NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **74**

PROTECTIVE COATINGS FOR HIGHWAY STRUCTURAL STEEL

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NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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PROTECTIVE COATINGS FOR HIGHWAY STRUCTURAL STEEL

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS IN COOPERATION WITH THE BUREAU OF PUBLIC ROADS

SUBJECT CLASSIFICATION:
- BRIDGE DESIGN
- GENERAL MATERIALS
- MAINTENANCE, GENERAL

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
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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.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by Highway Planning and Research funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, non-profit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. 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 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 responsibilities of the Academy and its Highway 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.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

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FOREWORD

By Staff

Highway Research Board

The most generally accepted method of providing corrosion protection for the steel members of highway bridges and other structures is painting. This report contains a current state-of-the-knowledge with regard to painting of highway structural steel, based on a thorough review of literature and current practice, an inspection and evaluation of more than 4,000 paint exposure tests, and the conduct of paint film thickness measurement studies. Due to the comprehensive nature of the investigation dealing with factors that influence paint selection, such as performance, appearance, costs, availability, and air pollution requirements, the report will be of interest and value to a wide range of highway personnel, including materials, maintenance, and bridge engineers, and specifications writers. The specific recommendations, summarized in Table 3, for typical preferred paint systems (including surface preparation, pretreatment, application methods, thickness, primer, intermediate coat, and finish coat) for various environmental exposure conditions, will materially aid highway agencies in the selection of suitable steel coating systems and are sufficiently explicit to permit direct application.

Highway engineers have for years been faced with the problem of selecting suitable materials and methods for painting steel bridge members. The need for separating fact from fiction—documented evidence of performance under known conditions vs opinions and advertising claims—is becoming increasingly important in view of rising labor and material costs, new developments in steel products and coatings, emphasis on safety and aesthetic considerations, and the larger number of structural steel members requiring protection, both in bridges and other appurtenances that are being incorporated into Interstate and other multi-lane highway facilities. Many highway engineers are responsible for a variety of overall steel painting considerations, such as specifications, materials, design, construction, and maintenance, without the aid of a paint or coating specialist. The problem is compounded by the fact that much of the information available to the highway engineer on this specialized subject is presented from the point of view of only one type of product.

Because of its previous and current research in the subject area, the Steel Structures Painting Council (SSPC) was selected as being eminently qualified to conduct a critical review of literature and current practice as a basis for development of recommended protective coatings for highway structural steel. An annotated bibliography containing more than 1,000 items related to the painting of structural steel and covering the period of 1955-1968 was prepared by the agency. It supplements a satisfactory bibliography to 1955 which appears in the *Steel Structures Painting Manual* (Vol. 1). A survey of current steel painting practices of 50 state highway departments, plus other agencies, was conducted by interviews, questionnaires, and the collection of specifications and other documents. As additional sources of information, a number of inspections were made of 30 field paint test exposure sites that had previously been established by the SSPC. Although some

of the inspections involved railroad bridges and test panel sites, most of the results were considered to be directly applicable to highway structures.

Because paint film thickness is a direct measure of steel protection and more than half of the state highway departments interviewed identified film thickness measurement as one of their greatest problems, a limited experimental investigation on the effect of film thickness on paint life and methods of paint film thickness measurement was authorized as an extension to the project.

The literature review, survey of current practices, inspection of field evaluation sites, and film thickness experimental program constituted the data collection phase of the study that was used as the basis for recommendations on preferred coatings for highway structural steel. Information on all aspects of the data collection phase are included in this report. In addition, the complete bibliography has been reproduced as *NCHRP Report 74A,* "Protective Coatings for Highway Steel, Literature Survey, 1955-1967," and the complete details of the state highway department survey as *NCHRP Report 74B,* "Protective Coatings for Highway Steel, Current Highway Practices." These documents are published in extremely limited quantities for distribution to researchers and others having a need for detailed background information. They can be obtained through the HRB Publications Office. The SSPC plans to keep the bibliography up to date and to publish supplements periodically.

During this study, it was found that variations in environmental exposure, surface preparation, and coating thickness overshadow the differences in performance between types of coatings. There is no one "best" paint for all conditions or types of exposure. Under "Recommended Application of Findings" the report indicates that environment is the most important consideration in the selection of a paint system, and lists preferred systems and alternates for principal zones of exposure severity. Severity of exposure can change sharply over very short distances. The zone descriptions are intended to represent specific exposure of the portion of the structure under consideration, rather than geographic areas.

Several additional aspects of the overall problem that should be of particular interest to highway agencies deal with economic evaluation methods (in some cases a high-cost system may easily be justified, but in others it may be a waste of money), blast cleaning (extends paint life, but requires more paint and creates thickness measurement problems), film thickness measurements (wet film thickness measurements, as presently carried out, are frequently erroneous and misleading), and proposed programs (manual specifically for painting of highway structural steel, updating of AASHO paint and painting specifications, performance specifications, highway steel information clearinghouse).

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ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 4-6 by the Steel Structures Painting Council, with John D. Keane, Director of Research, as principal investigator. The SSPC received excellent cooperation from all who were asked to provide information in this survey project. In particular, acknowledgment is due the officials of the 50 state highway departments who participated in meetings on this subject, sent information by correspondence, and supplied specifications. Officials of such states as Texas, California, Michigan, and Pennsylvania provided repeated consultations and inspiration for concepts developed in this report. The work of the bridge authorities and of railroad personnel is also acknowledged in helping to conduct steel painting tests, the results of which are applicable to all concerned with corrosion protection. Those who cooperated in the individual tests described included the Federation of Societies for Paint Technology; the Association of American Railroads; the American Iron and Steel Institute; the Pittsburgh-Des Moines Steel Company; the United States Steel Corporation; the Ambridge Water Authority; the Missouri Pacific, Santa Fe, Great Northern, Chicago Great Western, and Pennsylvania Railroads; and the Cap Tree and Mid-Hudson Bridge Authorities.

Too numerous to mention by name are other specialists who provided background information summarized in this report, including consultants, raw material suppliers, contractors, turnpike authorities, and fabricators, particularly those who are represented in the membership of the SSPC and its Research Committee (under the chairmanship of J. Bigos); also, AASHO, the Bureau of Public Roads, and the Highway Research Board.

The American Society for Testing and Materials and the National Paint, Varnish and Lacquer Association kindly granted permission to reproduce selected abstracts from their review publications.

Members of the SSPC staff who contributed substantially to this report included Mrs. C. Moritz, Mrs. K. Condiff, Miss J. Brislin, F. Hughes, and S. Porac. J. Bruno and A. Massaro contributed to the experimental portions.

PROTECTIVE COATINGS FOR HIGHWAY STRUCTURAL STEEL

SUMMARY

The purpose of this study has been to review critically the large amount of scattered and often contradictory information on the painting of structural steel for highway use, and to prepare a more definitive evaluation than now exists. To assist highway personnel in the selection and use of materials and methods, recommendations are presented in this report. They are the result of a critical survey of current practices, of a literature survey of the past 10 years, and of first-hand experimental work involving about 4,000 test areas.

Selecting Paint Systems

Specific recommendations are given for selecting typical paint systems on the basis of six environmental zones, which represent the tremendous range of severity of environment in which highway steel structures are located in the United States.

Zones range from 1A (dry interiors), where a single coat of shop paint is the economical solution, to Zone 2B (frequently wet with condensation and salt water), where a zinc-rich system is recommended over carefully blast-cleaned steel surfaces and thoroughly protected with a vinyl, or alternate, finish coat system. Between these extremes are Zone 1B (dry exteriors), representing the environment of the majority of highway structures, which can be protected with an oil-base-alkyd system over carefully wire-brushed steel; and Zone 2A, where a vinyl system is recommended to protect against condensation and fresh water. Zone 3 covers chemical exposures. Zone 4 covers special conditions such as galvanized steel, welds, temporary protection, and mildew. Model specifications are suggested for surface preparation, application, material procurement, and paint system.

In Zone 1, where conventional oil-base paint systems on wire-brushed steel have in the past given 6 to 20 yr of protection before retouching or repainting, it is difficult to justify mandatory blast cleaning. In Zones 2 and 3, on the other hand, where conventional paints now last 5 yr or less, the best in surface preparation is usually justified. Material costs represent only a small fraction of the total, and low-quality paints are seldom, if ever, justified.

Alternate Paints

As a result of several thousand paint evaluations made during this project, alternate paint systems have been proven for use in place of the primary systems in each zone. These include epoxies, chlorinated rubber, coal tar epoxies, silicone-alkyd finish coats, and high-build coatings, as proven by steel-painting experience of highway departments and many other users. Criteria influencing the choice are discussed, including cost, appearance, design, available materials, and available know-how.

Over wire-brushed steel, most users still specify some type of linseed oil base paint. This vehicle is ordinarily pigmented with red lead or basic lead silico chromate combined with iron oxide; zinc dust/zinc oxide is also good, and zinc chromate is effective if the exposure is short before topcoating. Two new white primer pigments are very promising.

Other coatings discussed which deserve special attention for highway use include: water-base paints, solvent-free materials, colored aluminum paints, non-leafing aluminum intermediate coat, colored finish coats, and reformulations meeting air pollution control requirements. Conditions are also indicated under which painting might be eliminated in favor of metallizing, galvanizing, grease-coating, or use of unpainted steel.

A unique cost approach helps in the choice among alternate systems.

