, both in dry dock and underwater, to remove high explosives from munitions, and to augment the cutting action of mechanical bits for oil well drilling (98).

A family of hand-held cavitating water jet tools was designed, built, and tested to determine their effectiveness for cleaning bridges prior to repainting under contract with the Federal Highway Administration (99). The jets were laboratory tested on various painted and rusted panel surfaces, and operator handling ability, cleaning rate, and effectiveness were field tested on a bridge. Both laboratory and field tests proved the technique to be effective in cleaning to white, near-white, commercial, or brush blast surface finishes. However, the rates did not approach the proposed rate of 150 ft²/hr. The cleaning rate, using the optimum tool and nozzle to produce a surface that was 88 percent cleaned, ranged from 4 to 12 ft²/hr. To produce a surface that was 50 percent cleaned, the cleaning rate ranged from 30 to 78 ft²/hr.

A separate study (100) showed that the cleaning rates attained for complete paint removal at 10,000-psi nozzle pressure with optimum nozzles ranged from about 6 ft²/hr for three-coat epoxy paint to about 25 ft²/hr for three-coat oil-alkyl paint.

A cavitation blast tool for removing paint from structural steel is currently under development for the Federal Highway Administration. A schematic of the hand gun is shown in Figure D-43. Preliminary field tests of a prototype unit on bridge structural steel (Fig. D-44) were recently conducted (101). Brush-off and commercial blast quality cleaning were achieved at rates of 225 and 111 ft²/hr, respectively.

A prototype containment and recovery system for cavitation blasting has been designed and laboratory tested under a Navy contract, and is scheduled to be shipyard tested in the summer of 1983 (102). A sketch of the containment shroud is shown in Figure D-45. Specific details of the recovery system cannot be revealed at this time because of Navy contractual restrictions.

A proposed (103) truck-mounted cavitation blasting system with a water recovery and recycling system is shown in Figure D-46. It is anticipated that this system will require less water than do nonrecovery systems, prevent paint and rust chips from contaminating the area, allow use of rust inhibitors that might otherwise be prohibitively expensive and environmentally objectionable, and provide an independent water supply. A two-stage separation/filteration system is proposed. In the first stage, centrifugal separation removes particles that have specific gravities substantially different from water. The second stage employs a filtering medium.

The Air Force sponsored the development of a controlled cavitation erosion system for removing coatings from aircraft surfaces (104). The development and engineering analysis of this system showed that polyurethane coating and epoxy polyamide primer can be effectively removed without damage to the substrate with a high-pressure (10,000 psi) water jet system. The maximum removal rates averaged 28.5 ft²/hr.

Flash Blasting

A new technique for cleaning painted surfaces is based on the use of very intense pulses of light that remove the paint by vaporization and charring. By adjusting the intensity of the pulses of light and the number of times the surface is irradiated, the thickness of paint removed can be controlled. The presence of surface contaminants such as oils and greases will not interfere with the process because they will be evaporated or incinerated along with the paint. The process does not produce dust and does not require abrasives or chemicals. Gases from the vaporization of the paint and solid residues may be removed by a vacuum system around the work area.

Two types of flash blast systems are under development. The first system, shown in Figure D-47, consists of a power supply and control module and heads equipped with xenon flash lamps. The power supply provides intense electrical discharges that are carried through cables to the heads where they give rise to the emission of short, intense pulses of light from the lamps. The heads must nearly contact the surface being treated because the intensity of the light drops rapidly with increased distance from the lamps. Applications that have been studied experimentally to date include the removal of polyurethane and epoxy paints from metal, removal of paint from antiskid surfaces, and underwater removal of marine growth from ship surfaces (105). For the epoxy paint the rate of removal was 0.00025 in. per flash.

