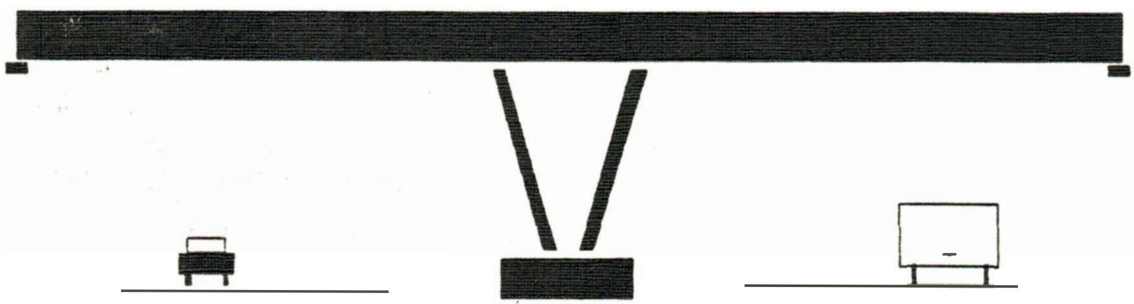
MAINTENANCE STRATEGIES FOR CORRODED STRUCTURAL STEEL



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Final Report

MAINTENANCE STRATEGIES FOR CORRODED STRUCTURAL STEEL

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Summary

The School of Civil Engineering and Environmental Science at the University of Oklahoma under agreement with the Oklahoma Department of Transportation has embarked on a series of studies entitled Technology Transfer with the purpose of determining the state-of-the-art of a specific process and reporting it - in its most updated form - to ODOT for possible implementation.

This report relates to the Maintenance Strategies for Corroded Structural Steel in existing highway bridges. To synthesize the information presented herein, the literature survey employed sources such as NTIS and HRIS computerized databases as well as the library resources of the local FHWA offices, the ODOT Research Division and the University of Oklahoma Engineering Library.

Maintenance of existing steel structures that were painted initially with lead-based type paints, has recently come under scrutiny by the local, state, and federal environmental agencies. The major area of concern concentrated in the potentially hazardous effects of current practices to the surrounding environment of the structures undergoing maintenance. Specifically, the use of abrasive blast cleaning, or more commonly known as "sandblasting", in the removal of old paint results in the creation of airborne waste particles which are carried by prevalent winds and are eventually deposited in the surrounding homes, businesses, open fields, streams, rivers and lakes. As a result of such dispersion of pollutants, lead concentration was detected in humans living closeby who breath the air and come in contact with the contaminated soil and water resulting in inhalation and ingestion of lead particles. Such conditions are particularly affecting children and only aggrevate the already alarming exposure to lead pollutant sources which exist mainly in urban environments. In rural areas the contamination of the land and aquatic environment results in the introduction of lead particulates in the food-chain.

Research in the field of new maintenance methods to minimize environmental side effects was initiated in the beginning of the 80's and has not attained maturity yet. The first methods developed concentrated mainly in the containment of pollutants during maintenance operations using enclosures and filtering equipment to collect, recover and dispose of the removed paint and rust waste. Recently, however new methods of removal such as cavitation blasting, flash blasting, water blasting and strippable coatings have been developed. Such methods utilize more efficient machine

tool designs, laser technology and chemical pastes to remove the old coatings and rust.

Concurrently, modern material technology introduced new paints and coating mixtures that are not based on lead or silicon-chromate compounds but rather on epoxies, aliphatic polyurethanes and vinyl resins. Such compounds when applied on the surface of the structural steel members create a barrier system, as contrasted to the inhibitive system that the oxidizing lead and lead-silicon-chromate form. Although the introduction of the new coating systems provided a solution to the environmental concerns it introduced new problems for the maintenance divisions of the agencies. These problems related to different cleaning and surface preparation needed for the coating system to achieve its full potential. In addition, the costs of the new systems is much higher than existing methodologies and only when potential litigation and remediation costs are taken into account do the new methods become cost effective. Another area of concern is the life performance of such systems whose estimates are only based on accelerated aging tests and on very limited field performance evaluation.

In addition, telephone interviews were conducted with several agencies which were considered forerunners in the area. The consensus from these interviews is that the agencies are facing formidable problems, with respect to the subject matter, to the point that they felt compelled to put the maintenance programs on hold and defer them until such time that these programs become manageable and reasonably cost effective especially in view of the impact of the 1990 Clean Air Act. Furthermore, the agencies voiced their concern that while at this time some type of zinc primer coating is permitted, in the future it may become non acceptable or declared a pollutant. On the other hand, the California method of using water borne based coatings appears to be the most acceptable system. In so far as containment is concerned using simple tarp material is preferred because the other materials/system are too costly to implement. Thus current information about general practices of these agencies with respect to removal and containment of old paint from highway bridges as well as new coating methods was obtained.

Introduction

Maintenance strategies for steel highway structures is an old topic revisited by the involved agencies due to recent changes and increasing awareness in the condition of the environment and the regulations relating to it. Considerations for the accountability for the hazardous wastes created, become an important element in the decision making process for the development of maintence strategies.

The present is a state-of-the-art report prepared for the Oklahoma Department of Transportation by the University of Oklahoma (Project 2112, ORA 158-266), and it was developed by assembling information from numerous sources. After the first screening the information was analyzed with the point of view of including all significant knowledge. The report concentrates on painted structural steel, and exclude A588 weathering type steels, bridge decking and concrete reinforcement. The information gathered was organized and evaluated on the basis of five subtopics which were considered the influential elements involved in the development of current maintenance strategies. These elements constitute the topics of the first five chapters, namely: 1) Methods of removal of the old paint and rust; 2) Application and performance of coating systems; 3) Types of coating systems; 4) Cost considerations; and 5) Environmental regulations and impact assessment.

Chapter 6 reports on the phone interviews conducted with selected agencies in order to gather information about any current performance evaluation of new methods and the general experience that these agencies have on the subject matter that has not found its way into a publication.

Chapter 1

METHODS OF REMOVAL OF THE OLD PAINT AND RUST

The 13 Methods

Attempts to contain and recover the waste materials generated during the removal of rust and old coatings from steel bridges led to the development of a wide variety of methods. There are at least thirteen methods, some of which are more conventional and consequently widely used, and some that reflect recent technological developments and therefore less used. The methods are:

1. Covers
   This method involves the use of canvas or other appropriate textile that is spread on the ground, held with floaters on the water surface, or suspended under the bridge and collects the debris. The waste material is collected manually, placed in containers and then disposed of. (Fig. 1.1, 1.2)

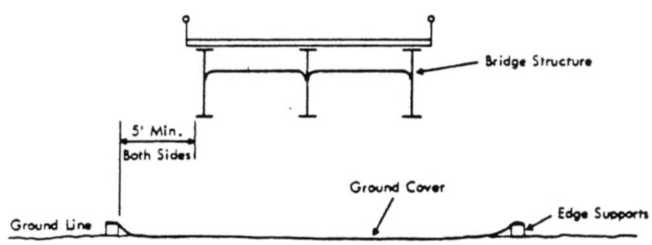

Fig. 1.1. Ground cover method.

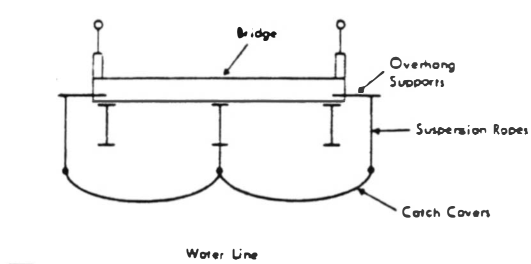

Fig. 1.2. Water cover method.

2. Water Screens

This involves the creation of small dams with a screen face which are anchored to the banks of small streams, both upstream and downstream and collect the floating particles. Such method is restricted to small and low flows of water. (Fig. 1.3)

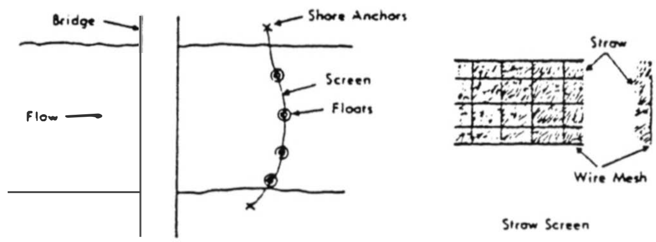

Fig. 1.3. Water screen installed on river.

3. Blast Enclosures

They are used to completely enclose abrasive blasting operations. The floor of the enclosure has funnels or a suction system in order to retrieve the airborne debris. Such method may include wet scrubbing for more effective recovery of the waste. Blast enclosures are mostly custom design for a particular operation. (Fig. 1.4, 1.5)

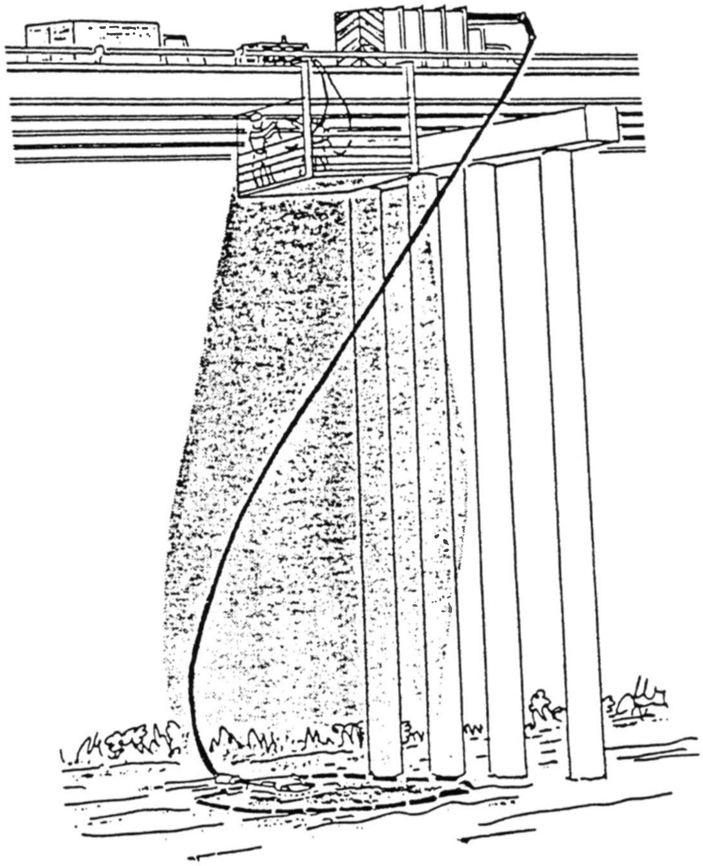

Fig. 1.4. Blast enclosure.