Good Practices

This report includes a resume of the best current practices of the highway and steel-painting industries. In the U.S. about one-fifth of the states require blast cleaning, and another fifth are considering it. Airless spray, hot spray, and roller application are proving effective, but many states require brushing of primer, particularly over hand-cleaned steel. New paints in use include basic lead silico chromate pigmentation in conventional vehicles; zinc-rich paints (both inorganic and organic) with suitable topcoats; and vinyl systems for other severe exposures. Under active field evaluation are epoxies, silicone-alkyds, chlorinated rubber, water-base paint, and several others. The most pressing problems were film thickness, inspection, painting edges, poor specifications, de-icing salts, painting bolted joints, and lack of objective test information.

It is important to eliminate, at the design stage, difficult-to-maintain features such as inaccessible areas of all kinds, surfaces where water can collect, and drain spouts or expansion joints through which de-icing salts drop onto steel. Good inspection is essential; the increased cost of hiring, training, and maintaining a corps of experienced field inspectors can be justified by the resulting increased paint life.

Blast cleaning usually can be justified economically in areas where paint life of 5 yr or less is being obtained on hand-cleaned steel. It is also used because of poor quality of available hand cleaning, improved weldability, reduced maintenance, and wider availability of blast-cleaning equipment.

Paint Thickness

The study showed that surface preparation, proper application, and film thickness are all far more important than the type of paint used. Because paint thickness measurement was considered the most neglected of these three aspects, a special experimental phase of the project was devoted to it. This showed that (1) a direct correlation exists between film thickness and paint life; (2) some current procedures in measuring dry thickness lead to serious errors; (3) the usual method of measuring wet film thickness is misleading; (4) the height of blast-cleaning peaks and valleys greatly affects the amount of paint necessary to achieve a given dry film thickness; and (5) each of the six most common thickness gages has its own merits, but requires special precautions in use.

Further Work

Further work is proposed for improving highway steel painting practices and reducing costs. This includes preparation of a manual; simplification and updating of state and AASHO specifications; an intensive study of film thickness measurement; an inspection guide; certain new specifications; and a clearinghouse for paint evaluation.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

Each structural material requires its own type of maintenance. For steel, most of this maintenance takes the form of painting. An estimated two billion dollars per year is spent on the protection of structural steel, a large part of which consists of bridges and other highway structures. Highway bridges alone are believed to number more than one million in the United States. Coatings provide corrosion protection for these structures, and make valuable contributions to their safety and appearance. The painting of steel can be described as the principal means of protecting the principal construction material against its principal weakness—corrosion. It has been shown that it would be remunerative to use much more costly paints today if their use could prolong the period between paintings by even one year.

Much of the information available on this specialized subject is presented from the point of view of one type of product or one kind of application. In many locations, painting is infrequent, with little or no protection required; in a few others, the total cost of protecting a structure throughout its lifetime may considerably exceed the entire original cost of that structure.

OBJECTIVES

The original objectives of the project were to:

1. Conduct a critical literature survey and prepare a short report on the performance of protective coatings on steel structures and appurtenances, including methods of surface preparation. No effective system was to be excluded.
2. Conduct a critical survey of current practices by industry, authorities, and government in the selection of materials and methods for the protection of steel surfaces. Emphasis was to be placed on supporting data and the reported reasons for the choices.
3. Report histories of superior performance of particular coatings, coating systems, and practices under given exposure conditions.
4. Prepare a more definitive ranking of coatings, systems, and practices than now exists. This ranking was to be based on field exposure data.
5. Prepare a research plan to develop the needed information, where adequate coatings were not proven for a given condition.

RESEARCH APPROACH

Although the highway engineer has many responsibilities other than paint, and often is not a specialist in painting steel, he is faced with a bewildering array of conflicting claims.

This report is designed to give guidance on the best materials and practices for each special need whenever there is sufficient evidence to do so. In cases where there was not sufficient evidence, this is stated, usually with recommendations on how it can be obtained. An attempt is made to present information and recommendations in such a way that they can be readily used by the highway engineer, even though he may not always be a specialist in protective coatings for metals. The report is intended to provide a basis whereby his judgment and experience may be used in the selection and use of the best materials and methods for each particular application. The survey and project included the following tasks:

1. Literature Critically Surveyed.—A review was made, and a bibliography was prepared that summarizes the published literature in the subject area for the period 1955 to 1968.
2. Current Practices Reviewed.—Interviews and questionnaires were used to obtain evaluations of experiences of highway departments, bridge authorities, railroads, other users, fabricators, contractors, and suppliers in the U.S. and other countries. The critical review of these diverse data, case histories, and experiences was a complex task. Because the accumulated information could be checked against test information and case histories of the Steel Structures Painting Council (SSPC) it was possible to avoid the mistake of merely taking a consensus of present test results, practices, experiences, and opinion.
3. SSPC Tests Inspected.—From the numerous sources, a wealth of generalized experience, average paint lives, data on improved specifications and the like were obtained. To permit the formulation of the judgments necessary in this project, however, it was necessary to supplement these outside sources with intimate first-hand knowledge of well-planned empirical exposure test data. These data were provided by inspecting, during this project, more than 4,000 of the most significant paint tests which had been initiated by the research agency.
4. Recommendations Made.—On the basis of all these sources, recommendations were drawn up presenting the relative merits of the various coatings systems and practices in typical environments and applications involving highway structures. Wherever possible, procurement information is furnished so that the highway engineer may be able to properly specify the most effective coatings, as well as proper surface preparation, application, thickness, and use. In many cases, differences in surface preparation and coating thickness overshadowed the smaller differences in performance of various types of coatings; therefore, considerable time was spent in the project in ascertaining the

problems and needs of the various states with regard to surface preparation. These results are reflected in specific recommendations on surface preparation for various coatings. The need for additional information on film thickness required a small extension in the time and scope of the project within the funds originally appropriated. Film-thickness difficulties constituted the one problem area most frequently mentioned by the highway departments during interviews and in questionnaires.

5. Additional Work Proposed.—For certain highway steel painting problems, it was found that existing materials and methods are less than adequate. Proposed research plans were therefore drafted to develop the necessary information on these.

CHAPTER TWO

FINDINGS

LITERATURE SURVEY

The published literature is one of the three principal sources of information used in this survey. In the present state-of-the-art of painting steel, many of the results of research, testing, and experience eventually find their way into published form. Therefore, a critical review was made of technology related to coating of highway structures, including papers, articles, correspondence, books, and other pertinent sources in the U.S. and other countries. For this project, the period 1955 through 1967 was selected because a satisfactory bibliography to 1955 appears in the *Steel Structures Painting Manual* (Vol. 1). The result of this review is an extensive annotated bibliography which, for various reasons, is published separately, and in extremely limited quantity, as *NCHRP Report 74A*. It contains more than 1,000 abstracts of published and unpublished material related to the painting of structural steel. Many references for 1968 are also included.

This phase of the project was unexpectedly difficult because, among the several thousand references that deal with this general area, only a small percentage represent original contributions or unbiased appraisals. It is believed that the critical review will aid the highway engineer in finding his way through a confusing proliferation of publications, a few of which are excellent aids in selecting paints for steel.

The essence of all this published information is reflected in this report, particularly in those sections dealing with recommendations, surface preparation, application, design, inspection, types of paints, alternatives to painting, and cost criteria.

Major Classifications

NCHRP Report 74A, the annotated bibliography, includes abstracts or summaries of each of the pertinent references and articles, covering the following categories:

1. Surface preparation—effect of hand cleaning vs blast cleaning, vs other methods of preparing highway structural steel for painting.
2. Pretreatment—chemical treatments and wash-priming of highway structural steel before painting; also, coatings for temporary protection.
3. Coating application methods—comparison of brush, spray, airless, hot spray, roller, electrostatic spray, and, to some extent, methods of future interest such as electrodeposition, and fluidized bed.
4. Coating exposure tests—tests comparing the performance of various coatings under known conditions of exposure—both panel tests and service tests—accelerated tests and outdoor exposures.
5. Types of coatings—(1) General use of paints (discussions and comparisons of diverse primers and topcoats for structural steel); (2) paint pigmentation (examples: red lead; basic lead silico chromate; white primers; aluminum paints; zinc-rich coatings); (3) paint vehicles (examples: oil base; chlorinated rubber; vinyl; water base; coal tar; grease paints; (4) metallic coatings (galvanizing, metallizing, etc.); (5) special coatings (porcelainizing, etc.).
6. Inspection—inspection, paint failures, specifications, and administrative practices pertaining to the use of coatings.
7. Economics—effects of costs on choice of a protective coating system for structural steel.
8. Effect of environment, design, and type of steel—use of unpainted steel, low maintenance, low-alloy steels, choice of design features, minimized corrosion, galvanized steel.
9. General reviews.

Literature Sources

The literature search could not be strictly limited to protective coatings for highway structural steel, because many of the problems in this field are common to all steel structures exposed to exterior environments.

The number of references was much greater than expected, and great care was required in determining which of the published works represented reliable, original, unbiased evaluations based on sound experimental approaches in laboratory tests, field evaluations, and engineering analyses. Some subjects, such as surface profile, paint thickness, and documented histories of paint life, had only a limited literature.