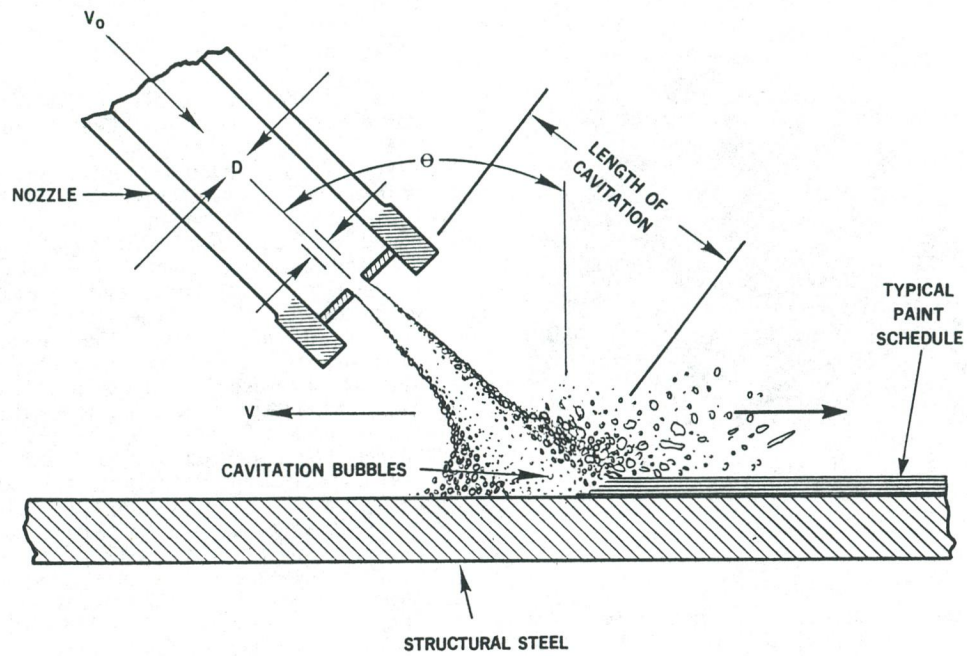


Figure D-42. Principle of controlled cavitation erosion technique as applied to removal of paint from structural members. (Courtesy: Daedalean Associates, Inc.)

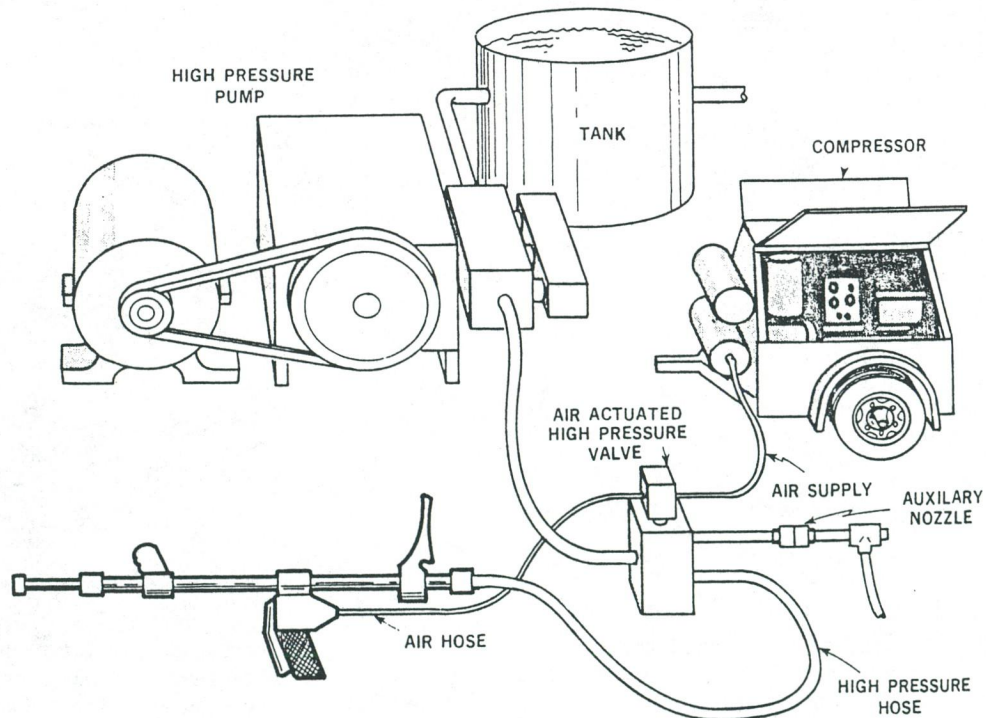


Figure D-43. Schematic of cavitation blasting system. (Courtesy: Daedalean Associates, Inc.)



Figure D-44. Photographic representation of cleaning operation. (Courtesy: Daedalean Associates, Inc.)

Another type of pulsed high intensity light system is being developed to remove paints from aircraft surfaces (106). This system uses a repetitively pulsed CO_2 laser beam as the light source. The beam will scan across the area to be cleaned and vaporize the paint layer. A vacuum system in the head will be used to evacuate the vaporized paint. The developer claims the system will have good ability to remove paints from metal and composite substrates, will not initiate corrosion, and will provide minimum cleanup costs. A concept of a system for paint removal from ships, steel, and other structures is shown in Figure