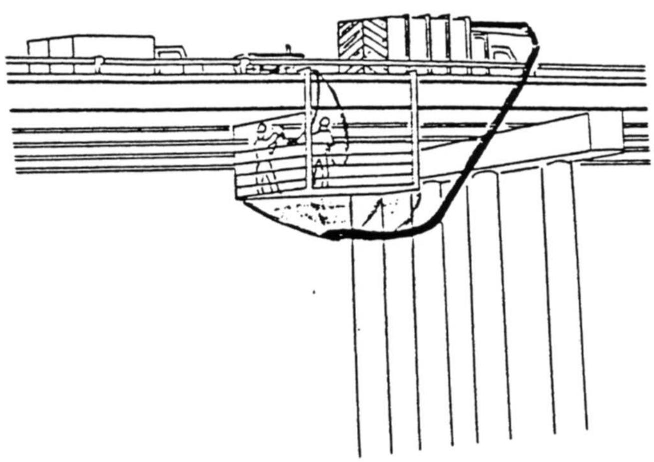

Fig. 1.5. Blast enclosure.

4. Vacuum Blasters

This method utilizes a special blast nozzle which simultaneously blasts and recovers debris with a suction device. (Fig. 1.6, 1.7)

Fig. 1.6. Vacuum blaster in operation.

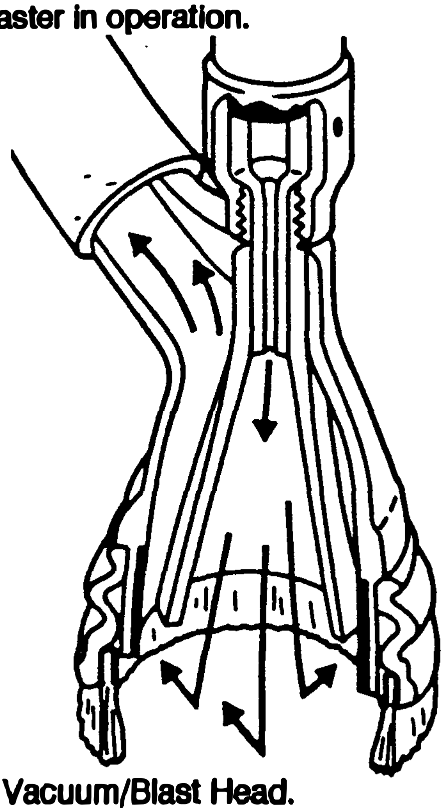

Fig. 1.7. Diagram of Vacuum/Blast Head.

5. Drapes

They are attached to the sides of a bridge to limit the direction of the debris plume downwards to a canvas cover or other collection device. (Fig. 1.8)

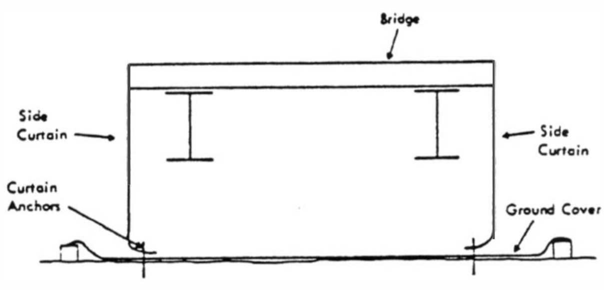

Fig. 1.8. Ground cover with side curtains.

6. Water Curtains

These involve the installation of nozzles along the edge of the bridge. Water sprays from the nozzles downward creating a curtain of water in a way that debris from blasting is washed down to collection through on the ground. (Fig. 1.9)

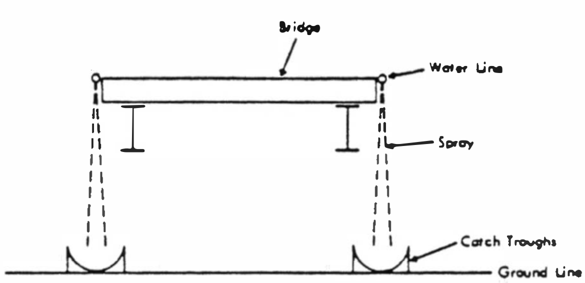

Fig. 1.9. Method for containment of water curtain runoff.

7. Wet Blasting

This technique involves wet abrasive or non-abrasive high pressure blasting which ensures dust-free removal of old paint and rust. The waste material is carried with water which is properly collected and treated. (Fig. 1.10)

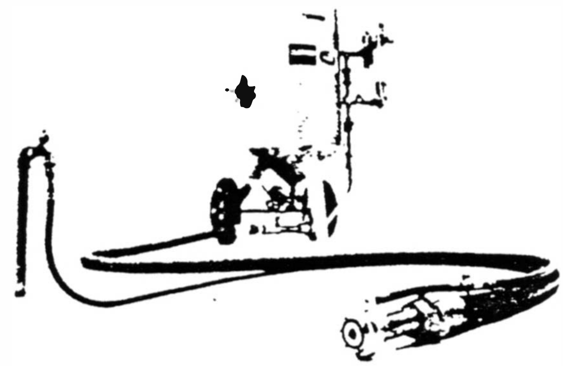

Fig. 1.10. Water injection device attached to conventional (dry) abrasive blast nozzle.

Tables 1.1, 1.2 and 1.3 present performance characteristics for different types of wet blasting.

Table 1.1. 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

Nozzle pressure: 80 to 100 psi.
Water (with rust inhibitor) rate: 0.156 gal/min.

Table 1.2. 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

Water pressure: 9,500 psi.

Table 1.3. 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)

8. Centrifugal Blasters

This method employs blasters that use high speed rotating blades to propel abrasive material against the surface. In addition, the blaster heads have suction covers to collect all paint debris. Although primarily produced for use in large surface areas, smaller hand-held units have been developed.

9. Vacuum-Shrouded Hand Tools

Such tools are used in order to minimize the dust and debris generated by the tool.

10. Cavitation Blasting

It is a method of high-pressure water blasting that uses bubbles produced by the water jet to remove paint and rust. Cavitation blasters with a containment and recovery system have been developed for the U.S. Navy. (Fig. 1.11, 1.12)

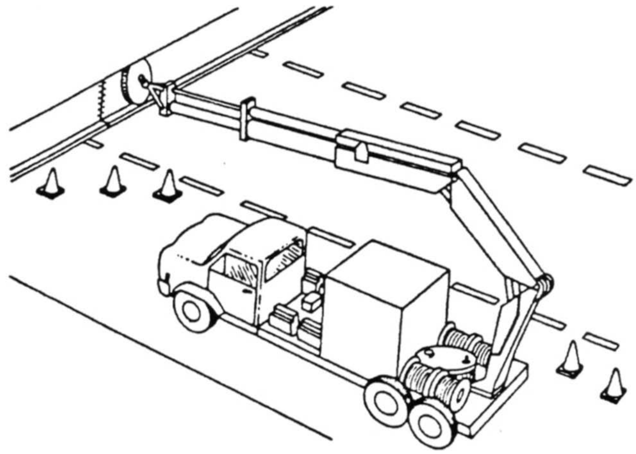

Fig. 1.11. Cavitation blasting system.

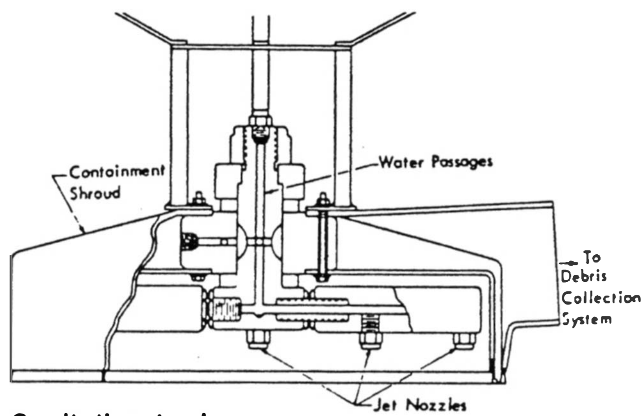

Fig. 1.12. Cavitation tool.

12. Flash Blasting

This is a method based on the use of xenon lamps and CO_2 lasers to vaporize paint with very intensive light pulses.

13. Strippable Coatings

These were developed and patented by the U.S. Navy. This method utilizes a chemical paste which is brushed on the steel surface and allowed to dry. The hardened layer which contains the corrosion products is then peeled and disposed. Although the process is effective only for rust, strippable coatings for the removal of paints are being developed.

Table 1.4 was provided in NCHRP Report 265 (21) as a technical evaluation summary of the methods presented.

Table 1.4. Technical evaluation of containment/recovery techniques.

○ = Poor ⊖ = Fair ◒ = Good ● = Superior Ⓤ = Unknown

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

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

Other typical methods

The Missouri DOT maintenance of the M.L. King Bridge at St. Louis (1) employed wet blasting to remove the old coating and was followed by dry blasting to remove the rust created by the wet blasting.

On several bridges maintained in Northern Ireland (20), wet blasting was selected as the most effective and environmentally safe method.

K.W. Lowrey in the ASTM Publication (19) suggested the use of zinc-coated abrasive material during blasting so that the steel surface will be cleaned and remain protected from rust development until the new paint is applied.

The California DOT report (4) concluded that the most effective method of surface treatment was abrasive blasting. However, whenever this is not possible due to possible environmental impact, hand-cleaning and use of primer coats was determined to be equally effective.