A number of journals were found to be especially reliable sources of original material, including the *Journal of Paint Technology, Materials Protection, Corrosion, Corrosion*

Prevention and Control, Werkstoffe und Korrosion, Journal of the Oil and Colour Chemists Association, and publications of the British Iron and Steel Research Association. Published reports, included with the permission of the author, were also obtained from private correspondence, from SSPC files, and from *Highway Research in Progress.*

The following indices were very helpful:

1. National Paint, Varnish & Lacquer Association—Abstract Review.
2. Highway Research Abstracts.
3. Abstract Review of Metal Literature.
4. Engineering Index.
5. Building Science Abstracts.
6. Applied Science & Technology Index.
7. British Technology Index.
8. Highway Research In Progress (Sept. 1965).

Another important source was the research agency's technical file (maintained for the past 15 yr) and its comprehensive specifications file.

CURRENT PRACTICES OF STATE HIGHWAY DEPARTMENTS

This survey of practices, specifications, and experiences of the 50 U.S. state highway departments complements and supplements the other parts of the survey as a basis for judgment in painting highway structural steel.

Because of the large volume of material, only a summary of findings is presented here; more details appear elsewhere in this report. A more comprehensive review of current practices, received from the state highway departments and other paint users as a result of interviews, questionnaires, etc., is also published separately and in extremely limited quantity as *NCHRP Report 74B.*

State Personnel Interviewed

In most cases, the interviews were arranged at the various state capitols to include representatives of more than one of the various departments concerned with the painting of steel—materials, construction, maintenance, bridges, design, and sometimes purchasing. This often resulted in a stimulating interchange of experiences and ideas.

Unusually good response was received from the states: 47 states provided specifications, and 40 responded to questionnaires (which included verification of the research agency's summary of their specifications, as shown in *NCHRP Report 74A*). Table 1 gives some of the states' responses.

Eighteen states participated in fairly detailed interviews and 12 others participated in informal interviews, telephone conversations, and special correspondence. The few cases of poor communications were attributed to failure to reach the proper people within the state.

Paint Life and Costs

Information on paint life and costs was difficult to obtain. Nevertheless, some approximate estimates of paint life were obtained, as shown in Table 2. The wide range in durabilities in various environments suggests that other states might benefit from a zoning arrangement in which more durable systems are used in the more severe environments.

A few states paint at regular intervals (say, every 5 or 10 yr), unless intermediate inspections indicate otherwise. Some have regular inspection intervals, as recommended by AASHO (for example; every 6 months for severe exposures; every spring for de-icing salt exposures; bi-annually for mild locations).

Most find it difficult to maintain a systematic card-file system on maintenance of bridges, or to distinguish between painting and other maintenance costs, such as repair damage.

Cost estimates gathered from 40 states are believed to be much lower than actual, because, for the most part, they do not include large new bridge painting or the more expensive repainting jobs. Regarding yearly expenses, 5% indicate that they spend less than $10,000; 45% list $10,000 to $100,000; 38% claim $100,000 to $1,000,000; only 2% estimate over $1,000,000; and for 10%, costs are unknown.

However, in one state, the annual steel painting cost exceeds $3,000,000; in several others, hundreds of thousands of dollars are spent on a number of single bridge paintings. The costs therefore show that even a modest

TABLE 1

STATE PROJECTS ON PAINTING OF STEEL

% OF STATES [a]	PROJECT
40	No special program.
58	Testing new paints.
22	Working on surface preparation or paint application.
62	Improving specifications.
35	Improving inspection or procedures.
15	Have written reports on this subject.

[a] 40 states responded to questionnaire.

TABLE 2

PAINT LIFE IN VARIOUS ENVIRONMENTS

ATMOSPHERE	PAINT LIFE (NO. OF STATES REPORTING) [a]: 10 YR OR MORE	7-9 YR	4-6 YR	1-3 YR	NOT SPECIFIED
Normal	21	12	3	—	4
Dry	12	3	1	—	24
Wet or humid	3	4	8	3	22
Urban or industrial	6	8	4	1	21
Marine or chemical	—	4	9	9	18

[a] 40 states responded to questionnaire.

increase in paint life would justify a considerable investment in paint testing, specifications, and the use of more durable materials.

Considerable information was obtained on current unit costs of surface preparation and painting per square foot per year.

Surface Preparation by Highway Departments

Ten states now require blast cleaning and another 10 are considering it. Some require white-metal blast cleaning (for example, SSPC-SP 5), others commercial (SSPC-SP 6), and an increasing number favor near-white (SSPC-SP 10). At least one state (Louisiana) has found it desirable to retreat from white metal to commercial blast cleaning, which they have found to be satisfactory for most work and much cheaper. Several states, as well as AASHO, originally specified sandblasting, but now permit blast cleaning with shot or grit. In some states, blast cleaning of the steel before fabrication is permitted; others require cleaning after fabrication. At least one state (Missouri) requires blast cleaning after erection. Some states require blast cleaning of new steel only, some in maintenance painting only, and others in both.

Specifications of some type for both hand cleaning and blast cleaning exist in 87% of the states. Only a few (for example, California) have adopted the zone system in which blast cleaning, and synthetic paints (for example, vinyls and zinc-rich), are required in severe exposures, whereas hand cleaning and conventional oil-base paints may be used in milder locations. This concept is an excellent one and is recommended in this report.

Types of Paint in Use

The types of paint now in use are discussed in greater detail in the appendices of this report. Like most users of structural steel paints, the majority of the state highway departments use some type of oil-base primer. These are usually based on a linseed oil vehicle, with or without small amounts of alkyd. Some of the primers are based on recognized paint specifications, such as those of AASHO, the Federal Government, or the SSPC.

Red lead is the most frequent primer and intermediate coat pigmentation; a long-oil alkyd aluminum paint is most often chosen as the finish coat. There are many minor differences in formulation, due either to proprietary origin or to purposeful variations over the years. It is believed that most of these minor differences could be resolved into a limited number of recognized specifications. An appreciable number give incomplete specifications with regard to either pigmentation or vehicle. Numerous experiences and tests indicate that the oil-base primer (for example, a red lead iron oxide pigmentation) is the safest type to use over hand-cleaned steel. Some states continue to use these kinds of paint in normal atmospheric exposure even after they have adopted blast cleaning.

Zinc-rich paints (either inorganic or organic) represent the one new type of paint system most frequently used in severe environments. The next most frequently used type in aggressive environments is the low-solids high-molecular-weight straight vinyl copolymer system. Although it may require slightly less careful surface preparation than some inorganic zinc-rich paints, it does require experience in the application of four or more coats.

Other systems that have passed the laboratory panel stage and are in field evaluation include polyamide epoxy, chlorinated rubber, and water-base paints.

The innovation which has been recently adopted by more states than any other is the use of basic lead silico chromate pigmentation in a conventional long-oil alkyd vehicle. Other new materials under careful study include the use of silicone-alkyd vehicle, which has resulted in better gloss retention and longer life. High-build coatings of several types are under study to reduce the number of coats, cut labor costs, and limit the danger of intercoat contamination. Colored topcoats (particularly green) are being considered, including those which use colored aluminum.

Table 1 shows that about half of the states are carrying out some kind of experimental program to learn more about painting steel.

Special State Practices

Some interesting painting practices of the various states were noted. For example, one state has set up an industry specification committee of manufacturer, user, and applicator.

Some are experimenting with unpainted bridges and guardrails. One state (Missouri) allows no shop painting of steel; others insist that the first coat of paint be applied in the shop.

Most bridge painting is done by contract, both on new bridges and in maintenance. Some bridges are large enough to justify regular maintenance and painting crews which can number several dozen men. A few states manufacture their own paints, but the majority purchase on open bid.

Six states are actively testing new coatings and have made reports available on their results. Six others are carrying out testing or semi-experimental work.

Most Difficult Problems

On several points there was a fair agreement among the various states: that good surface preparation is essential, and that this requires good specifications and inspection; that specifying paint film thickness is desirable, but presents difficulties; that good field inspection is well worth the extra cost; that blast cleaning gives longer paint life, greater uniformity, and better welds at a cost that varies widely.

Both in interviews and in questionnaires, a few problems in painting structural steel occurred more frequently than any others, particularly:

1. Specifying and measuring of paint film thickness, either wet or dry.
2. Training and retraining of inspectors.
3. Protection against de-icing salts, particularly under leaking joints.

4. Distinguishing between fact and advertising in paint claims and even in the literature.
5. Painting in wet or cold weather.
6. Protecting high-strength bolted joints.
7. Painting during normal traffic operations.
8. Poor reproducibility in sampling and testing.
9. Painting of edges.
10. Need for more information on true costs; environment vs paint system; effect of surface preparation; method of application; painting contact surfaces; thinning.

Advisory Services to States

During this project, some further insights into major problems were obtained when assistance was rendered to several state highway departments.

For example, the SSPC acted as a neutral observer on possible causes of poor paint performance on an expressway. Mud found on the bottom of deck girder flanges indicated that wet storage at the site was one contributing cause. Several experienced state officials questioned whether it was possible to prepare a definitive rating of coatings in the order of their performance, because each is designed for special application in special environments. In Missouri, one coat of red lead and one coat of aluminum paint have lasted 18 yr on the bridge over a lake. In another state, a serious paint failure occurred on a coastal bridge when a well-known proprietary paint was substituted for the specification paint.

Coastal bridges were inspected in which the paint undersides were further protected with non-hardening grease paints with apparent success. A number of states reported galvanizing of guardrails for 8 yr or more, and some were beginning to regalvanize with success.