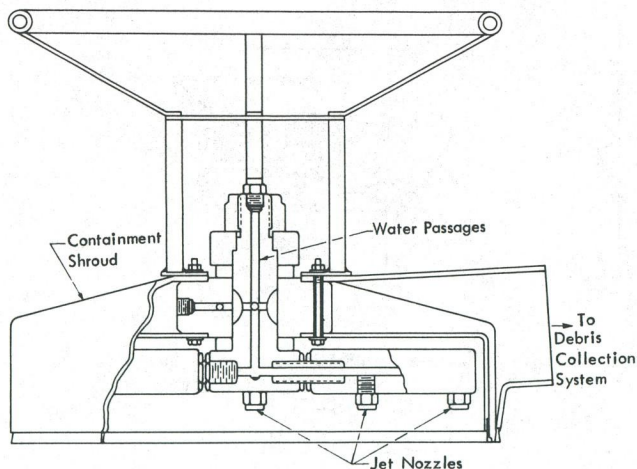


Figure D-45. Finalized design concept of controlled cavitation erosion paint removal and recovery tool (DAE Dwg. No. 8113-D-300). (Courtesy: Daedalean Associates, Inc.)

D-48.

Strippable Coatings

A patented strippable coating for cleaning corroded metal surfaces has been under development at the Naval Research Laboratory (107). A thick paste of polyvinylpyrrolodine (PVP), a water soluble polymer, and ethylenediamine-tetraacetic acid (EDTA), a chelating agent, is applied to the corroded surface. A plastic film forms, encapsulating the cleaning agent. The metal ions are dissolved by the chelant, and possibly the polymer, which causes the polymer to cross-polymerize and cure to a thick film. The hardened film, which contains the corrosion products, is then peeled from the surface like a strip of tape and disposed as solid waste. The cleaning material, shown being applied in Figure D-49, is allowed to clean and harden for a period of 8 to 12 hr at about 75°F. When the cured material is peeled away (Fig. D-50), a clean metal surface remains with a thin adherent layer of magnetite to protect the surface from rusting prior to repainting.

The advantages of this system are that the chemicals are economical, nontoxic, and the material can be readily applied with a brush or roller. The limitation of the present mixture is that it is effective only for rust, not paint. Furthermore, the film must be stripped by hand.

PROPRIETARY NEW SYSTEMS

Several companies have advised us that they are in the process of developing new and improved methods for removing paint from bridges. However, because of the proprietary nature of these activities, no detailed information on these new systems is available.

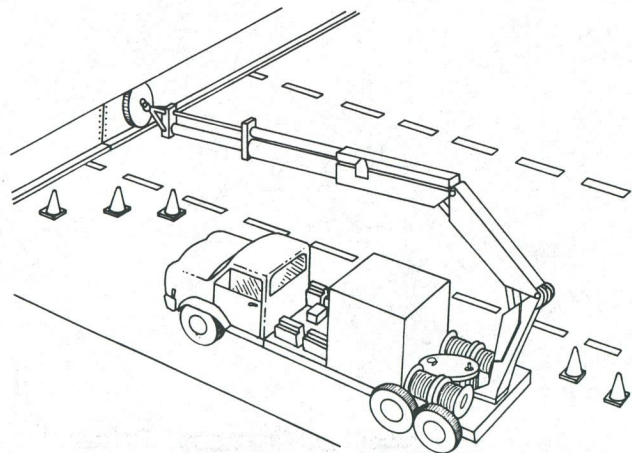


Figure D-46. Proposed cavitation blasting system: shown cleaning a highway overpass. (Proprietary to Hydronautics, Inc.; Courtesy: Hydronautics, Inc.)

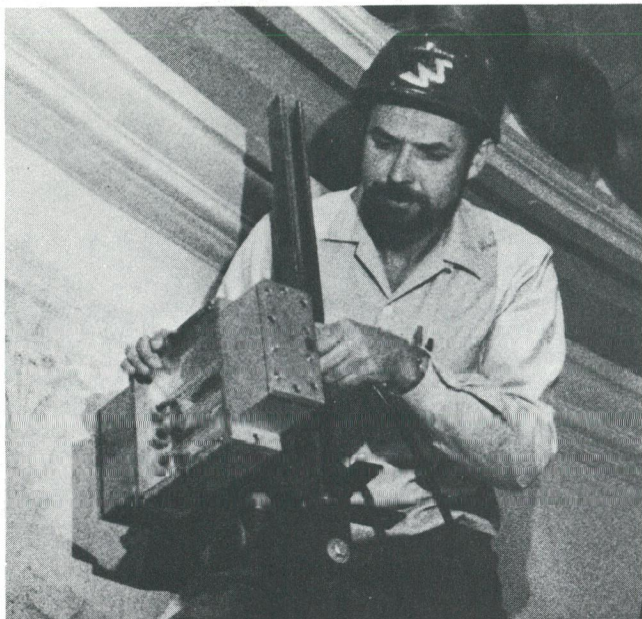


Figure D-47. Xenon flash blasting unit.
(Courtesy: Maxwell Laboratories)