The TRB report (11) provides Table 1.5 which identifies the type of surface preparation required based on the rust rating given by ASTM and SSPC. Chapter 2 provides a more detailed presentation of the rating system.

Table. 1.5. SSPC PA-4: Maintenance painting of oil-alkyd paint.

Condition	Paint System Defect	Surface Area Affected (%)	Equivalent Rust Rating	Surface Preparation Required
1	Rust, loss of topcoat	<0.1	9	Solvent clean (SP-1)
2	Rust, blisters; loose mill scale; loose paint	0.1-1.0	8-6	Hand clean (SP-2)
3	Rust, blisters; hard scale; loose paint	1-10	6-4	Hand clean, feather edges
4	Rust, pits; nodules; loose paint	10-50	4-1	Blast clean (SP-6), feather edges
5	Totally deteriorated	50-100	0	Blast clean entire area

The FHWA report (12) concluded that in terms of removing chlorides (salts) and sulfates (smog) from the surface of structural steel, water blasting was the most effective method compared to steam, detergent and wire brushing and solvent and wire brushing.

Chapter 2

APPLICATION AND PERFORMANCE OF COATING SYSTEMS

The selection of the appropriate coating system and its performance depend on several parameters such as type of surface of previously painted structural steel, adhesion characteristics, compatibility with primers used, environmental exposure in marine, industrial or rural areas, concentration of possible environmentally hazardous chemical compounds and their release due to weathering and resistance to corrosion.

Types of surfaces encountered on cleaned structural steel are: blast-cleaned, tight rust, aged paint and surfaces with inorganic contaminants. Such surfaces have certain physical and chemical properties that determine the potential for proper bonding, development of rust, and uniform coating application. Report (11) includes Table 2.1 outlining surface properties. The same properties apply to paints and their adhesion characteristics as presented in Tables 2.2 and 2.3.

Table 2.1. Surface characteristics.

	Substrate			
Characteristic	Blast-Cleaned Steel (Oxide)	Tight Rust	Aged Alkyd	Oil Film
Surface energy (dynes/cm)	>40	35-38	30-35	~25
Wettability	High	Medium	Medium	Low
Surface area	High	High	Low	Variable
Bond strength to metal	Very high	High	Medium	Low
Specific properties	Thin, dense, stable	Thick, porous	Brittle, fully reacted	Very thin layer

Table 2.2. Properties of paints affecting film adhesion.

	Paint			
Property	Oil-Alkyd	Vinyl	Epoxy	Inorganic Zinc
Surface energy (dynes/cm)	25-30	30-35[a]	30-35[a]	25-30[a]
Wettability	Good-excellent	Fair	Fair-good	Fair-good
Viscosity stability	Good-excellent	Poor	Poor-fair	Poor
Bond to metal	Polar	Primary (slight)	Primary (strong)	Primary
Bond to organic	Polar and primary	Polar	Polar (strong)	Polar (weak)

[a]These data are based on solvent properties.

Table 2.3. Overall strength of adhesion.

	Substrate			
Paint	Blast-Cleaned Steel (>40)[a]	Tight Rust (35-38)	Aged Alkyd (30-35)	Oil Film (~25)
Oil-alkyd (25-30)[a]	G	G	G	F-P
Vinyl (30-35)	E	F	F	P
Epoxy (30-35)	E	G	F	P
Inorganic zinc (25-30)	E	G-F	F-P	P

Note: E = excellent, G = good, F = fair, P = poor.

[a]Solid and liquid surface energies in dynes per centimeter.

The performance of a coating system is measured by its long term ability to maintain its integrity and prevent corrosion of the structural member. The deterioration of coated structural steel follows a behavior presented in Figure 2.1. The curve shows an increase in the rate of degradation with time. This is because of the combined

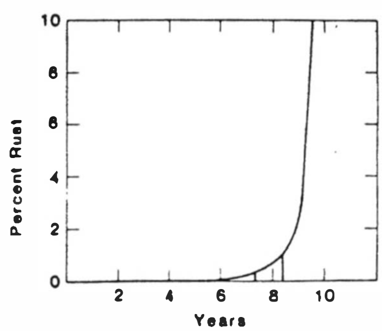

Fig. 2.1. Deterioration of coated steel.

negative effects of the coating and steel performance; i.e., the breakdown of the coating accelerates the steel corrosion and, in turn, the corrosion of steel accelerates coating degradation. The corrosion performance criterion can be quantified by a rust rating developed by ASTM (REF ?). It is based on a mathematical logarithmic formula:

$$R = -2 \times (\text{Log} < \%\ \text{Rust} >) + 6$$

where R is the rust rating. A schematic representation of the rating system is shown on Fig. 2.2.

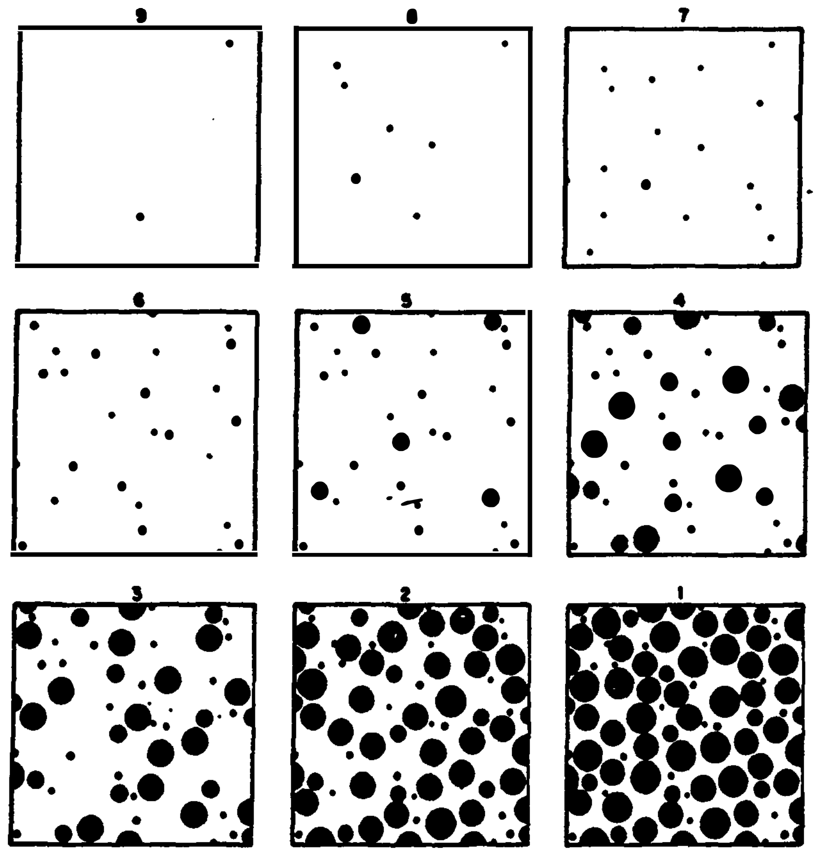

Fig. 2.2. Rating of painted steel surfaces as a function of percent of area rusted.

Other similar ratings which have been developed in the U.K. (27, 28) are given in Table 2.4.

Table 2.4. British standards.

Condition 1: sound paint;
Condition 2: chalking, loss of topcoat;
Condition 3: thin film, blistering, pinhead rusting;
Condition 4: sound film, rusted areas < 25 percent; and
Condition 5: rusted areas > 25 percent.

Condition	Failure Requiring Preparation	Insufficient Topcoat Thickness
1	0-5	0-5
2	6-20	6-25
3	21-35	26-100
4	36-60	100
5	61 or more	100

The synthesis report NCHRP 136 (5) includes Table 2.5 comparing performance and conditional criteria for coating systems.

Table 2.5. Coating system control criteria.

Specifications	Criteria
Surface Preparation	Allowable climatic conditions (temperature, humidity, dew point, wind speed, and where applicable wind direction) Surface preparation methodology Media type and size range (for blasting) Inhibitor type (wet blasting) Equipment type (for power-tool cleaning) Solution types and concentrations, equipment and rinsing schedules (for washing) Required surface quality Mil profile Blast prime interval
Coating Preparation	Homogenization Mixing (of components) Thinning (solvent type and amount) Induction time requirement
Coating Application	Allowable climatic conditions (temperature, humidity, dew point, wind speed, and where applicable wind direction) Allowable application methodology Wet film thickness (minimum and maximum allowable) Dry film thickness (minimum and maximum allowable) Recoating intervals (minimum and maximum allowable) Pot life limitations Description of required appearance Itemization of nonacceptable conditions and required rectification
Coating Materials (Compositional specifications)	Nonvolatile content Pigment content Nonvolatile vehicle content Weight per gallon Vehicle type as determined by I.R. Spectra Zinc content (where applicable) Quantitative determination of key pigmentary elements (Pb, Cr, etc.)
Coating Materials (All specifications)	Viscosity Dry time - touch Dry time - hard Dry time - recoat (may include coin test and solvent rub tests for zinc primers) Pot life Color Gloss Flexibility Sag Resistance Salt Fog Weatherometer or fluorescent UV condensation exposure Immersion salt water Immersion fresh water Bullet hole
Coating Materials (Complete system)	Adhesion and cohesion Salt fog Weatherometer or fluorescent UV condensation exposure Immersion salt water Immersion fresh water Hot/cold/UV/salt cycling environment
Field Evaluation of Finished System	General appearance Dry film thickness Adhesion Touch-up procedures

The FHWA report (12) describes the amount of deterioration of the coating system under various environmental conditions and the results are depicted in Fig. 2.3.