A serious safety problem was encountered in which methyl alcohol was being used as an antifreeze in air lines in such a way that the fumes could reach the painters' respirators. The SSPC urged immediate discontinuance. Other cases included improvement of paint sampling, advantages of roller application, and an improved bridge inspection chair.

Specifications

A review was made of the AASHO specifications; recommendations for possible further work and further improvements are given in *NCHRP Report 74B*. A tabulation of the specifications of all the states for paint, paint application, surface preparation, and special requirements is also included in that report.

PRACTICES OF OTHERS WHO PAINT STEEL

Appendix B discusses the practices of the many kinds of structure owners who paint steel. Those experiences and practices that are believed to be applicable to highway steel painting problems are reviewed in detail.

Interviews were carried out and questionnaires were used with those responsible for bridge painting in the various authorities of the International Bridge, Tunnel and Turnpike Association. A review was made of the experience, practices, and case histories of many others whose needs parallel those of the highway program in 50 petroleum refineries, waterworks, chemical plants, missile ranges, and tracking stations. Even more fruitful was the information obtained from steel fabricators, who are usually responsible for surface preparation and application of the first coat of paint.

Interviews were held with representatives of eight railroads, and inspections of paint tests were made on six of the railroads. Interviews also were held with steel-painting specialists from Great Britain, Sweden, Japan, Canada, Australia, and New Zealand (to supplement the literature available from those countries) and with several paint contractors representing the Painting and Decorating Contractors of America.

Special questionnaires were used and studies were made with regard to the use of special types of paint, including epoxies, zinc-rich, and aluminum paints.

The raw-material suppliers and paint manufacturers were helpful in being able to cite from unbiased sources some case histories on the various generic types of paint, surface preparation, and application.

The Highway Research Board shared experience and case histories on paints for metals. Information on present practices was obtained through the AASHO Committee on Materials, and members of the U.S. Bureau of Public Roads.

This project was the subject of two open discussion meetings of the research agency, with emphasis on relative performances of various coatings and the special needs of the highway steel painting program.

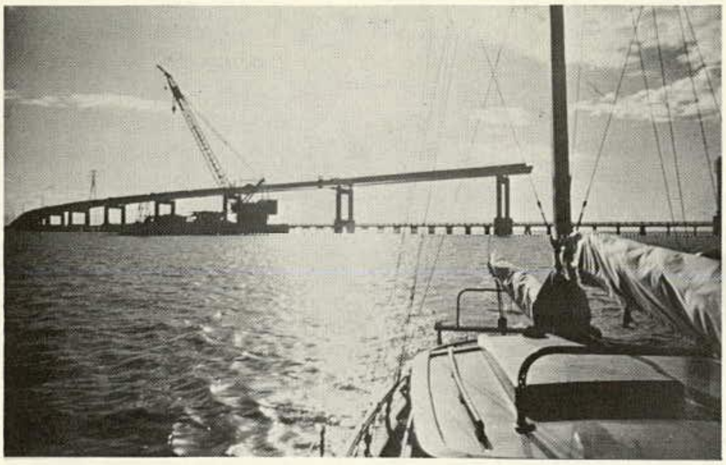
FIELD OBSERVATIONS

In a survey of this kind, there is no substitute for first-hand exposure data to supplement the valuable information obtained from the literature. However, it was recognized that information from accelerated tests would be unreliable, and that the term of this project was too short to permit new empirical tests to be carried out under actual outdoor exposure conditions.

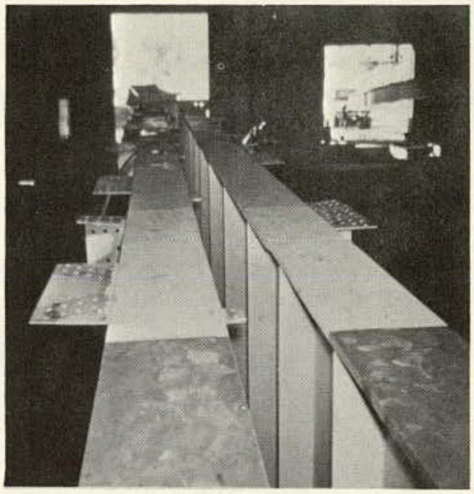
For this reason, a number of inspections were made of the most significant paint tests that had been initiated by the SSPC over a period of 15 yr. These include 22 separate series located at 30 exposure sites, several of which are shown in Figure 1. Only a brief resume of the results is given (see Appendix A), but results are reflected in the evaluations and recommendations sections of this report. Conclusions from field work also appear in Appendix A.

It is believed that these tests meet the required criteria needed for drawing conclusions about performance of a wide range of coatings systems: sufficiently long exposure; coatings of known composition; careful design of test plan; adequate controls; use of hot-rolled structural steel as the substrate; a range of environments typical of highway structures; careful control of coating thickness; and historical information on the steel, surface preparation, possible contamination, application methods, weather, and other environmental factors.

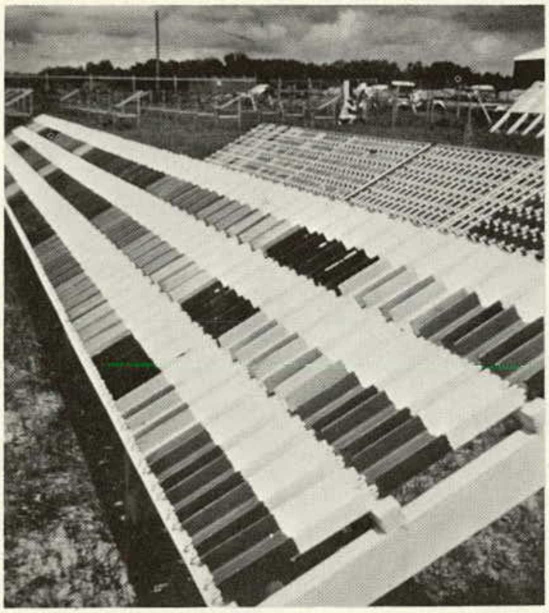
Several of these inspections relate to railroad bridge tests



Application of zinc-rich system to a highway bridge.



Shop-painted girders on test for protecting load-bearing surfaces.



Site for evaluation of paints for hand-cleaned steel.

Figure 1. SSPC paint tests.

and to panel tests. Because of the test methods used, most of the results are (with proper interpretation) directly applicable to equivalent exposure on highway bridges.

Each of the test series inspected during 1965-1968 served a special purpose in the appraisal of materials and methods for coating structural steel. Most of them have been the subject of detailed reports giving full information on surface preparation, formulation, application, ratings, statistical significance, and meanings in terms of available commercial coatings.

PAINT THICKNESS MEASUREMENT

Importance

During this project it became evident that the effect of film thickness often overshadowed normal variations observed between the various types of coatings—yet more than half of the state highway departments interviewed identified film thickness measurement as one of their greatest problems because of lack of available information. Results of an investigation of the subject are summarized here and are given in more detail in Appendix C.

Thickness is a direct measurement of the total quality of solid protective barrier purchased, and is directly related to the adequacy of application. In addition, the increased use of blast cleaning has introduced a heretofore unknown effect on measurement and on the amount of paint required.

Results of Thickness Study

An investigation of the effect of paint film thickness on paint durability revealed a direct relationship between the two. Data developed jointly by the Federation of Societies for Paint Technology and the SSPC in 1968 indicate that paint life is a direct function of the thickness of coating. This is shown in Figure 2.

The effect of surface profile on paint consumption was studied. It was attempted to determine the order of magnitude of additional paint required to fill in various typical profiles obtained by grit blast cleaning in comparison with the theoretical consumption over smooth surfaces. Results now show the amount of paint which would give a thickness of 2.7 mils on a smooth surface could result in an above-the-peak thickness of only 1.5 mils on a grit-blasted surface. Still greater losses occur when coarser grit is used.

Because some states prefer specifying wet film thickness,

a brief study was made of the relationship of wet to dry thickness. Measurements show that wet thickness begins to drop sharply immediately after application and, thereafter, approaches the dry film thickness during the next period of minutes or hours. Therefore, wet film thickness correlates with dry in accordance with the usual volumetric conversion formula only immediately after application.

The six most commonly used thickness gages, and procedures for their use, are described.

Typical calibration curves were made for the three most popularly used magnetic gages. Present methods of using the Mikrotest and some of the other magnetic instruments can lead to serious error in measuring the thickness of the paint barrier being purchased by the states.

Because of these types of difficulties, many states do not measure paint thickness at all—a most serious lapse in quality control. It is important that additional work be done on these findings and on the other uncertainties associated with thickness measurement. In addition, a specification should also be developed for proper measurement procedures.

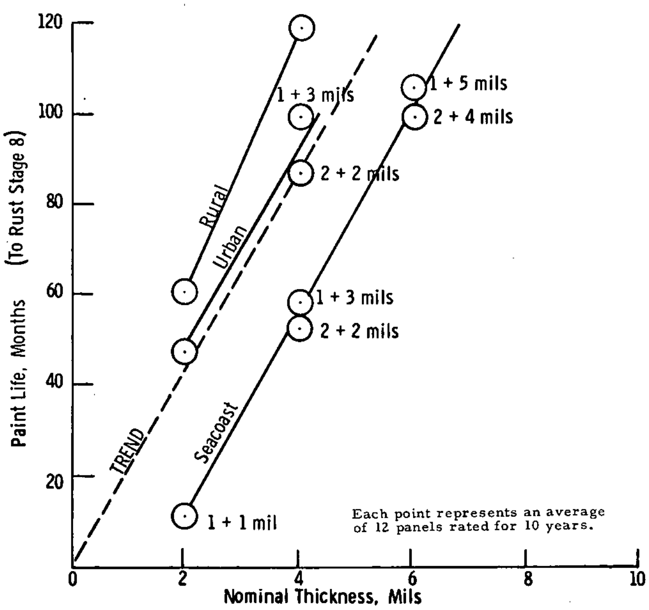


Figure 2. Average paint life vs thickness (oil and alkyd paints).