Figure D-49. Application of PVP/EDTA cleaning formulation to rusty iron surface. (Courtesy: Naval Research Laboratory)

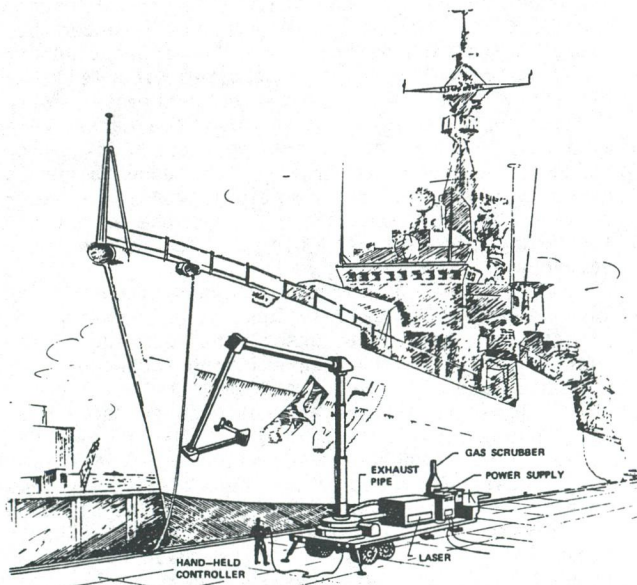


Figure D-48. Concept of pulsed laser paint retrieval system for ships and other steel structures. (Courtesy: AVCO Everett)



Figure D-50. Removal of cleaning strip which contains the rust and other corrosion products. (Courtesy: Naval Research Laboratory)

APPENDIX E

COST ANALYSIS

METHODOLOGY

Costs were estimated for each paint containment and recovery system. These cost estimates include: capital equipment, labor, fuel, utilities, and supplies (e.g., sand, grit). Estimates were not made for final disposal cost (landfill, etc.), maintenance costs, overhead expense, or profit margin. These cost/price factors are very hard to estimate considering that they are dependent on the location where work is being done, the general business operation of the contracting firm, and the desire by the contractor to obtain the work. Because the objective of this analysis is to compare costs of each system against each other in a like manner, these cost/price factors were therefore eliminated. This may mean that the cost per square foot is underestimated relative to a contractor's full cost, but this estimation difference will be the same for all techniques discussed and will not affect the relative cost of each.

Standardized assumptions were made in order to ensure that the system costs estimated were similarly constructed. These assumptions include the following: all costs are in 1983 dollars, depreciation is calculated using the straight-line method over 5 years and 2,080 hr/year (this is an area where contractor's costs may appear higher, e.g., because of accelerated depreciation); labor costs* are \$14.00/hr/worker; fuel costs* are \$1.00/gal of diesel and \$1.05/gal of gasoline; and other costs are figured at \$0.01775/lb of sand,** \$0.30/lb of steel shot,** \$0.05/kW-hr of electricity,* \$0.435/1,000 gal of water,* \$0.05/sq ft of cloth,*** \$0.08/sq ft of cargo netting,*** \$5.00/bale of straw,* \$0.3065/lb of NaNO_2 (rust inhibitor), and \$0.475/lb of $(\text{NH}_4)_2\text{PO}_4$ (rust inhibitor). Costs other than these standardized assumptions will be discussed in the following section.

Some of the containment systems (e.g., wet blasters) incorporate paint removal as a portion of the entire package; thus, the containment function cannot be easily separated out with regard to costs. For this reason, the containment systems not including paint removal utilize a cost estimate based on dry sand blasting to near white specifications at a production rate of 210 sq ft/hr. An estimated 7.2 lb/sq ft of sand is used, 10 gal of diesel fuel per hour, one operator, and capital expenditures of \$25,000 (15). The result is an estimated cost of \$0.26/sq ft. As mentioned, this cost estimate is not intended to depict the full cost to a contractor.

* Average costs for the Mid-America Region.
 ** Chemical Marketing Reporter, Feb. 28, 1983.
 *** Information from American Rigger's Supply, Inc. and Jones Rope & Rigging Company, Inc., of Kansas City. Costs reflect being able to utilize cloth and rigs 48 times before replacement.

The data used for the cost analysis came from the Transportation Departments of Iowa, Wisconsin, Florida, Louisiana, California, and Canada. In addition, cost information was made available by the Massachusetts Port Authority and the following corporations: VacuBlast, Maxwell, Daedalean, Desco, ARO, Seaward, Fisher-Klosterman, Wheelabrator-Frye, Ford Motor Company, Williams, and Kue Engineering.