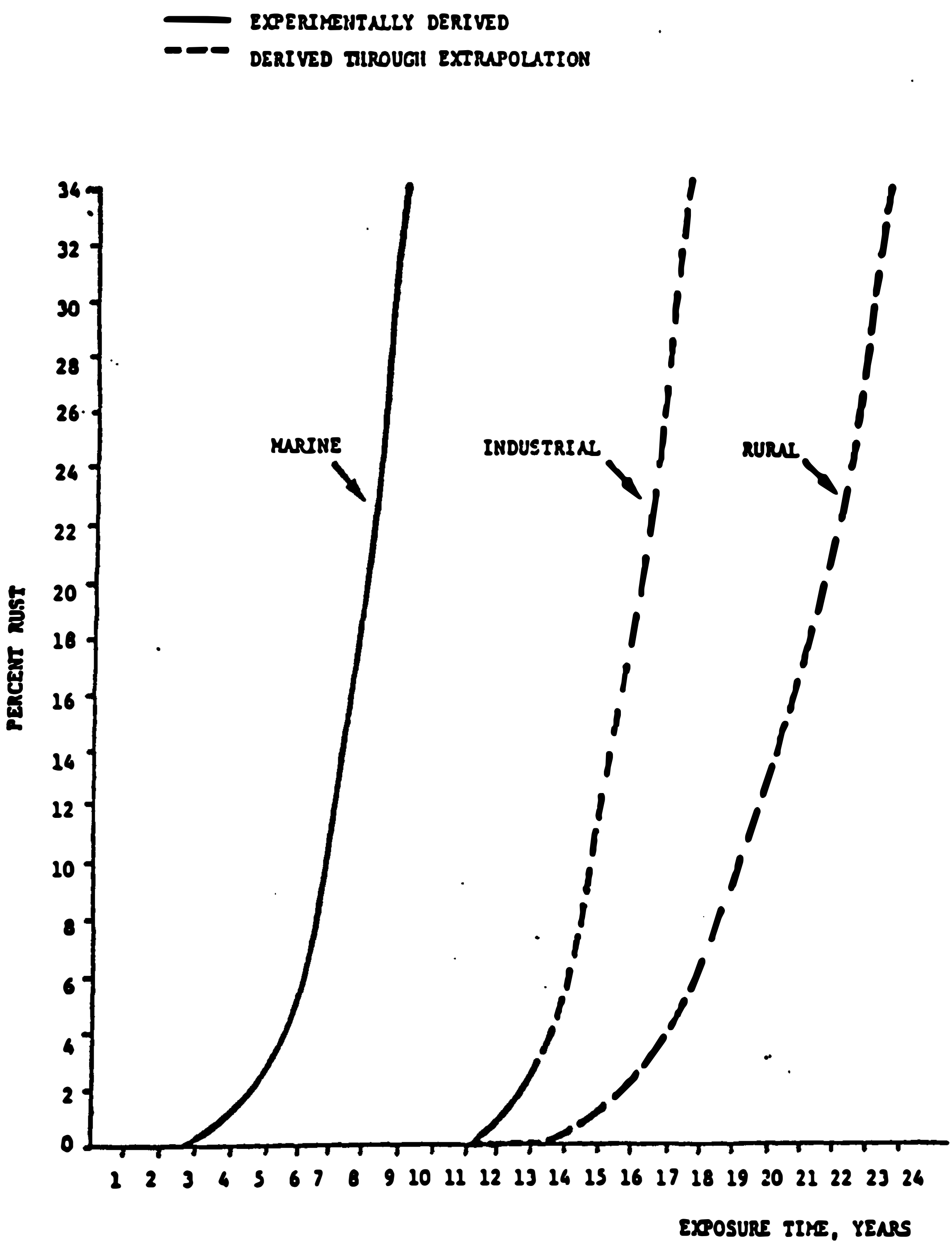

Fig. 2.3. Deterioration versus environmental conditions.

Chapter 3

TYPES OF COATING SYSTEMS

There are numerous combinations of primer and finish coating systems. In addition, the introduction of polymers in use as coatings has increased the possible choices even further. The need, however, for special surface preparations, lack of extensive field performance data and higher costs have retained the feasible alternatives within an acceptable range. There are several general families of coatings such as:

a. Red lead/linseed oil systems which have been widely used for over one-hundred years.
b. Lead-silicon-chromate systems developed in the early 1960's.
c. High-build epoxies.
d. Aliphatic polyurethanes.
e. Vinyl resins.

Another categorization of different types of coating systems is in: (A) Inhibitive and (B) barrier systems.

(A) Inhibitive systems are the most commonly used type for bridge protection. They employ oxidizing intermediate and finish coats. Tables 3.1 and 3.2 taken from the NCHRP report (5), compare different types of inhibitive coating systems with respect to utility and application.

(B) Barrier systems are relatively newly developed and thus less in use in the corrosion protection of bridges. They are heavy duty impermeable systems. Barrier systems are divided into two groups: (1) Thermoplastic (vinyls) and (2) Thermosetting (epoxies). Table 3.3 presents a comparison of typical barrier systems.

The tables that follow provide a comprehensive, yet simple evaluation of the capabilities of different groups of coating systems. The coating system groups are tabulated with respect to the required thickness of a coat, the minimum surface preparation, the sensitivity of their performance to improper application, time between coatings, compatibility with old coating systems, ease of local repair and cleanup.

Another article (2) reports that the Steel Structures Painting Council is currently conducting a laboratory study of twenty seven shop- applied powder coated/metallized systems and high solids/waterborne systems in order to identify environmentally acceptable and cost-effective materials. The study involves accelerated performance testing, and a cost comparison based on projected life-cycle costs.

Table 3.1. Inhibitive coating systems.

System Group No.	System Description	Volume Solids (%)	Typical Film Thickness (dry mils)	Surface Prep. (Min.) SSPC-SP	Adaptability to Poor Surfaces	Probability of Early Failure from Deviations in Application	Recoat Times (days)	Solvent Type	Usual Mode of Application	Compatibility with Old Coatings	Ease of Spot Repair	Ease of Cleaning (Salts and Soils)
I	Red Lead/Linseed Oil[a]	95	2.0	2	Excellent	Very low	3	Mineral Spirits	Brush	Excellent	Excellent	Good
	Red Lead-Iron Oxide/Oil-Alkyd[b]	80	1.5						Brush, Roller, or Spray			
	Aluminum/Alkyd or Phenolic[c]	48	1.0				2					
	BLSC/Oil Alkyd[d]	75	1.0									
II	Zinc Chromate/Alkyd[a]	48	2.0	3 or 7	Good	Low	1	Mineral Spirits	Brush	Excellent	Excellent	Good
	Zinc Chromate/Alkyd[b]	48	1.5						Brush, Roller, or Spray			
	Aluminum/Alkyd or Phenolic[c]	48	1.0									
	BLSC/Oil-Alkyd[d]	75	1.0									
III	BLSC/Linseed Oil-Alkyd[a]	77	2.0	3 or 7	Very Good	Low	2	Mineral Spirits	Brush	Excellent	Excellent	Good
	BLSC/Linseed Oil-Alkyd[b]	75	1.5						Brush, Roller, or Spray			
	BLSC/Linseed Oil-Alkyd[c]	75	1.5									
IV	Nontoxic Inhibitive/Oil-Alkyd[a]	63	2.5	6	Fair	Moderate	1	Mineral Spirits	Brush, Roller, or Spray	Good	Very Good	Good
	Nontoxic Inhibitive/Oil-Alkyd[b]	51	2.5									
	Nontoxic Inhibitive/Oil-Alkyd[c]	45	2.0									
	Aluminum/Alkyd or Phenolic[d]	48	2.0									
V	Inhibitive Latex[a]	45	2.0	6	Fair	Moderate	1	Water	Brush or Air Spray	Fair	Excellent	Poor
	Inhibitive Latex[b]	45	2.0									
	Noninhibitive Latex[c] (two coats)	39	3.5									
	Noninhibitive Latex Aluminum/Latex[d]	37	1.5									

[a] Primer coat.
[b] Intermediate coat.
[c] Finish coat.
[d] Finish coat alternative.

Table 3.2. Zinc based coating systems.

System Group No.	System Description	Volume Solids (%)	Typical Film Thickness (Dry mils)	Surface Prep. (Min.) SSPC-SP	Adapt-ability to Poor Surfaces	Probability of Early Failure from Deviations in Application	Recoat Times (days)	Solvent Type	Usual Mode of Applica-tion	Compati-bility with Old Coatings	Ease of Spot Repair	Ease of Cleaning (Salts and Soils)
VIa	Alkyl Silicate Zinc[a] High-build Vinyl[c]	65 33	3 5	6	Poor	High	1-7[d]	Alc./G.E. Ke./Es./ Arom.	Airless Spray	Poor	Poor-Fair	Very Good (Zinc-Poor)
VIb	Alkyl Silicate Zinc[a] WP-1 Vinyl Wash Primer[b] High-build Vinyl[c]	65 9 28	3 0.3 5	6	Poor	High	1-4[d] 0.02-1.0	Alc./G.E. Alc. Ke./Es./ Arom.	Airless Spray	Poor	Poor-Fair	Very Good (Zinc-Poor)
VIc	Alkyl Silicate Zinc[a] Epoxy/Polyamide (High-build)[b] Aliphatic Urethane[c]	65 60 52	3 4 2	6	Poor	High	1-7[d] 1	Alc./G.E. Alc. Ke./Es./ Arom.	Airless	Poor	Poor	Excellent (Zinc-Poor)
VId	Alkyl Silicate Zinc[a] Epoxy/Polyamide (High-build)[b]	65 60	3 5	6	Poor	High	1-7[d]	Alc./G.E. Ke./Es. Arom.	Airless Spray	Poor	Poor	Excellent (Zinc-Poor)
VIe	Alkyl Silicate Zinc[a] High-build Aliphatic Urethane[b]	65 60	3 4	6	Poor	High	1-7[d]	Alc./G.E. Ke./Es.	Airless Spray	Poor	Poor	Excellent (Zinc-Poor)
VIIa	Alkaline Silicate Zinc[a] WP-1 Vinyl Wash Primer[b] Vinyl[c]	60 9 17	3 0.3 2	5	Poor	Very High	1+ 0.25 1.0	Water Alc. Ke./Es. Arom.	Airless Spray	Very Poor	Very Poor	Very Good (Zinc-Poor)
VIIb	Alkaline Silicate Zinc[a] Vinyl[b] Vinyl[c]	60 20 25	3 1 1.5	5	None	Very High	1+ 0.1	Water Ke./Es. Arom.	Airless Spray	Very Poor	Very Poor	Very Good (Zinc-Poor)
VIIIa	Phenoxy Zinc[a] WP-1 Vinyl Wash Primer[b] Vinyl[c]	38 9 28	3.0 0.3 5	6	None	Moderate-High	1+[d] 0.02-1.0	Est./Ket. Alc. Ket./Est. Arom.	Airless Spray	Fair	Fair	Very Good (Zinc-Fair)
VIIIb	Phenoxy Zinc[a] Epoxy/Polyamide (High-build)[b] Aliphatic Urethane[c]	38 60 52	3 4 1.5	6	Fair	Moderate-High	1+[d] 1	Ke./Es. Arom.	Airless Spray	Fair	Fair	Excellent (Zinc-Poor)
IX	Chlorinated Rubber Zinc[a] Chlorinated Rubber High-build[b] Chlorinated Rubber Finish[c]	68 35 36	3 3.5 2	6	Fair	Moderate	1+[d] 3	Arom./Alc. Ke./Es.	Airless Spray	Fair	Good	Good (Zinc-Fair)