CHAPTER THREE

RECOMMENDED APPLICATION OF FINDINGS

As used here, the term "paint system" includes surface preparation, pretreatment (if any), paint application, paint thickness, primer, intermediate coat, and finish coat.

In the interests of simplicity and brevity, reference is made to existing specifications and guides, such as those provided by AASHO, the Federal Government, and the SSPC. Some states have specifications similar to these; however, a single state specification has not been cited when it was possible to cite an equivalent public specification that is national in scope.

DETERMINING FACTORS

At present, the painting of steel is an art and not a science. There is no one "best" paint, but rather a dynamic competition among alternate materials, some of which are best for one purpose, others for another. Although firm guidelines are given here, the final choice entails mature consideration of the requirements of environment, appearance, costs, the design, special features, available facilities, and means of procurement. Other factors influencing recommendations—including costs, topcoats, surface preparation, paint application, air pollution requirements, and maintenance painting—are discussed in the appendices of this report.

Environment

The broadest environmental category is atmospheric exposure in which the steel is normally dry, but exposed to the weather. This classification assumes an absence of industrial, marine, and exhaust conditions, but varies considerably from the northern to the southern parts of the U.S. The other exposures include wet or humid; splash or immersion; salt-water immersion; and chemical exposure.

Where reliable exposure information is available, past tests are the best basis for paint selection. California has used its experience to divide the state into four zones according to the expected service life: coastal; near-coast and bays; high-rainfall areas; and the remainder of the state. Paint systems are chosen accordingly.

Severity of exposure can change sharply over short distances, owing to prevailing weather patterns of wind and spray. It is suggested that paint specifications provide for those portions of certain structures that are subjected to very special conditions, such as de-icing salts, exhaust fumes, and heavy abrasion.

Appendix E illustrates the vast differences in corrosiveness obtained in ASTM tests of various atmospheres throughout the world, varying by a factor of 1,000. It was concluded that some maps purporting to give corrosivity factors are not sufficiently detailed to indicate the wide

local differences often caused by prevailing wind direction relative to the major sources of pollution. It should also be noted that paint life is not necessarily a direct function of corrosiveness. Experience has shown that, in many locations, the controlling factor may be abrasion resistance, freeze resistance, salt resistance, etc. Here, the specific properties of each paint system should be considered, as described in this report.

Costs

Some of the cost considerations in choice of paint system, including a proposed new approach to economic evaluation, are discussed in Appendix D. Ideally, the engineer seeks to minimize the cost per square foot per year, based on past experience in similar locations. In general, there is less incentive for a major change in existing paint systems if it gives 10 yr or more of service, and good incentive if service is less than 5 yr. The factors that determine cost, in addition to initial outlay, are the risk of paint failure, expected paint life, the surface preparation required, application costs (usually 2 to 10 times the material cost), and materials' cost per square foot of surface. Appendix D illustrates the economic approach which ascertains that a highly sophisticated paint system could effect large cost savings in one type of environment (say, Zone 2B) where present paint life with conventional systems is fairly short (less than 4 yr). In another zone (for example, Zone 1B) it could be impossible to justify the expensive system, no matter how long its life.

Appearance

A green, gray, brown, aluminum, or tinted topcoat may be chosen to harmonize with or contrast with adjacent topographic features. For through structures, guardrails, end-posts, etc., night visibility is of prime importance. Appearance plays an increasingly important role in structural painting on highways and elsewhere, but corrosion prevention is necessary to retain that appearance.

Design

Poorly designed structures, including many older bridges, may require excessive care to protect crevices, horizontal surfaces that hold moisture and debris, areas subject to salt drippings from leaking joints, back-to-back angle irons, sharp edges, and inaccessible surfaces. Because labor costs are now high relative to material costs, it is good policy to eliminate these features in new designs.

Bridges constitute the bulk of highway structures requiring paint protection. However, the same principles apply to all types of structures, such as corrugated culverts, guardrails and posts, light poles, truck scales, buildings, road signs, and many special structures. Deck bridges—particularly the shorter spans of beams, girders, and rigid frames—are more difficult to protect than the beam and girder types with broad, smooth surfaces. The English, for example, have concluded that the expense of metallizing is often justified on built-up trusses, but seldom on girder spans.

Usually there is more corrosion below an open deck than under a solid concrete slab, except in high-humidity environments where poor drying conditions can cause much more rapid corrosion below solid-deck structures. On stringer spans, the worst corrosion often occurs at the tops and edges of the bottom flanges where salt drippings, condensation, and debris accumulate. Expansion joints on many bridge designs are a constant problem because, in northern climates, they subject the steelwork beneath to the action of melting de-icing salts. These difficult areas should be the subject of special consideration in design and maintenance.

Experience has also given guidelines on painting other types of highway steel structures: the subsurface portion of steel piling is not usually painted if driven into dry ground, but is painted when placed in loose backfill; steel to be encased in concrete should not be painted; exposed piling should be protected. Some recommendations are given in Table 3 (Zones 2A and 2B).

Galvanized cables on lighter structures are subject to considerable flexing, and the recommended coating system must take this into consideration. On heavy bridges the suspension cables can usually be painted with a zinc-dust paint or special emulsion paint, without the need for extraordinary flexibility.

Available Facilities

To an increasing extent, fabricators and painting contractors in many parts of the U.S. have the necessary equipment, skills, and materials for blast cleaning, and for applying newer synthetic paints such as zinc-rich, vinyl, and epoxies. These matters still limit the choice of paint systems and contractors in other areas.

Availability of Specifications

Most engineers prefer to stipulate paint systems for which adequate specifications are available, because public policy encourages the procurement of materials on an open competitive basis. In the past, the best procurement method has been a problem with zinc-rich paints, epoxies, silicone-alkyds, and others (as discussed in detail in Appendix E).

1. Public bodies usually prefer not to specify by brand name alone if this is avoidable.
2. The use of "or equal" is usually unenforceable.
3. A qualified product list is often difficult to administer, but may be based on field tests, laboratory performance tests, composition, or past performance.
4. In theory, performance tests would be ideal, but the necessary correlation between laboratory tests and actual performance is seldom achieved.
5. Composition specifications are the most frequently used, but may automatically exclude new or improved formulations.

Many agencies, including the SSPC, are attempting to establish good performance specifications; in the meantime, these must be augmented by composition requirements.

In the administration of any set of specifications, provisions should be made for continuing test work which makes it possible to update and strengthen them from time to time.