The majority of the cost data are given in terms of dollars per hour of operation because of the nature of paint removal and containment. Some costs (e.g., fuel, cloth) are supplied in terms of dollars per square foot. This unit appears to be the most appropriate measure of comparative costs because it accounts for at least some production efficiencies. In the technical evaluation section of this report, production rates are discussed in terms of square feet per hour.

The cost values calculated are estimates and are subject to some uncertainty. Therefore, ranges of costs were developed based on the degree of uncertainty associated with the estimates. As stated earlier, the cost estimates are also subject to differences in the geographic location of the activity (e.g., northeast U.S. versus southeast U.S.). Certain costs are not included because of location dependency. The ranges used are based on ± 15 percent for estimates with less uncertainty and ± 40 percent for estimates with greater uncertainty. When such estimates were available, the ranges were developed using the range of published estimates. The uncertainty is directly related to the practical experience associated with each technology (i.e., the extent the technology has been used for paint containment and recovery).

The next section of this appendix discusses the data used and the calculations made in estimating the cost of each paint containment technique. The cost estimates for the two existing techniques not presently used on bridges and the four developmental systems are sketchy at best because these systems are not used in the field. The authors believe it is inappropriate to compare these systems' cost estimates with the existing systems when the only available data are for the blasting of structures other than steel bridges. Therefore, the cost discussion of the developing systems will be separate and more qualitative than quantitative.

DATA AND CALCULATIONS

The data used were obtained from public documents (both state and local), periodicals, trade publications, symposium proceedings, and telephone contacts with government offices and corporations. Brief descriptions of each paint containment system and its associated cost estimates follow. NOTICE: Explanatory notes keyed to this section

are numbered sequentially and are presented at the end of the appendix under the heading, "Footnotes."

Existing Paint Recovering Systems

Ground and Water Covers

The use of ground and water covers involves cloth as covers, a part-time worker to set up the covers as well as help fill the truck with debris, and a truck with driver and fuel. This results in estimated costs as follows:

Truck	\$2.11/hr ¹
Labor	\$21.00/hr ²
Fuel	\$1.25/hr ²

These costs total \$24.36/hr, which is \$0.12/sq ft (at a production rate of 210 sq ft/hr³). Adding the cost of the cloth (\$0.05/sq ft), the total estimated average cost per square foot is \$0.17/sq ft (\$0.43/sq ft for paint containment and removal). The estimated cost ranges from \$0.14 to \$0.20/sq ft (\$0.37 to \$0.49/sq ft for paint containment and removal).

Water Screens

This technique requires straw barriers to act as "screens" in the water; workers to maintain the screens as well as remove the debris; and a truck, driver, and fuel to transfer the debris. This involves estimated costs of:

Truck	\$2.11/hr ¹
Capital equipment	\$0.10/hr ⁴
Labor	\$35.00/hr
Fuel	\$1.25/hr ²

These costs total \$38.46/hr or \$0.18/sq ft (production rate of 210 sq ft/hr³). The straw is estimated to be \$0.08/sq ft⁵ resulting in a total estimated average cost of \$0.26/sq ft (\$0.52/sq ft for paint containment and removal). The estimated cost range is \$0.21 to \$0.31/sq ft (\$0.42 to \$0.62/sq ft for paint containment and removal).

Blast Enclosures

Boston Blast Enclosures. The method used in Boston involves the construction of a rigid housing; the use of hoses, compressors, and a wet scrubber to get the air-suspended materials out of the housing; a truck to remove the debris; and labor to set up the housing, move it, and drive the truck. The cost estimates associated with this system are:

Truck	\$2.11/hr ¹
Housing, compressors, hoses	\$0.96/hr ⁶
Wet scrubber	\$3.08/hr ⁷
Supplies	\$50.00/hr ⁷
Set-up	\$0.14/hr ⁸
Labor	\$35.00/hr
Fuel	\$11.25/hr ^{2,9}

The total estimated average cost of this system is \$102.54/hr or \$0.76/sq ft at a production rate of 135 sq ft/hr¹⁰ (\$1.02/sq ft for paint containment and removal). The estimated cost range is \$0.53 to \$0.99/sq ft (\$0.71 to \$1.33/sq ft for paint containment and removal).