Table 3.2 (continued)

System Group No.	System Description	Volume Solids (%)	Typical Film Thickness (Dry mils)	Surface Prep. (Min.) SSPC-SP	Adaptability to Poor Surfaces	Probability of Early Failure from Deviations in Application	Recoat Times (days)	Solvent Type	Usual Mode of Application	Compatibility with Old Coatings	Ease of Spot Repair	Ease of Cleaning (Salts and Soils)
X	Vinyl Zinc Rich[a]	20	2.0	10	Poor	Very High	0.2-1.0	Ke./Es./	Airless	Poor	Good	Very Good
	Vinyl[b]	28	3.0				0.2	Arom.	Spray			(Zinc-Fair)
	Vinyl[c]	28	3.0									
XIa	Epoxy/Polyamide Zinc Rich[a]	47	3.0	6	Good	High	1.0	Alc./G.E. Ke./Es./	Airless Spray	Fair	Good	Excellent (Zinc-Fair)
	Epoxy/Polyamide Midcoat[b]	60	4.0				1.0	Arom.				
	Epoxy/Polyamide Finish[c]	60	2.0									
XIb	Epoxy/Polyamide Zinc Rich[a]	47	3.0	6	Good	High	1.0	Alc./G.E. Ke./Es.	Airless Spray	Fair	Very Good	Very Good (Zinc-Fair)
	Epoxy Polyamide Zinc Rich[b]	47	1.5				1.0	Arom.				
	Vinyl Aluminum[c]	14	3.0									
XIc	Epoxy/Polyamide Zinc Rich[a]	47	3.5	6	Good	High	1.0	Alc./G.E. Ke./Es.	Airless Spray	Fair	Very Good	Good (Zinc-Fair)
	Epoxy/Polyamide Red Lead[be]	49	1.5				1.0	Arom.				
	Vinyl Toluene/ Acrylic Finish[c]	50	1.5									
XIIa	Uralkyd Zinc Rich[a] (two coats)	55	3.5	6	Very Good	Moderate-High	1.0	Arom./Al.	Brush/ Airless Spray	Fair-Good	Very Good	Good (Zinc-Fair)
	Vinyl Toluene/ Acrylic[c]	50	1.5									
XIIb	Moisture-curing Urethane Zinc[a]	63	2.0	6	Fair	High	1.0	Ke./Es. Arom.	Brush/ Airless Spray	Fair	Fair	Excellent (Zinc-Fair)
	Epoxy/Polyamide Midcoat[b]	60	2.0				1.0					
	Aliphatic Urethane Finish[c]	52	2.0									
XIII	Galvanizing[a]	100	5.0	8	Poor	Moderate-High		None	Dip		Fair	Excellent
XIIIa	Galvanizing[a]	100	5.0	8	Poor	High	0.25	None	Dip		Good	Very Good
	WP-1 Vinyl Wash Primer[b]	9	0.3				0.02-1.0	Alc. Ke./Arom.	Airless Spray			
	Vinyl[c]	28	5.0									
XIIIb	Zinc Metallizing[a]	100	5.0	5	Poor	High	0.25	None	Met. Spray	None	Good	Very Good (Zinc-Poor)
	Vinyl (Carboxylated)[c]	20	2.0					Ket./Arom.	Airless Spray			

Table 3.2 (continued)

System Group No.	System Description	Volume Solids (%)	Typical Film Thickness (Dry mils)	Surface Prep. (Min.) SSPC-SP	Adaptability to Poor Surfaces	Probability of Early Failure from Deviations in Application	Recoat Times (days)	Solvent Type	Usual Mode of Application	Compatibility with Old Coatings	Ease of Spot Repair	Ease of Cleaning (Salts and Soils)
XIIIc	Zinc Metallizing[a]	100	5.0	5	Poor	High	0.25	None	Met.	None	Good	Very Good (Zinc-Poor)
	WP-1 Vinyl Wash Primer[b]	9	0.3				0.02-1.0	Alc. Ke./Arom.	Spray Airless			
	Vinyl (Hydroxylated)[c]	17	2.0						Spray			

[a] Primer coat.
[b] Intermediate coat.
[c] Finish coat.
[d] Critically dependent on attainment of full cure and solvent release.
[e] Marine environment only.

Table 3.3 Barrier coating systems

System Group No.	System Description	Volume Solids (%)	Typical Film Thickness (Dry mils)	Surface Prep. (Min.) SSPC-SP	Adaptability to Poor Surfaces	Probability of Early Failure from Deviations in Application	Recoat Times (days)	Solvent Type	Usual Mode of Application	Compatibility with Old Coatings	Ease of Spot Repair	Ease of Cleaning (Salts and Soils)
XIVa	Vinyl (Carboxylated)[a]	20	1.5	10	Poor	Moderate	0.1	Ke./Es./ Arom.	Airless Spray	Poor	Excellent	Very Good
	Vinyl (2-5 coats)[b]	20	1.5(x3)				0.1					
	Vinyl[c]	20	1.5									
XIVb	WP-1 Vinyl Wash Primer[a]	9	0.3		Fair	Moderate-High	0.02-1.0	Alc.	Airless Spray	Poor	Very Good	Very Good
	Vinyl (Hydroxylated)[b] (plus 2-4 vinyl coats)	17	1.5(x3)	8			0.1	Ke./Es. Arom.				
	Vinyl[c]	17	1.5									
XV	Chlorinated Rubber Primer[a]	32	1.5	6	Fair-Good	Moderate	1.0	Arom./Ali. Ke./Es./ G.E.	Airless Spray	Good	Excellent	Good
	Chlorinated Rubber Midcoat[b]	35	3.0				1.0					
	Chlorinated Rubber Finish[c]	33	1.5									
XVIa	Epoxy/Polyamide[a]	55	2.5	8	Good	Moderate-High	1.0	Alc./G.E.	Airless Spray	Good	Good	Excellent
	Epoxy/Polyamide[b]	60	2.5				1.0	Ke./Es.				
	Epoxy/Polyamide[c]	60	2.0					Arom.				
XVIIa	Aluminized Epoxy Mastic[a]	85	5.0	2 or 7	Very Good	Moderate		Arom.	Brush/ Spray	Very Good	Very Good	Excellent
XVIIb	Aluminized Epoxy Mastic[a]	85	5.0	2 or 7	Very Good	Moderate	1.0		Brush/ Airless Spray	Very Good	Very Good	Excellent
	Aluminized Epoxy Mastic[c]	85	5.0									
XVIIc	Aluminized Epoxy Mastic[a]	85	5.0	2 or 7	Very Good	Moderate	1.0	Alc. Ke./Es. Arom.	Brush/ Spray	Very Good	Very Good	Excellent
	Epoxy/Polyamide Color Coat[c]	80	5.0									
XVIIIa	Moisture Cure Urethane Aluminum[a]	50	2.5	6	Fair-Good	Moderate-High	1.0	Arom.	Brush/ Roller	Good	Fair	Excellent
	Moisture Cure Urethane Aluminum	50	2.5				1.0					
	Moisture Cure Urethane Aluminum[c]	50	2.5									
XVIIIb	Moisture Cure Urethane Aluminum[a]	50	2.5	6	Fair-Good	Moderate-High	1.0	Ke./Es. Arom.	Brush/ Airless Spray	Good	Fair	Excellent
	Moisture Cure Urethane Aluminum[b]	50	2.5				1.0					
	Aliphatic Urethane Color Coat[c]	52	2.0									
XIX	Coal Tar Epoxy[a]	71	8.0	10	Poor	High	0.2-1.0	Arom.	Airless Spray	Poor	Poor	Very Good
	Coal Tar Epoxy[c]	71	8.0									

[a] Primer coat.
[b] Intermediate coat.
[c] Finish coat.

Chapter 4

COST CONSIDERATIONS

Unit costs for maintenance should be expected to vary depending on the type of *removal method* and the *coating* system selected in addition to the geographic location and the surface area of the structure to be maintained.

The average costs for the Central U.S. region (1983 prices) for different removal methods are as follows:

1.	Ground and Water Covers	\$0.17/sq. ft.
2.	Water Screens	\$0.26/sq. ft.
3.	Blasting Enclosures	\$0.76/sq. ft.
4.	Vacuum Blasters	\$0.67/sq. ft.
5.	High Pressure Water Blasting	\$0.78/sq. ft.
6.	Wet Abrasive Blasting	\$0.46/sq. ft.
7.	Drapes	\$0.30/sq. ft.
8.	Water Curtains	\$0.40/sq. ft.
9.	Vacuum Shrouded Hand Tools	\$0.60/sq. ft.
10.	Cavitation Blasting	\$1.62/sq. ft.
11.	Flash Blasting	\$1.00/sq. ft.
12.	Strippable Coatings	\$4.00/sq. ft.

The above values were provided by state D.O.T.s and manufacturing firms and includes transportation and disposal of waster material. Detailed explanation is included in NCHRP report (21).