TABLE 3
SUMMARY OF TYPICAL STEEL COATING RECOMMENDATIONS

ZONE [a]	ENVIRONMENT	PREFERRED SYSTEM	ALTERNATES
1A	Interior, normally dry (or temporary protection) Unusual in hwy. work, very mild (oil base paints would last 10 yr or more)	One coat of fast-drying shop paint (example: SSPC-Paint 13) over nominally hand-cleaned steel. Finish coat optional. (See SSPC-PS 7.01)	(1) Other one-coat primers (example: TT-P-636) (2) Rust proofing (SSPC-PS 8.01), or (3) More durable systems as per Zone 1B, or (4) Approved proprietary paint.
1B	Exteriors, normally dry (Includes most highway areas where oil base paints now last 6 yr or more)	Apply 2 coats oil base primer (example: SSPC-Paint 14) over wire-brushed steel. 1-2 finish coats of long oil alkyd (SSPC-Paint 101 aluminum or SSPC-Paint 104 white, gray or green) 4.0 mils or more thickness (5.0 mils for 4 coats). (See SSPC-PS 1.01, 1.02, or 1.03)	(1) Blast clean (SSPC-SP 6) and use same paints or shorter oil alkyds. (2) Alternate primers (SSPC-Paint 2; TT-P-57, Type I; AASHO M72-57, Type I or II; or TT-P-615, Type V) or (3) Alternate intermediate TT-P-86, Type II or non-leafing aluminum, or (4) Equivalent state system, or (5) Same systems as Zone 2A or 2B, or (6) Proven proprietary system.
2A	Frequently wet by fresh water Involves condensation, splash, spray, or frequent immersion. (Oil base paints now last 5 yr or less)	Near-white blast clean surface; 4 coats (4.5 mils) of vinyl system (example: SSPC-Paints 8 or 9) (See SSPC-PS 4.04 or 4.02)	(1) Pickle (SSPC-SP 8) instead of blast cleaning. (2) Alternate vinyls are VR 3 or approved proprietaries. (3) Epoxy system guide (SSPC-PS 13.00), coal tar epoxy (SSPC-PS 11.01), chlorinated rubber system, or approved proprietary system.
2B	Frequently wet by salt water Involves condensation, splash, spray or frequent immersion. (Oil base paints now last 3 yr or less)	Near-white blast clean surface; apply zinc-rich primer (example: SSPC-PS 12.00 or MIL-P-23236 or California Highway Spec. 66-G-55) followed by approved wash primer and finish coat. (Example: SSPC-PT 3 plus SSPC-Vinyl Paint 8 or 9, 3+ mils) Assure satisfactory adhesion of finish coats.	(1) Use finish coat with same vehicle as zinc-rich primer (inorganic, epoxy, chlorinated rubber, vinyl, etc.) (2) Use vinyl paint system with wash coat and inhibitive primer (example: SSPC-PS 4.01 or 4.03) (3) Use as alternate finish coats or by themselves, coal tar epoxy (SSPC-PS 11.01), epoxy (guide SSPC-PS 13.00), or approved chlorinated rubber system, or other proven proprietary system.
3	Chemical exposures (Acidic, alkaline, oxidizing, solvents, etc.)	Same as for Zone 2B, but with chemically resistant finish coat system specially chosen to protect primer and base metal against specific chemical agent. (Zinc-rich unsatisfactory for very acid or very alkaline conditions.) Assure satisfactory adhesion of finish coats.	Same choices as for Zone 2B, but with special finish coats. (1) Coal tar epoxy (SSPC-PS 11.01) (at least 16 mils). (2) Straight vinyls for acid and alkali (SSPC-PS 4.01 or 4.03). (3) Epoxies for alkalies, salts, aliphatics, acid splash; not for strong solvents. (4) Neoprenes and other proven proprietary systems to resist specific conditions.
4	*Special Conditions*		
	Painting galvanized steel	Solvent clean to remove oil and grease. Wire brush to remove any rust. Apply zinc dust-zinc oxide paint TT-P-641 (Type II for new steel, Type I for old, as per SSPC-PS 2.05 and 1.04). Somewhat better adhesion if surface is weathered before painting.	(1) Chemical pretreatment of new work by commercial hot phosphate or wash primer. (2) Zinc-rich primer (example: Guide SSPC-PS 12.00). (3) Prime with SSPC-Paint 5. (4) Prime with proven proprietary cement-base, polyvinyl acetate emulsion, or acrylic latex.
	Mildew	After surface preparation, wash mildewed surface with trisodium phosphate and dry. Add mildewcide to each coat of paint (example: 8-quinolinoleate). Vinyl, chlorinated rubber resins, and barium metaborate and zinc-rich pigmentations tend to resist mildew.	Alternate mildewcides and fungicides include copper naphthenate, chlorinated phenols, phenyl mercuric dodecylsueinate, proprietary agents. Add in amount recommended by the manufacturer.
	Temporary protection and rustproofing	See system for Zone 1A. Also see SSPC-PS 8.01, "Rust Preventive Compounds" (thick non-hardening films over minimum surface preparation)	Soft, heavy, or hard film compounds as per 52-MA-602, Type B, C, or D; or use proprietary rustproofing compounds.
	Painting welds	Before welding, do not paint within 2 in. of edges. Blast clean after welding. See SSPC-PA 1, Sections 3.5.2.4 and 3.5.2.5.	Chip and wire brush weld thoroughly. Wash with 5% phosphoric acid and rinse. See SSPC-SP 1, Section 3.1.6.

[a] These are intended as specific exposure zones of the portion of the structure under consideration rather than geographic zones. Severity of exposure can change sharply over very short distances due to such factors as wind, spray, condensation, and use of de-icing chemicals.

ZONE DEFENSE SYSTEMS

Because environment is the most important consideration in the selection of the paint system, painting recommendations are presented herein on the basis of six principal environmental zones of severity. These zones represent an effort to cover, in a limited number of categories, the immense variety of environments in which highway facilities are located in the U.S. These range from tropical to arctic; from chemical to industrial to rural; from lake to ocean; and, most important, from humid to dry. The details for putting these recommendations into practice are given in Appendix E. Insofar as factors other than environment (cost, drying, appearance, availability of materials and facilities, maintenance, etc.) affect paint choice, the use of alternate materials and methods within each zone must also be dealt with.

Table 3 gives the principal environmental zones and the recommended paint systems for each.

1. Zone 1 is normally dry: Interior exposure is 1A, and exterior is 1B; the latter represents the environment for the majority of highway structures.
2. Zone 2 is frequently wet by fresh water (2A), or by salt water (2B).
3. Zone 3 (chemical exposure) covers a wide variety of chemical exposures which may be acidic, alkaline, oxidizing, or solvent-containing.
4. Zone 4 (special conditions) is used to designate a variety of special painting problems, such as painting of galvanized steel, or welds, or painting for temporary protection, or for mildew.

It is difficult to show zones on a map, because severity of exposure can change sharply over short distances, owing to prevailing weather patterns of wind and spray. Furthermore, one end of a bridge may be in a mild rural or urban atmosphere (Zone 1B), while the other, owing to prevailing winds, may be subject to severe chemical fumes (Zone 3). Similarly, the curb plates may be subjected to de-icing salts (Zone 2B), and the steel pilings splashed by waves (Zones 2A or 2B); the below-deck areas wet by condensation (Zones 2A or 2B); the superstructure exposed only to the atmosphere (Zone 1B); and the maintenance building joists exposed to dry interior only (Zone 1A). It is suggested that, within practical limits, paint specifications provide for portions of certain structures that are subjected to corrosive conditions, while keeping the number of paint systems to a workable few. (When specification codes are cited, the latest issue should be used.)

Zone 1A, Normally Dry Interiors

Zone 1A is the zone of mildest exposure. In highway painting practice, there are a few instances in which dry interiors of buildings, warehouses, maintenance structures, etc., are painted. This includes structural steel that will be enclosed in masonry, or in the interiors of buildings where temperature does not fall below the dew point, where humidity does not exceed 70%, and where corrosive chemical conditions do not exist. It also covers some special cases of temporary protection.

Recommendation.—For purposes of economy, the minimum surface preparation for this zone consists of a nominal cleaning of steel to remove very detrimental foreign matter, loose mill scale, loose rust, accessible weld slag, and heavy deposits of oil and grease. Unless otherwise specified, a standard inexpensive primer should be used. Recommended is SSPC-Paint 13, "Red or Brown One-Coat Shop Paint;" alternates are TT-P-636 or equivalent proprietary product acceptable to the highway department.

Unless otherwise specified, no topcoat is required in this zone. Should topcoating be specified, however, these primers are compatible with the finish paints listed under Zone 1B.

Zone 1B, Normally Dry Exteriors

Zone 1B encompasses the locations of most bridges in the U.S., involving exposure to low or moderate humidity and infrequent use of de-icing salts. It is suggested that this Zone 1B paint system be used only in those mild atmospheric rural and urban environments where oil-base paints over wire-brushed steel have, in the past, given a paint life of 6 yr or more.

Recommendation.—The recommended surface preparation consists of thorough hand cleaning or power-tool cleaning (SSPC-SP 2 or 3). With this type of surface preparation it is essential that a primer having good surface wetting and inhibitive pigmentation be used. The recommended primer is SSPC-Paint 14, "Red Lead-Iron Oxide Linseed Oil Primer." Alternates are SSPC-Paint 2; TT-P-57; AASHO M-72-57, Type I or II; or TT-P-615, Type V. Ordinarily, the intermediate coat of paint should be the same as the prime coat, but tinted to a contrasting color. The preferred finish coat is a long-oil alkyd of the desired color and quality. Recommended are SSPC-Paint 101, "Aluminum Alkyd Paint," or SSPC-Paint 104, "White or Tinted Alkyd Paint;" alternate finish coats are AASHO M-67-60, Type I (foliage green); or AASHO M-68-52 (black). Total dry film thickness should be at least 4 mils at any point.

Inasmuch as the intermediate coat need not wet bare steel, its drying rate may be speeded by using more alkyd than in the prime coat (for example, TT-P-86, Type III). If aluminum finish coat is to be used, a non-leafing aluminum is preferred over use of a tinted aluminum intermediate coat.

Specifications should also cover a provision for paint application, storing, mixing, thinning, application temperatures, weather conditions, shop priming, field painting, touch-up, contact surfaces, painting welds, time between coats, handling, and inspection. These details are covered in SSPC-PA 1.

Even in these mild environments, longer paint life will be obtained with more thorough surface preparation by blast cleaning (SSPC-PS 6, 10, 7, or 5) or pickling (SSPC-SP 8), especially when condensation is expected.

Zone 2A, Frequently Wet by Fresh Water

Zone 2A involves high humidity, condensation, splash, spray, or immersion in fresh water. This paint system

should be considered in all locations where paint life has been less than 5 yr with a conventional oil-base paint system of the general type specified for Zone 1B.

Recommendation.—The recommended paint system consists of blast cleaning to near-white metal (SSPC-SP 10) or pickling (SSPC-SP 8), and application of four coats of vinyl paint for a total dry film thickness of at least 4.5 mils at any point. The recommended vinyl paint system is SSPC-Paint 9, "White or Colored Vinyl Paint," with every other coat tinted for color contrast. (Alternate vinyl paints include U.S. Bureau of Reclamation VR-3 white or gray.) For the finish coat, aluminum vinyl such as SSPC-Paint 8, "Aluminum Vinyl Paint," or VR-3 (aluminum) may be used.

This type of vinyl chloride-vinyl acetate copolymer resin combination system, with high molecular weight and low percentage solids, is also excellent for immersion in fresh or salt water, and for most chemical exposures. For constant exposure to de-icing salts or salt water, vinyl paint systems SSPC-PS 4.01 or 4.03 should be used, because they provide a wash primer, red lead vinyl primer, and inert vinyl finish coats.