California Blast Enclosures. The California variety of moveable blast enclosures involves the draping of burlap cloth around a work platform. A cloth tube to catch debris leads down from the enclosure to a truck. The cost estimates for this type of enclosure are:

Truck	\$2.11/hr ¹
Cloth	\$2.96/hr ¹¹
Labor	\$14.00/hr
Fuel	\$1.25/hr ²

This results in a total estimated average cost of \$0.10/sq ft (\$0.36/sq ft for paint containment and removal). The estimated cost range is \$0.08 to \$0.12/sq ft (\$0.29 to \$0.43/sq ft for paint containment and removal).

Canadian Blast Enclosures. The procedure used in Canada involves the construction of a 30 ft x 60 ft x 150 ft enclosure around the area to be cleaned. The trapped debris is shoveled through funnels to a truck that carries it off for disposal. The estimated costs include:

Truck	\$2.11/hr ¹
Housing	\$34.62/hr ¹²
Hosing	\$0.10/hr ¹³
Set-Up	\$0.97/hr ¹⁴
Labor	\$28.00/hr
Fuel	\$1.25/hr ²

These estimated average costs total \$67.05/hr or \$0.32/sq ft³ (\$0.58/sq ft for paint containment and removal). The estimated cost range is \$0.24 to \$0.40/sq ft (\$0.44 to \$0.73/sq ft for paint containment and removal).

Vacuum Blasters

Vacuum blasters are systems that are self-contained, removing and recovering paint simultaneously. The estimated costs include:

Capital equipment	\$3.17/hr ¹⁵
Supplies	\$12.50/hr ¹⁶
Labor	\$17.50/hr
Fuel	\$3.00/hr ¹⁷
Grit	\$2.40/hr ¹⁸
Electricity	\$1.70/hr ¹⁹

These estimated average costs include paint removal and total \$48.27/hr or \$0.67/sq ft (production rate of 60 sq ft/hr²⁰). The estimated cost range is \$0.50 to \$0.84/sq ft.

Wet Blasters

High-pressure water blasting has the following estimated costs:

Capital equipment	\$1.45/hr ²¹
Labor	\$14.00/hr ²²
Fuel	\$1.05/hr ²²
Water	\$0.12/hr ²²
Rust inhibitors	\$2.95/hr ²³

The total estimated average cost includes paint removal and is \$19.57/hr or \$0.78/sq ft (production rate 25 sq ft/hr²⁰). The estimated cost range is \$0.55 to \$1.01/sq ft.

Wet sand blasting estimated costs are:

Capital cost	\$2.40/hr ²⁴
Labor	\$14.00/hr ²²
Fuel	\$10.00/hr ²²
Water	minimal ²²
Rust inhibitors	\$0.55 ^{23,25}
Sand	\$0.16/sq ft ²²

The estimated total average cost for wet sand blasting includes paint removal and is \$0.46/sq ft (production rate is 90 sq ft/hr²⁰). The estimated cost range is \$0.32 to \$0.60/sq ft.

Air/sand/water blasting systems have not yet been used on bridges in the United States. The Williams Company has provided some data, however, and the resulting cost estimates are:

Capital equipment	\$7.21/hr ²⁶
Labor	\$28.00/hr ²⁷
Fuel	\$27.00/hr ²⁷
Sand	\$29.00/hr ²⁸
Water	\$0.04/hr ²⁸
Rust inhibitor	\$2.00/hr ²⁶

The estimated average costs include paint removal and total \$93.25/hr or \$0.69/sq ft at a rate of 135 sq ft/hr. The estimated cost range is \$0.41 to \$0.97/sq ft.

Drapes

This technique involves the hanging of cloth drapes on either side of the bridge. Estimated costs associated with this system are \$14/hr for labor and \$0.10/sq ft for cloth. This results in an average estimated cost of \$0.17/sq ft³ (\$0.43/sq ft for paint containment and removal). The estimated cost range is \$0.14 to \$0.20/sq ft (\$0.37 to \$0.49/sq ft for paint containment and removal). This technique involves alternative methods of collecting the debris. The first utilizes a barge below the curtain to catch the debris. This requires an estimated additional \$7.00/hr in labor and \$50/hr for the barge (\$400/day rental), resulting in an average cost estimate of \$0.44/sq ft³ (\$0.70/sq ft for paint containment and removal). The estimated cost range is \$0.33 to \$0.55/sq ft (\$0.52 to \$0.88/sq ft for paint containment and removal). A variation uses cargo netting to catch the falling debris, which is then hauled away in a truck. The additional costs are: a truck for \$2.11/hr, an additional \$7/hr in labor, \$1.25/hr in fuel cost, and \$0.08/sq ft in netting. This means that the average cost estimate is \$0.30/sq ft (\$0.56/sq ft for paint containment and removal). The estimated cost range is \$0.22 to \$0.38/sq ft (\$0.42 to \$0.70/sq ft for paint containment and removal).