NCHRP synthesis report 136 (5) offers Table 4.1 showing relative costs of removal methods and a comparison between field and shop costs. It was also noted that application costs varied from contractor to contractor. It was stated, however, that roller application is one third as fast as airless spray and three times as fast as brushing. Table 4.2 shows range estimates for different coatings and application techniques.

Report (25) provided a computer model for calculation of bridge corrosion costs. However, the model needs to be adapted to fit individual cases in order to be accurate. Report (24) suggested the use of discounted cash flow analysis for comparison between coatings and methods.

The FHWA report (26) identified the following potentially influential variables to the cost.

1. Environmental exposure condition
2. Protection method
3. Coating thickness
4. Bridge type
5. Bridge size

The report also presented the Bridge Corrosion Cost (BCC) Model as a decision making tool on maintenance policies.

Report (3) stated that the estimated blasting and coating costs ranged from \$1.87/sq. ft. to \$3.88/sq. ft. (1988 prices). In addition, the hazardous waste disposal costs ranged from \$70 to \$650 per ton.

Table 4.1 RELATIVE COSTS FOR DIFFERENT COATING SYSTEMS

Surface Preparation	Shop Cleaning (New Steel)	Field Cleaning (Low Rolled Beams in Place - Alkyd Coated - 15% rust) ($/ft^2)	Field Cleaning (High Complex Truss in Place - Alkyd Coated - 15% Rust) ($/ft^2)
SSPC-SP-1 (Cleaning of Old Finish)		0.15-0.30	0.20-0.35
SSPC-SP-2 (Hand-tool Cleaning)	0.25-0.30	0.45-0.55	0.55-0.65
SSPC-SP-3 (Power-tool Cleaning)	0.32-0.36	0.60-0.70	0.75-0.85
SSPC-SP-7 (Brush-blast Cleaning)		0.50-0.60	0.60-0.70
SSPC-SP-6 (Commercial Blast Cleaning)	0.28-0.32	0.85-1.00	1.00-1.25
SSPC-SP-10 (Near-white Blast Cleaning)	0.32-0.37	1.15-1.35	1.40-1.60
SSPC-SP-5 (White blast Cleaning)	0.45-0.55	1.60-1.75	1.90-2.10

Table 4.2

RANGE ESTIMATES FOR COSTS OF COATING APPLICATION ON STEEL BRIDGES IN SHOP AND FIELD (1986)

Application Example	Shop Application ($/ft^2)	Field Application (Low Simple Rolled Beam Structure in Place) ($/ft^2)	Field Application (High Complex Truss Structure in Place) ($/ft^2)
Oil/alkyd by brush	0.13-0.15	0.17-0.19	0.21-0.24
Oil/alkyd by roller	0.10-0.12	0.13-0.15	0.16-0.18
Oil/alkyd by spray	0.09-0.10	0.11-0.13	0.13-0.15
Organic zinc rich by spray	0.19-0.21	0.24-0.26	0.29-0.32
Inorganic zinc by spray	0.21-0.23	0.25-0.31	0.31-0.37
High-build (two pack) epoxy by spray	0.17-0.19	0.20-0.25	0.24-0.30
High-build vinyl by spray	0.18-0.20	0.21-0.26	0.26-0.31
Aliphatic polyurethane finish by spray	0.16-0.18	0.18-0.23	0.22-0.28

Chapter 5

ENVIRONMENTAL REGULATIONS AND IMPACT ASSESSMENT

Environmental regulations drastically altered the criteria for selection of the removal method and the type of coating system to be used. Moreover, new methodology is continuously developed in an attempt to comply with federal, state and city regulations.

NCHRP Report (21) provided Table 5.1, that represents environmental regulations that may impact bridge maintenance practices, and Table 5.2 which presents the status of environmental controls employed by various state agencies.

Table 5.1 Environmental regulations which impact bridge maintenance.

Environmental Regulation	Comment
National ambient standard for lead	1.5 μg/m³ averaged over calendar quarter
National ambient standard for particulate matter	
Primary (effective Dec. 31, 1982)	75 μg/m³ annual mean 260 μg/m³ max 24 hr
Secondary	60 μg/m³ annual mean 150 μg/m³ 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/m³ divided by % SiO_2 + 2
Quartz (total dust)	30 mg/m³ divided by % SiO_2 + 2
Federal OSHA standard for inert or nuisance dust	Applies if quartz ≤ 1% of dust
Respirable fraction	5 mg/m³
Total dust	15 mg/m³
State contract specification	More effective than regulation when used

Table 5.2 Status of bridge paint removal controls and paints in the 50 states.

		STATE																								
		Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticut	Delaware	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massachusetts	Michigan	Minnesota	Mississippi	Missouri
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	•	•	•					•	•	•	•	•	•			•	•								•
Permit or Notification Required					•	•																				
Type of Control Measures Used	Tarps				•	•	•	•								•			•	•	•	•	•	•	•	
	Water Booms				•	•									•	•								•		
	Boats and Barges					•													•							
	Other					1															2					
Common Removal Methods Used	Abrasive Blasting	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Power Tool			•				•				•								•		•				
	Hand Clean		•	•				•				•		•								•				
	Other									5																
Paints Currently Used	Red Lead	•	•	•	•		•					•		•							•				•	
	Basic Lead Silicochromate				•		•	•							•			•		•	•		•			•
	Zinc Rich	•			•	•			•	•	•				•	•	•	•	•	•	•		•	•	•	•
	Other (Iron Oxide, Aluminum, etc.)			•		•						•	•	•								•			•	

		STATE																								
		Montana	Nebraska	Nevada	New Hampshire	New Jersey	New Mexico	New York	North Carolina	North Dakota	Ohio	Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina	South Dakota	Tennessee	Texas	Utah	Vermont	Virginia	Washington	West Virginia	Wisconsin	Wyoming
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		•			•	•			•		•					•	•	•	•						•
Permit or Notification Required														•											•	
Type of Control Measures Used	Tarps			•	•			•			•				•	•						•	•	•	•	
	Water Booms			•				•					•								•	•			•	
	Boats and Barges								•																	
	Other																				3		4			
Common Removal Methods Used	Abrasive Blasting	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Power Tool														•							•				
	Hand Clean					•					•			•	•	•	•				•					
	Other														6											
Paints Currently Used	Red Lead	•		•			•		•	•							•						•			
	Basic Lead Silicochromate	•			•	•		•			•	•		•	•		•	•			•	•		•	•	•
	Zinc Rich		•								•	•		•		•		•	•	•				•	•	
	Other (Iron Oxide, Aluminum, etc.)						•				•		•			•			•	•		•	•			

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.

Extensive testing and research by environmental research establishments has long determined that all "lead-based paints" pose a hazard to public health. During blasting operations a plume of airborne lead particles is formed and carried by the wind to nearby ground, homes, water sources and on humans. Such hazard is prevalent in urban environments. It must be noted however, that there has been no study that has isolated the public health effects from bridge maintenance operations. Consequently most toxicity studies do not pinpoint paint removal as a contamination source, and the data presented has been borrowed from other lead contamination studies. Figures 5.1 and 5.2 show typical relationships between wind speed, lead particle size and distance traveled.

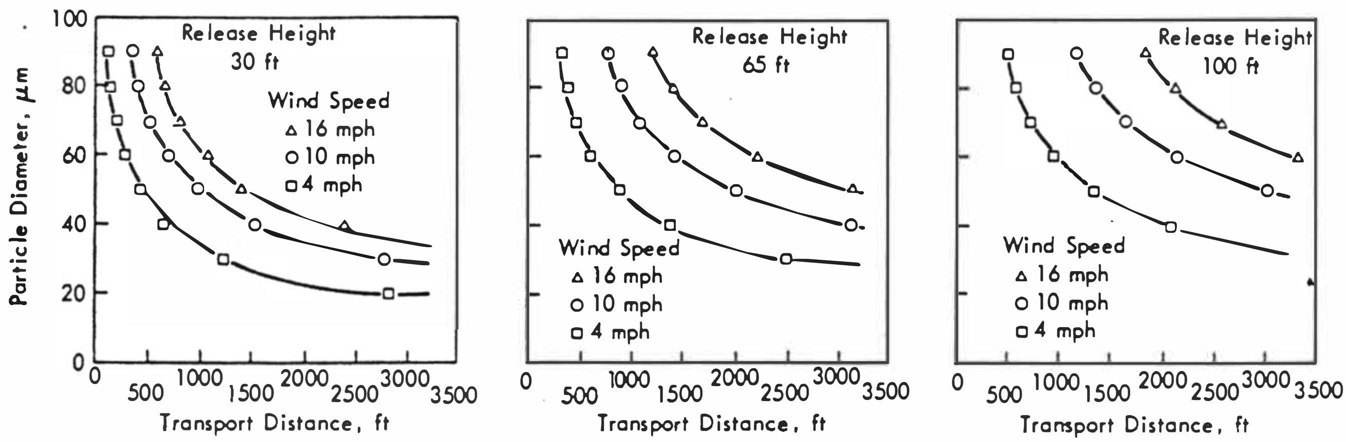

Fig. 5.1. Particle diameter vs. transport distance and wind speed.

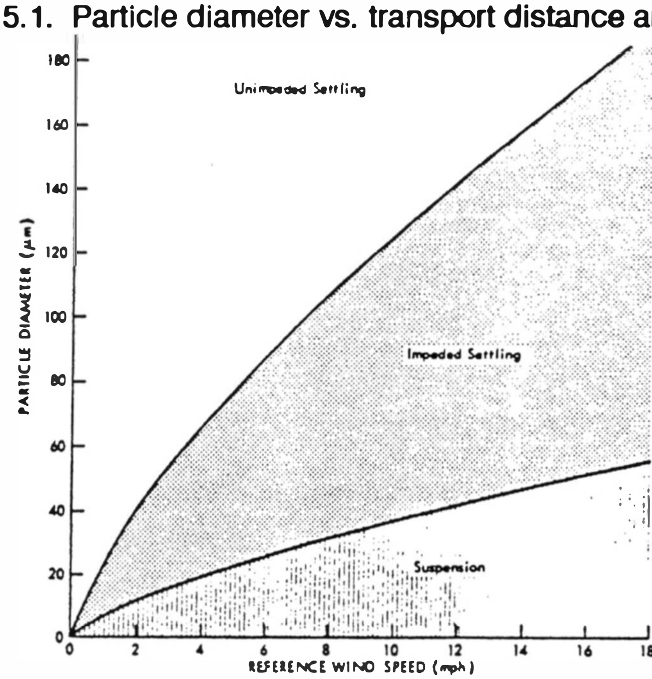

Fig. 5.2. Particle settling and suspension regimes.