Zone 2B, Frequently Wet by Salt Water

Zone 2B involves condensation, high humidity, splash, spray, or frequent immersion in salt water. The paint system recommended for this zone should also be seriously considered in any location where the conventional paint system of the general type recommended for Zone 1B has given a paint life of 3 yr or less. It is also recommended for floor systems of bridges exposed to de-icing salts, brine, brine drippings; for condensation; or for very severe weather exposure, chemical atmospheres, pier protection plates, heavy condensation, and sometimes for constant immersion.

For this exposure zone, zinc-rich coatings have, as a class, proven their effectiveness in high humidity and marine atmospheres, sometimes even without finish coats. There are two principal types: the organics require somewhat less carefulness in surface preparation profile; although a few inorganics are equally tolerant. The inorganics tend to be more resistant to solvents and chemicals.

Recommendation.—The surface should be blast cleaned to near-white metal (in accordance with SSPC-SP 10). At least 2.5 mils (or more, if recommended by the manufacturer) of approved zinc-rich paint (example: SSPC-PS 12.00 or qualified product list of MIL-P-23236 or California Highway Specification 66-G-55) should be applied. After the specified weathering period, 0.3 to 0.5 mil of vinyl wash primer (MIL-P-15328 or SSPC-PT 3) and 3 or more dry mils of the approved vinyl finish coat (recommended SSPC-Paints 8 or 9, or VR-3, or California Vinyl 67-G-75) or other approved finish coat should be applied. The danger of potential incompatibility between many zinc-rich paints and finish coats is great, and no combination should be used without the manufacturers' recommendation and/or proven tests of the combination as per the requirements of the specifications (example: the salt-spray tests required under MIL-P-23236 or SSPC-PS 12.00 in comparison with approved control samples).

Alternate finish coats include epoxies (for examples see guide SSPC-PS 13.00 or MIL-P-23236 qualified product list; or MIL-P-52192 plus finish coat; or MIL-P-23377 plus MIL-C-22750) or chlorinated rubber. When a dark color is acceptable, a coal tar epoxy (SSPC-Paint 16) is an excellent finish coat.

Unfortunately, along with the outstanding zinc-rich paints, a number of poorer ones are now available. For this reason, the cited specifications require authenticated case histories and identification methods as well as quantitative requirements for percentage zinc in the non-volatile portion, a scratch test, a V-notch salt-spray test, and sometimes a complicated sequence of immersion tests.

Several alternative systems which do not employ a zinc-rich primer have proven themselves in this kind of application. These include a coal tar epoxy system (SSPC-PS 11.01), epoxy paint system (SSPC-PS 13.00 guide), vinyl paint systems (SSPC-PS 4.01 and 4.03), and chlorinated rubber paints (SSPC *Manual,* Vol. 2, 2nd ed., pp. 130-131). Coal tar systems (SSPC-PS 10.01 and 10.02 or CA-50) are well proven in this application, but few good applicators are now available.

Zone 3, Chemical Exposures

Zone 3, occasionally encountered in highway structure locations, covers a wide variety of exposures to severe corrosive fumes, gases, or vapors in the atmosphere, and occasional splash or spillage from very corrosive chemicals. Specific recommendations must consider the type of surface and chemical environment. If the zinc-rich primer is used, it must be completely protected by a suitable chemically resistant finish coat system, because zinc is rapidly attacked by either acidic or alkaline media.

Recommendation.—Recommended is zinc-rich primer (for example, SSPC-PS 12.00, MIL-P-23236 qualified products list) over which one of the following types of finish coats should be considered (tie-coats are necessary in some cases): (1) vinyl paint system for acid, alkali salts (for example see SSPC-PS 4.00 guide); (2) coal tar epoxy for a wide range of chemical resistance (for example see SSPC-Paint 16); (3) epoxy paint system for resistance to alkali, salts, non-concentrated mineral acids, aliphatic hydrocarbons, gasoline, acid splashes (for example see SSPC-PS 13.00 guide).

Although the zinc-rich primer provides sacrificial protection at breaks in the film, there are many instances in which the finish coat systems in these recommendations can be used without the zinc-rich primers, provided an inhibitive primer is used, sufficient barrier is provided (6 to 20 mils), and the coating as indicated is properly selected.

Zone 4, Special Conditions

Zones 1B, 2A, and 2B cover the vast majority of environments to which highway structural steel is subjected. The following recommendations represent a guide to a choice

of coatings for other more specialized problems in protecting structural steel.

Recommendation

1. Painting Galvanized Steel.—Oil, grease, and dirt should be removed by solvent cleaning (SSPC-SP 1), and rust removed by vigorous wire brushing (SSPC-SP 2). The preferred primer is zinc dust/zinc oxide (TT-P-641, Type 1 for rusted galvanizing, and Type II for unrusted galvanizing). Alternate primers include wash primer, some zinc-rich paints, and certain cement-base, acrylic, and polyvinyl emulsion paints. Before application of these conventional paints, weather new galvanized steel, if possible. When pretreatment of newly galvanized steel is possible at the mill, commercial hot phosphate pretreatment or wash primer should be considered.

2. Rustproofing and Temporary Protection.—See recommendations for Zone 1A. Also see rust-preventive compounds discussed in SSPC-PS 8.01. (These are thick grease films which are easily removed from bridge bearings, base plates, journals, chains, etc.)

3. Mildew.—Vinyl or chlorinated rubber vehicles and zinc-rich or barium metaborate pigmentations tend to resist mildew. Add mildewcides or fungicides to each coat of these or other types of paint, using such materials as copper 8-quinolinoate, copper naphthenate, and TBTO in recommended quantities.

4. Non-Skid Surfaces.—Clean and prime steel. Apply second thick wet coat of paint (example: vinyl guide SSPC-PS 4.00) over wet paint, sprinkle sand, aluminum oxide, flint, or garnet. Apply finish coat (see MIL-C-5044).

5. Painting Welds.—Leave 2-in. strip unpainted before welding and blast-clean after welding and before painting. A less desirable alternative is to chip and wire-brush weld area thoroughly and wash with 50% phosphoric acid, rinse, and dry before painting. (See SSPC-SP 1, Section 3.1.6 and SSPC-SP 2 or 3, Section 3.5 and SSPC-PA 1, Section 3.5.2.4 and 3.5.2.5.)

Alternate Materials for Use in Zones 2 and 3

The paint industry offers a wide choice of alternate materials which have been used successfully (almost equal to those recommended) in the difficult environments of Zones 2 or 3, or as finish coats over a zinc-rich primer. These include catalyzed epoxies (for example, SSPC-PS 13.00) which are somewhat more tolerant than vinyls in their surface-preparation requirements. They also provide equal film thickness in a smaller number of coats and have outstanding adhesion. Possible drawbacks include chalking, and poor tolerance on intercoat adhesion. Where a dark color is acceptable, a two-coat coal tar epoxy system provides excellent protection in Zones 2 or 3 (for example, SSPC-PS 11.01), but care should be taken to provide adequate film thickness at all edges and irregularities. In SSPC tests for more than 8 yr, chlorinated rubber formulations have provided excellent protection in Zones 2A and 2B. Limitations include chalking, poor solvent resistance, and need of careful formulation to avoid cobwebbing or over-dilution with alkyds and other modifiers. Phenolic paint systems (see SSPC-PS 3.00) have been used longer than any other for this application. Although they require less stringent surface preparation than those recommended, they sometimes present problems in quality control and intercoat adhesion.

The conditions under which these and other alternates may be used in place of vinyls appear in Appendix E.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

Although this project has helped to answer many questions, it has also disclosed the need for further work to improve the quality, appearance, and safety of highway structural steel painting, and to reduce its costs. Some of the proposed programs include the following.

MANUAL

The possibility should be considered of developing a manual specifically for painting of highway structural steel. It should be brief and complete in itself, but so arranged that new materials and methods can be added by an approved procedure. This project has developed most of the background and information necessary for such a manual, which could eventually include the results of most of the other work suggested in this chapter.

SIMPLIFICATION OF STATE SPECIFICATIONS

Some diversity is necessary and desirable among the methods used by the various states for procuring paint, in surface preparation, and in paint application by specification. At present, however, many trivial and random differences exist among otherwise similar specifications. These tend to increase the cost to the taxpayer, to create inventory problems for the supplier, and to perpetuate the use of archaic formulations which have long since been improved.

A beginning toward necessary consolidation and simplification has been made here in gathering and summarizing information on present specifications, and in recommending certain preliminary revisions in the AASHO specifications. It is suggested that future consolidation be accomplished by completing a proposed set of model specifications for both paints and painting.

UPDATING AASHO PAINT AND PAINTING SPECIFICATIONS

The updating of AASHO paint and painting specifications, started in this project, should be continued. Many of the necessary revisions can be drawn from this report (Appendix E) and from the SSPC specifications, which are condensed to apply to highway steel. The numerous good points from state highway specifications, as listed herein, should also be incorporated.

FILM THICKNESS STUDY

The one problem encountered most often during this project has been the need for additional work on paint film thickness. The experimental work done on this project has resulted in valuable information on the limitations of present dry film thickness gages, and on their proper use. It has also indicated that wet film thickness measurements, as presently carried out, are frequently erroneous and misleading. Unexpectedly large amounts of paint were found necessary to fill in the valleys of blast-cleaned steel. Future studies should carry this project one step further by preparing an adequate guide and specification on measuring paint film thickness with the six types of gages that are available.