Water Curtains

This technique involves placing hoses with nozzles at the top of a steel structure and allowing a fine spray to fall from the top of the bridge. With a readily available supply of water (e.g., a river) the estimated costs are:

Hose and pump	\$0.72/hr ²⁹
Labor	\$14.00/hr
Fuel	\$0.32/hr ³²

This results in an estimated average cost of \$15.22/hr or \$0.08/sq ft.³ The estimated range is \$0.07 to \$0.09/sq ft.

If there is no readily available water source, this will mean an additional \$2.00/hr for a truck, \$1.25 for fuel, an additional \$7.00/hr in labor, and \$0.40/hr in water. This brings the estimated average cost to \$0.13/sq ft (\$0.39/sq ft for paint containment and removal). The estimated cost range is \$0.10 to \$0.16/sq ft (\$0.31 to \$0.47/sq ft for paint containment and removal).

Existing Systems Not Presently Used on Bridges

Vacuum-Shrouded Hand Tools

Data on these types of systems were obtained from ARO and Desco Manufacturing companies. The estimated costs for a typical system are:

Capital equipment	\$0.32/hr ³¹
Labor	\$14.00/hr
Fuel	\$0.32/hr ³²

At a rate of 25 sq ft/hr the estimated average cost per square foot is \$0.60 (includes paint removal). The estimated cost range is \$0.39 to \$0.81/sq ft.

Centrifugal Blasters

Centrifugal blasting has been used by Nelco Manufacturing, Inc., to clean road beds and oil tanks (areas with large flat surfaces). For these uses, Nelco estimates costs (including paint removal) at less than \$0.10/sq ft. This cost estimate is not comparable to the others because of the differences between the surfaces on which this equipment has been used and the surface of bridge structures.

Developing Paint Retrieval Systems

Cavitation Blasting

Some cost estimates were provided by Daedalean, although tests have not been concluded on the use of cavitation blasting on steel bridge structures. The estimated costs are:

High pressure water delivery system	\$2.69/hr ³³
Coating removal device	\$0.26/hr ³⁴
Hand-held cleaning gun nozzle	\$0.10/hr ³⁵
Labor	\$28.00/hr
Fuel	\$0.38/sq ft

Daedalean claims a 25-sq ft/hr production rate for commercial blast, which would mean an estimated average cost of \$1.62/sq ft. This figure includes paint removal. The estimated cost range is \$0.97 to \$2.27/sq ft.

Flash Blasting

Development of pulsed high intensity light systems is occurring using either xenon lamps or CO₂ lasers. The xenon system has a capital cost of \$70,000 and is estimated to cost \$1/sq ft for bridge steel structures including paint removal (cost range of \$0.60 to \$1.40/sq ft). Development of the CO₂ laser system is in the initial stages and, therefore, cost estimates are not available. Currently, tests have not been conducted on bridge structures for either the xenon or the laser method.

Strippable Coatings

Tests using strippable coatings on bridge structures have been conducted, but the data thus far are inconclusive. The Air Force has used strippable coatings at an estimated cost of \$4.00/sq ft (cost range of \$2.40 to \$5.60/sq ft), but the processes are different from those that would be used on bridges.

Potential Improvements to Existing Systems

The following discussion briefly covers the costs associated with proposed improvements for ground and water covers, water screens, blast enclosures, water curtains, and wet blasters. An additional \$0.26/sq ft for paint removal should be added to each cost estimate except the Boston grit blast system.

- **Ground and Water Covers.** Ground and water covers with side covers would involve an additional \$0.10/sq ft for cloth. This raises the estimated cost to \$0.27/sq ft (cost range of \$0.20 to \$0.34/sq ft).
- **Water Screens.** Replacing the straw and buoy system of water screens with a vacuum and solid barrier system would require an estimated additional cost of \$0.01/sq ft. This would include \$6,750 capital cost for the vacuum system (\$0.65/hr), an additional \$3,900 capital cost for the solid barrier (\$0.38/hr), and \$0.06/hr in fuel (3 HP engine), and would result in a total estimated cost of \$0.27/sq ft (cost range of \$0.16 to \$0.38/sq ft).
- **Blast Enclosures.** There are several suggested improvements for the blast enclosures. Placing a seal on the base of the moveable blast enclosure (Boston) would increase the cost an estimated \$0.01/sq ft to \$0.77/sq ft. If a recyclable steel grit blast system were used, the estimated costs would be:

Truck	\$2.11/hr ¹
Capital cost	\$7.21/hr ^{26,36}
Supplies	\$50.00/hr ⁷
Set-up	\$0.14/hr ⁸
Labor	\$35.00/hr
Fuel	\$11.25/hr ^{2,9}
Housing	\$0.48/hr ³⁷
Grit	\$15,000/hr ^{26,28}

The total estimated average cost is \$0.65/hr or \$1.22/sq ft (at a production rate of 100 sq ft/hr). The estimated cost range is \$0.80 to \$1.65/sq ft.