EPA's test method 1311 has reclassified numerous cleaning residues from bridge maintenance operations as hazardous waste.

Report (3) reported that as late as 1983 more than one-half of the state agencies still specified coatings containing lead or chromate pigments, and sixteen of the states used them exclusively.

Impact of new regulations:

Several Federal regulations apply to maintenance of steel bridges governing the types of coating systems to be used, the selection of proper containment methods during blasting operations, the safety of the maintenance crews, the collection, classification, containment, storage, hauling and disposal of the waste material.

The following are new environmental regulations that affect or directly regulate steel bridge maintenance operations:

1) Clean Air Act of 1990: It regulates the V.O.C. (volatile organic compounds)content of the paints and coating systems to be used. The new regulations lower V.O.C. limits to 2.8 lbs/gal. from 3.5 lbs/gal. for a coating system and put further restrictions to solvent-borne paints.
2) Hazardous and Solid waste Amendments to RCRA of 1984: The amendments ordered federal, state, and local agencies to adopt the new T.C.L.P. (Toxic Constituent Leaching Procedure) test, to replace the EP toxicity test for all new hazardous waste sources (29). Maintenance operations fall under new sources. The TCLP test is a more aggressive test which will result in designating more waste material as hazardous waste.

Chapter 6

CONTACT WITH AGENCIES

Ten of the agencies that published field project reports were contacted via telephone interviews in order to obtain information regarding the long term performance of the projects or reported. These were:

The agencies that were surveyed were:

1) California (CalTrans) DOT
2) Connecticut DOT
3) Florida DOT
4) Louisiana DOT
5) Missouri DOT
6) New Jersey DOT
7) New York DOT
8) Ohio DOT
9) Pennsylvania DOT
10) Texas DOT

Overview of Questionnaire

The following questions provided the general guidelines around which the interview revolved:

1) How extensive is steel bridge maintenance currently?
2) What types of paint removal procedures are employed?
3) What methods of containment and environmental safeguards are used?
4) What types of paints and coating systems are used?
5) What is the life expectancy and the cost of such systems?
6) Has there been any corrosion performance evaluation?

Interview Responses:

1) California (CALTRANS)
Interviewed: Mr. Norman Moore, a paint specialist

California has currently 700 lead-paint bridges out of a total of 1,100 steel painted bridges.

The remaining 400 bridges have been painted with a coating system which consists of a primer and finish coats of water-borne paint formulated by the CalTrans Laboratories and produced according to specifications by the local industry in 50 gallon containers destined for use only in highway bridges.

A water-borne paint system is the only type of paint that would meet California Air-Resources Board pollution standards since solvent-based paints are prohibited. In addition, such a system has low V.O.C. (Volatile Organic Compounds) less than the 2.8 lbs./gal., this is a standard which was first adopted by CalTrans and currently adopted by federal and other state agencies.

For bridges close to the Pacific Coastline and in the humid northern parts of California, a phenolic-tung oil is used as finish coat which has proven to be more forgiving in such conditions. New bridges paint systems employ a waterborne inorganic zinc primer.

CalTrans specifies only sand blasting (air) for paint removal and surface preparation. Containment methods consist mainly of drapes. However, before the removal process begins, the CalTrans environmental engineer has to inspect the site and approve the set up.

The Fish and Game and Water Quality agencies must inspect and approve the setup provided by the contractor. During operations, maintenance crews use fully encapsulating protective uniforms with oxygen masks. CalTrans is currently considering the use of a decontamination chamber on site and the complete disposal of the uniforms instead of laundering them. A CalTrans inspector visits work in progress to ensure the containment methods work as planned. The removed hazardous material is stored on-site in special containers and then hauled by hazardous waste transportation specialists to the only licensed landfill in the State of California.

On the basis of 10 year performance data for their water-borne system Cal Trans concluded that water-borne systems perform very well. The cost of maintaining a bridge is currently at $2.50-3.00/ft.^{2} including abrasive blasting surface preparation and new paint system.

2) Connecticut Department of Transportation
Interviewed: Mr. Ben Dirgins, Bridge and Structure Engineer
Mr. Peter Barlow, Paint System Specialist

Mr. Dirgins expressed the concern of the agency with the cost of handling removed paint and rust debris, its storage and eventual disposal in lieu of the hazardous nature of the waste and state regulations prohibiting the disposal of hazardous waste in the state of Connecticut. Containment facilities and testing of maintenance crews is specified, however, local paint contractors have been reluctant to absorb the added costs involved, and several bridge painting contracts are currently delayed.

The Department of Transportation is currently in litigation with individual maintenance personnel regarding hazardous waste exposure. Several workers have been diagnosed with blood poisoning although they met the lead exposure standards set by OSHA for construction, 200 mg./m^3 - 8 hr. As a result, the DOT of Connecticut is writing specifications requiring contractors to provide protection to meet the general industry lead exposure standard as set by OSHA of 50 mg./m^3 - 8 hr.

Mr. Peter Barlow, Paint System Specialist for the agency, mentioned that all the bridges in the state of Connecticut have lead-based paints. For the removal of the lead based paints, the following methods were considered: air-abrasive blasting, water blasting, vacuum blasting, chemical stripping and cryogenic blasting. Of these methods, chemical stripping and vacuum blasting were rejected as labor intensive. Cryogenic blasting involves the use of CO_2 pellets to remove the paint coat only, then use abrasive blasting to clean the steel surface; the method was rejected due to high material and labor cost.

The State of Connecticut is currently using the following maintenance strategies:

a. For bridges with 20% of paint surface deterioration, apply a single coat of Alkyde resin-oil to extend life for about 5-8 years until regular maintenance. It was noted, however, that alkyde resin-oil allows water to pass through.

b. For bridges with 30% deterioration, blast clean paint and rust with abrasive media, apply an organic zinc primer, an epoxy mastic intermediate coat and an eliphatic urethane as a finish coat. During the last 3 years, 50 bridges have been painted with the zinc-epoxy-urethane system and have performed very well, even in semi-submerged conditions.

c. Epoxy mastic has been tested as a finish coat but failed because it burns the old paint coat and then peels off.

The following costs, which reflect removal and preparation costs, materials and labor, are associated with the coating systems mentioned:

zinc-epoxy-urethane system	$5.50/ft^2$
alkyde resin-oil	$3.00/ft^2$
for reference lead-paint	$1.60/ft^2$

Connecticut D.O.T. also requires V.O.C. (Volatile Organic Compound) compliance for the paint systems with a limit of 3.5 lbs./gal. of paint. Currently the state is modifying its specifications to include the lead content of a bridge in the abrasive blasting contract, to aid contractors in assessing the potential hazardous exposure to their workers and thus provide the appropriate protective measures.

3) Florida Department of Transportation
Interviewed: Mr. Dick Ramsey, Bureau of Materials and Research

There are no more steel bridges remaining with lead-based paints. All steel bridges have been repainted with solvent borne coating systems that meet a 3.5 lbs./gal. V.O.C. standard. There are two main categories of coating systems used:

a) Inorganic zinc primer wiht acrylic latex or vinyl topcoat system. The latter is used 99% of the time due to lower costs. The coating system has grey or white pigmentation to avoid fading from excess sun exposure. It was reported, however, that vinyls and acrylic topcoats have degraded earlier than expected.

b) On the other hand, the system composed of inorganic zinc primer, epoxy intermediate coat and urethane topcoat is used only in special cases. It has performed better to date but has a higher cost.

In addition, aluminum mastics are used for touch up work. Wet sand blasting and high pressure water blasting are the methods used for paint removal and surface preparation. Power tools are also employed for removal operations in minor jobs.

Containment of blasting operations involves the use of curtain walls and tarps on the sides and under the bridge.

4) Louisiana Department of Transportation
Interviewed: Mr. Curt Clement, Paint Maintenance Engineer

Louisiana DOT began painting steel bridges with zinc primer as early as 1968 replacing the lead-lead based primer coats. Lead-based coats were concurrently used to a lesser extent up until 1975 when they were discontinued entirely.

Since then zinc based epoxy primer is used. The system consists of two coats of zinc epoxy with a topcoat of vinyl. Mr. Clement stressed what he considered an important difference between the zinc epoxy used by Louisiana and the other zinc epoxies used in other states. The specific epoxy was formulated in Louisiana by its D.O.T. and is organic instead of inorganic. The advantage of the organic coat is that it provides better surface adhesion properties, and the vinyl topcoat bonds better on such a surface rather than on an organic one. However, with the advent of V.O.C. standards set forth by the Environmental Protection Agency, the use of such a system is being curtailed due to its greater than 3.5 lbs./gal. V.O.C. content.

In 1982, Louisiana DOT began experimenting with water-borne paints which have V.O.C. contents in the range of 0.2-1.5 V.O.C. for the complete system (i.e., primer + interim + finish) and thus are expected to meet the more stringent standards that are set forth by the new Clean Air Act of 1990.

Louisiana DOT permits contractors to choose different methods of containment. In that respect, all different methodologies have been used on different bridges. Sand blasting has been used successfully considering the consequences involved, i.e., excessive amounts of hazardous waste. Recyclable abrasive material such as shotgrit has been used with mixed results. Recyclable abrasive blasting requires a sealed containment environment so that most of the abrasive material can be recovered. However, such enclosure increases dramatically the amount of airborne lead inside the working area. This, in combination with inefficient recycling procedures, elevates lead exposure in maintenance crews.

Although single use suits, breathing apparatus and decontamination chambers are mandatory, several cases of blood-poisoning have been detected in maintenance crews. It was noted that such exposure can not necessarily be associated to the method of removal itself but also to the negligence of the crews, whose habits are reckless. For example, during several inspections performed cigarette remnants inside the containment area were found. Also crew members would not wash and clean their hands and faces before going to lunch.

Another removal method currently used by some contractors is blasting using "starblast" containing 3% steel. The waste material produced in such operations has been tested using the TCLP (Toxic Constituent Leaching Procedure) test and has been labeled as non-hazardous. Louisiana DOT is also planning to experiment with cryogenic blasting using CO_2 pellets in future contracts.

The cost of maintenance on simple plate girders is currently in the range of $1.00/ft^2 for painting without containment, $2.00-4.00/ft^2 with containment. However, containment is complex truss bridges has stopped due to the excessive costs involved. Typical costs for such bridges over the Mississippi River range between $20,000,000 - $40,000,000 making replacement of structural members with new ones economically feasible.

Finally, Louisiana DOT is concerned that in the near future zinc coatings will also be restricted creating a new problem for state agencies that use such paint systems.

5) Missouri Department of Transportation
Interviewed: Mr. Allan Trampe, Bridge Maintenance Engineer
Mr. Ken Fryer, Maintenance Engineer

Maintenance painting over the Mississippi River and other major waterways has been put on hold due to the excessive cost of containment of the blasting operations and the problems associated with the collection, storage and disposal of the waste material which is hazardous. Typical full containment cost ranges between $\$12\text{-}18/ft^2$.

Missouri has 800 bridges with lead-based paint coats. Repainting of existing bridges using inorganic zinc epoxy primer with vinyl topcoat was first introduced during the late 1970's to replace lead-based paints. The coating system has green or silver pigmentation and has performed satisfactorily to date.

The existing paint removal is accomplished using sandblasting. Tarps are used predominantly for containment purposes althought D.O.T. is currently experimenting wiht sealed vacuum containment to recover the waste. Projects in Kansas City and St.Louis have had problems with containment. It was noted that currently all paints used are solvent borne systems. Missouri DOT has experimented wiht some water borne systems but experienced application problems during cold weather painting periods.

6) New Jersey Department of Transportation
Interviewed: Mr. Al Brenner, Bureau of Maintenance Engineering

New Jersey DOT is currently using organic zinc and inorganic zinc coating systems as a replacement for lead based paints. The organic zinc coating system consists of an inorganic zinc rich primer, a high build epoxy intermediate coat and a urethane finish coat. The inorganic zinc coating system is similar to the organic but the primer is different. The primer coats are tinted to contrast the base metal. The intermediate coats are white and the finish coats have green pigmentation.

Paint removal and surface preparation methods include abrasive blasting using recyclable shotblast or shotgrit. All removed material including recyclable abrasive, and paint chips is vacuumed by a special truck that collects and stores the waste material. All methods of containment are allowed pending approval of the state Engineer. Contract specifications designate all waste material as hazardous in that it may contain red lead and/or basic lead silico-chromate particles. In addition, the contractor is required to provide an emergency management plan and safety measures in case the primary containment methods fails to contain the materials and results in the pollution of the environment. Such plan is authorized by state environmental and health agencies and comply with federal regulations.

7) New York Department of Transportation
Interviewed: Mr.. Richard Frederick, Technical Services Division

It was reported that almost all of the steel bridges have lead-based paints. Approximately 4,000 bridges contain silicon chromate rust inhibitors and lead-based paints. Due to New York Environment Conservation Department's concern with high lead exposure, NY D.O.T. initiated an evaluation of new coatings which led to the selection of new systems. The most commonly used system involve the use of an aluminum epoxy mastic as base with a urethane topcoat.

NY D.O.T. currently uses sandblasting as a removal method but does not remove all the paint and rust. Only spots that show evidence of degradation are cleaned and repainted. The remaining structure is painted with the epoxy coating sealing the lead paint. It was determined that old hot-rolled steel bridges which are over 50 years old have several coats of paint on top of each other and were deemed too costly to clean surfaces to the bare metal.

Bridge repainting is currently proceeding at about 300 bridges per year. Even with spot sand blasting, 1,000,000 yd^3 of hazardous waste per year is generated and disposed of in two in-state licensed landfills. The type of test used to classify the waste material is very crucial to the economics of the maintenance operation. The same waste tested using the EP Toxicity test failed 50% of the time; while using the TCLP test the waste material failed 95% of the time. NY DOT adopted the TCLP test a requirement which went into effect on September 1990, by EPA.

Methods of paint removal and surface preparation also experimented with include vacuum blasting and high pressure water blasting. Vacuum blasting was deemed successful only on flat plate bridges. Water blasting was used on the old bridges with partial success.

Containment methods used involve tarps on the sides and below the blasted area. All paints used are solvent borne and are likely to be affected by new Clean Air Act V.O.C. standards.

The maintenance contracts are awarded on a lump sum basis for each individual structure.

8) Ohio Department of Transportation
Interviewed: Mr. John Waberly, Bureau of Maintenance

It was reported that 50 percent of the state's steel bridges have lead-based paint systems. For spot maintenance, on-site galvanizing is used at a cost of $1.00 per sq. ft. For complete removal and repainting, an organic zinc primer, epoxy intermediate an urethane finish coat system has been adopted since the Spring of 1988. Removal of the old paint is accomplished using recyclable abrasive steelgrit with an encapsulating containment system made of tarps placed on the sides and the bottom on the blasted area. There have been no problems reported with excess lead exposure to the maintenance crews from the use of steelgrit. The cost of placing the new coating system is $8.00-$9.00 per sq. ft. The new coating system is expected to perform satisfactorily for 15 years. Nevertheless, all maintenance painting has been placed on hold due to high costs. The agency is currently researching alternative coatings and removal methods that are cost effective and will ensure compliance with environmental regulations.

9) Pennsylvania Department of Transportation
Interviewed: Mr. Joe Moehlmann, Bridge Maintenance Engineer
Mr. Bob Davidson, Chief Chemist

Mr. Moehlmann mentioned that Pennsylvania has approximately 5,000 steel bridges, of which 93% are painted with lead-based paints, a few are weathering steel and the remaining are bridges build since 1983 that use zinc inorganic primer in lieu of lead-based primer.

State specifications call for the use of an inorganic zinc as coating if SSPC-SP10 (Steel Structures Painting Council designation for 95% residue-free, blast cleaned, steel surface area) can be achieved. If an SSPC-SP6 (66% residue-free, sandblasted) surface is the best that may be achieved, then an aluminum filled mastic is specified as primer. V.O.C. compliance level is 3.5 lbs./gal. and P.D.O.T. has adopted paints systems approved by the Florida D.O.T. Such systems include the use of micaceous iron oxide as pigment in primers, the use of zinc epoxy urethane, zinc chlorinated rubber, zinc vinyls and acrylics as intermediate and finish coats. Mr. Bob Davidson mentioned that two waterborne rust inhibitors are also used. He noted, however, that the new Clean Air Act of 1990 will in effect exclude the use of epoxy mastics and some other solvent-borne urethanes due the the high V.O.C. levels they exhibit. He added that there are still several waterborne products that will meet the new standards.

Surface preparation is achieved by abrasive blasting using 95% recyclable abrasive material such as "steelshot" or "steelgrit." The on-site equipment has the capability to effectively separate the abrasive material from the paint waste. The combination of the required total containment of the cleaning area and the use of recyclable abrasive has made the operation more cost effective. In addition, the hazardous waste volume is significantly reduced which in turn minimizes the hauling and disposal costs.

According the Mr. Moehlmann, contractors are responsible for collecting and transporting the hazardous waste material to a D.O.T. storage area, and from there a separate contract is awarded to haul the material to a designated landfill out of state. It should be noted that the type of containment is specified by the State Engineer in the contract.

Since 1986, when the coating systems mentioned above were adopted, several bridges have been rehabilitated using such coatings, and the performance to date has been excellent.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

This study aimed at synthesizing the information which was available in the most recent literature and enriching it with the information on the current practice and experience of selected DOTs. On the basis of the data obtained from these sources the following conclusions may be drawn:

1) Use of recyclable abrasive material (steelshot, steelgrit) in combination with sealed enclosure during blasting operation should be considered, and the cost involving recycling of blasting material should be compared to the cost of storing, transporting and disposing the sand-paint chip waste material produced by sand blasting operations.

2) The adoption of waterborne based paint coating systems should ensure compliance with all present environmental regulations and the regulations that will emanate from the new Clean Air Act of 1990. California's 10 year experience with such paint systems may be used as a guideline to develop a qualified product list.

3) The adoption of the OSHA general industry standards for lead exposure, which is 50 mg./m^3 - 8 hr., instead of the OSHA construction standard of 200 mg./m^3 - 8 hr. should eliminate potential for blood poisoning in crews. This measure should involve use of special gear and uniforms for cleanup crews. That should be furnished by the contractor.

4) The TCLP (Toxic Constituent Leaching Procedure) test should be adopted in place of the EP toxicity test for testing the material generated by the blasting operations. The TCLP test is required by federal regulations as of September 25, 1990 for all new hazardous waste sources to which scheduled bridges for maintenance painting will fall under.

It is further recommended that:

1) Experience from other departments indicate that bridge maintenance should have a specialist who is involved in the coating system, selection and performance, paint removal methods and site containment, environmental regulations relative to air, water, soil pollution and maintenance crew protective measures.

2) Due to the emphasis put recently on expert systems ("Expert System To Cost Feasible Bridge-Painting Strategies", S.McNeil et.al., TRR 1145), ODOT should be mindful of future studies to be conducted for the possible development of an identification and ranking system of bridge maintenance operations, utilizing knowledge-based expert systems. Such a system may serve as a comprehensive management tool to simplify the decision making process in the maintenance of steel bridges. Knowledge-based expert systems have been developed and are currently used successfully in other areas of transportation engineering.

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