Replacing the wood floor of a fixed blast enclosure (Canadian) with a waffle-grating floor would increase the capital cost by approximately \$18,000 (\$1.73/hr) for the floor and \$22,000 (\$2.11/hr) for an additional truck. Also, a third more set-up time (\$0.33/hr) and a part-time worker (\$7/hr) would be needed. These estimated costs would increase the cost \$0.06/sq ft to \$0.38/sq ft (cost range of \$0.25 to \$0.51/sq ft).

The state of Louisiana has proposed several blast enclosures for use when sandblasting. An estimated cost of this type of enclosure is:

Trucks	\$4.22/hr ¹
Compressors, hoses, etc.	\$0.96/hr ⁶
Labor	\$35.00/hr
Fuel	\$12.50/hr ^{2,22}

The total estimated average cost at a production rate of 210 sq ft/hr is \$0.23/sq ft. The estimated cost range is \$0.14 to \$0.32/sq ft.

- **Water Curtains.** Adding a water catch system and a screening and water recycling system to the water screen technique would raise the estimated cost \$0.04/sq ft and \$0.29/sq ft, respectively. These estimated cost increases would include \$3,000 for the catch trough (200 ft at \$15/ft), 16 hr labor for set-up, and a part-time employee. For the screening and recycling system the additional estimated cost would be \$42,000 for the system, \$250 to \$400/day cost for supplies, and a part-time employee. This would mean a total average cost estimate of \$0.46/sq ft. The estimated cost range is \$0.30 to \$0.62/sq ft.
- **Wet Blasters.** The proposed new wet blast nozzle would cost an estimated \$200 for the nozzle, \$400 for the hose (100 ft @ \$4/ft), and if necessary a 3 HP pump. This system would cost an estimated \$0.01/sq ft.

FOOTNOTES

1. \$22K truck depreciated straight line over 5 years and 2,080 working hours (Source: Ford Motor).
2. 50 miles at 5 miles/gal of diesel fuel.
3. Sand blast rate for near white.
4. \$1K for buoys and scrapers depreciated in normal manner (Source: American Rigger's Supply, Inc. and Jones Rope & Rigging Co., Inc.).
5. 18 bales of straw at \$5 per bale for 1,125 sq ft of structure.
6. \$10K depreciated in normal manner (Source: ARO and Desco).
7. \$32K depreciated in normal manner plus \$400 per day of supplies (Source: Wheelabrator-Frye & Fisher Klosterman).
8. 3 workers, 3-1/2 hr for a 1,040-hr job (Source: Maxwell).
9. \$10.00/hr for compressor, etc. (Source: Department of Transportation, Florida.).
10. Boston stated a 35 percent reduction in production rate from manual.
11. 2,050 sq ft of burlap at \$3/sq ft expensed over 2,080 hr.
12. \$36K (60 x 150 at \$4/ft) expensed over 1,040 hr (Source: Dodge estimates).
13. \$1K (100 ft at \$10/ft) depreciated in normal manner (Source: Seaward).
14. 3 workers, 3 days.
15. \$32,950 depreciated in normal manner (Source: Vacublast).
16. \$100 per day.
17. Vacublast data.
18. 8 lb/hr (Source: Vacublast).
19. 110 V and 30 amps (Source: Vacublast).
20. For near white.
21. \$15K depreciated in the normal manner (Source: Department of Transportation, Florida).
22. Department of Transportation, Florida.
23. 1.25 lb/hr NaNO₂ and 5.42 lb/hr of (NH₄)₂PO₄ (Source: Department of Transportation, Florida).
24. \$25 depreciated in the normal manner (Source: Department of Transportation, Florida).
25. 0.23 lb/hr NaNO₂ and 1 lb/hr of (NH₄)₂PO₄ (Source: Department of Transportation, Florida).

26. MRI estimates.
27. Kue Engineering data.
28. Williams data.
29. 25-HP pump and hoses.
30. 25-HP pump.
31. \$2,400 depreciated in the normal manner (Source: Desco).
32. 15-HP motor.
33. \$28K depreciated in the normal manner (Source: Daedalean).
34. \$2.7K depreciated in the normal manner (Source: Daedalean).
35. \$1K depreciated in the normal manner (Source: Daedalean).
36. \$75K depreciated in normal manner.
37. \$5K depreciated in normal manner.

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