NEW SPECIFICATIONS

There is a need for prototype specifications for several types of paint systems for highway use. An improved oil-base paint system is indicated in this report. Such a system is suitable for use on hand-cleaned steel, has excellent wetting properties, and provides some latitude in thoroughness of cleaning.

An adequate specification is needed for a zinc-rich paint system. A need also exists for paint systems to be used in special environments—paint systems such as silicone-alkyds, epoxies, chlorinated rubber, and high-build finish coats. As presented in this report, a few specifications are available in each of these categories which have been developed for purposes other than highway use. To select the outstanding products available from among the many mediocre ones, the highway engineer should have access to suitable open specifications. Such specifications also give the states and other public authorities some assurance that the materials procured are comparable with those that have been tested in the past. In the interim, qualified products lists are helpful but difficult to administer.

SURFACE PREPARATION AND PAINT APPLICATION SPECIFICATIONS

There is a need for both an inspection guide and a strong specification on paint application to assist inspection in both shop and field. It is suggested that assistance be rendered to the highway effort in incorporating the best features of the presently available knowledge on the subject, including the AASHO booklet on painting of bridges, the SSPC specification PA-1 on paint application and the chapter on inspection in the SSPC *Manual* (Vol. 1).

Existing surface-preparation specifications should be improved to include provision for the use of photographic references (such as SSPC-Vis 1) and for measuring the cleanliness of blast-cleaned steel.

Eventually, provision should be made for a practical method of measuring profile, thereby making it possible to set more meaningful profile standards for various types of paint systems.

ENVIRONMENTAL ZONES

An objective method should be considered for helping the states to establish environmental zones (such as those used in this report) as a basis for specifying coatings systems.

ECONOMIC COMPARISONS

It has been suggested that further work be done on a uniform basis for making economic comparison of alternate paint systems (for both new and maintenance painting) at various locations so as to minimize total annual cost to the taxpayer. One new approach is suggested in this report.

PAINTING CONTACT SURFACES

Most specifications now prohibit the use of any type of coatings on contact surfaces of high-tension bolted joints. In severe environments, there is some possibility that this practice could lead to crevice corrosion. The rule also tends to make galvanizing and certain other types of coatings difficult or impractical. Work is under way to determine which types of surface preparation and coating should be permitted. Other work may be advisable from the standpoint of adequately protecting the critical contact surfaces from corrosion.

CLEARINGHOUSE

This report shows the value of the work done by individual states to provide several points of view in the selection of painting materials and methods, and a cross-check of results under local conditions. However, there appears to be a need for certain kinds of evaluation, which could be carried out at a specialized central clearinghouse.

Perhaps the most important function of such a clearinghouse would be to keep adequate statistically valid records of a cross-section of new bridge painting throughout the country, beginning with the surface preparation and priming at the fabricator's shop. At a reasonable cost, this record could be extended to include maintenance painting. This project has shown that unless such records are kept from the beginning, it is impossible to reconstruct the true painting history of almost any structure, even those where methodical records have supposedly been kept.

A secondary function of such a testing station would be to communicate with the various states with regard to their

work in this problem area, supplementing local tests with carefully designed, unbiased practical tests of new or proposed materials and methods.

Continued awareness of new developments is essential. Further innovations affecting coating performance can be expected at each stage in the life of the highway structure. For example, at the steel mill, new compositions and new structural products require less painting, or different kinds of painting, or no painting at all in certain environments. Also at the mill, descaling and/or coating at the hot-roll stage is a future possibility. At the fabricating shop, preblast cleaning, pre-painting, orthotropic design, new welding methods, coating of high-strength bolted joints, etc., pose new painting opportunities and problems. Improved surface preparation and better paint-application methods are becoming available. New coatings, both organic and inorganic, promise to be quick-drying, rugged, long-lasting, attractive, and low in maintenance.

APPENDIX A

FIELD OBSERVATIONS

The time allotted for this project was relatively short and it was known that accelerated tests would be unreliable. For this reason the necessary first-hand data were obtained by careful inspection and interpretation of exhaustive exposure tests of the SSPC, most of which had already been under way for some time. These tests include 22 separate series located at 30 exposure sites (see Table A-1). Results are summarized herein.

Each summary that follows is based upon a carefully planned experimental design and, whenever possible, on statistically valid interpretation of findings. Results should, however, be considered in the light of further information on both soundness and practical field experience, as presented in other parts of this report. Further details are available in separate SSPC reports on most of these projects.

TEST (1): SALT-RESISTANT BRIDGE PAINTS

The test sites in this 12-yr test exposure are two bridges near St. Louis, Missouri, on the Missouri Pacific Railway, which are subject to constant attack of salt brine drippings from passing railroad refrigerator cars.

One bridge was sandblasted before painting; the other was chipped, scraped, wire brushed, and steam cleaned. No further touch-up has been applied to the blast-cleaned bridge, but the hand-cleaned one had to be completely retouched after 3 yr.

Because of the pertinence of this work to the problem of protecting highway bridges from de-icing salts, as well as railroad bridges from brine drippings, a special inspection of this test was made in July 1965.

Some of the results are summarized in Table A-2; others are as follows:

1. The inspection demonstrated the importance of good surface preparation by blast cleaning, and good application, particularly as a basis for the most effective coatings systems, which were vinyls, chlorinated rubbers, and certain phenolic alkyd combinations. These are still in excellent condition after 12 yr.
2. The next most effective systems were styrene-butadiene, conventional oil-base paints (red lead primer and graphite topcoat), coal tar mastic, and asphalt mastic. Wash primers were helpful on the severely exposed sections with several of these systems.
3. On those areas of the bridge that were exposed to less severe drippings, a number of other systems were also very effective, including a zinc-dust paint, certain tapes, two vinyl mastics, and a urethane.
4. Even over hand-cleaned steel, good results were obtained with several systems, but, in this case, retouching was necessary 3 yr after the initial application. Here, good results were obtained with a specification vinyl, phenolic, over oil-base primer, and oil-base system. Three types of grease paint failed very early, but have given good performance since their reapplication 9 yr ago, particularly the wax-free rust-preventive grease.
5. The conventional system, applied under close supervision after careful hand cleaning, performed much better than the same system applied without these special precautions.
6. The most severe exposure of all exists on the tops of the floor beams and stringers, which are still in excellent condition after being metallized with 0.012 in. of zinc 25 yr ago.
7. Nearly all of the most effective systems were based on specifications or formulations of known composition that are still available.

TEST (2): EIGHT HIGHWAY BRIDGES

During this project, paint exposure tests were initiated on eight highway bridges throughout the U.S., in cooperation with the International Bridge, Tunnel & Turnpike Association.

TABLE A-1

PAINT EXPOSURE TESTS INSPECTED

SUBJECT	LOCATION	NUMBER OF TEST AREAS	DURATION	DATE INSPECTED	SSPC COOPERATIVE TEST WITH:
Paints for Salt Brine	Bridges near St. Louis	2 bridges, 40 areas	12 years	July 1965	Missouri Pacific Railway
Bridge Paint Tests (8 Bridges)	New York City, Passiac, N. J.; Annapolis, Md.; Wilmington, Del.; San Francisco, Calif.		1 - 3 years	1966-67-68	International Bridge, Tunnel and Turnpike Association.
Painting Hand-Cleaned Steel	Pittsburgh, Pa. Kure Beach, N.C.	1,220 areas	8 years	1965-66-68	SSPC
Surface Preparation Versus Durability	Pittsburgh, Pa. (Two sets)	68 panels (Phase I)	3 years	June 1966	SSPC
Primer Composition	Coraopolis, Pa. Kure Beach, N.C.	360 panels	6 years	1965 - 68	Glidden Company (Wetting Additives)
Low Bridges Over Salt Water	Bay Shore, N.Y.	2 x 66 areas plus 16 new areas	Part 1 - 8 years Part 2 - 1 year	October 1965 to April 1968	Two Robert Moses Bridges (Cap Tree Bridge)
High Bridge Over Fresh Water	Poughkeepsie, N.Y.	2 x 44 areas	6 years	July 1965	Mid-Hudson Bridge
Painting Galvanized Steel	Three locations in Pennsylvania & Ohio	3 areas, 972 panels	6 years	August 1965	American Iron & Steel Institute
Zinc-Rich Paints	Various locations		1 year	1966-67-68	ILZRO; consultants; U.S. Steel; Golden Gate Bridge Authority
Painting Cold and Wet Steel Surfaces	Sewickley, Pa.	258 panels	2 years	1966-68	Federation of Societies for Paint Technology
Protecting Load-Bearing Surfaces	Byron, Illinois	5 spans, each 70 feet long	7 years	July 1965	Chicago Great Western Railway
Maintenance Painting Test	Harmarville, Pa.	1 bridge, 6 areas	6 years	June 1965	Bessemer & Lake Erie Railway
Bridge Paints for Mild Exposure	Kansas City, Kansas	3 bridges, 14 areas	13 years	July 1965	Santa Fe Railway
Weathering Versus Shop Painting	Breckenridge, Minn.	6 areas	8 years	August 1965	Great Northern Railway
	Rayland, Ohio	8 areas	7 years	August 1965	Pennsylvania Railroad
Paints for Water Immersion	Pittsburgh, Pa.		3 years	January 1966	SSPC
	Ambridge, Pa.	54 areas	15 years	November 1966	Ambridge Water Authority - PDM
Temporary Coatings	Mellon Institute Roof Pittsburgh, Pa.	200 areas	2 years	January and November 1966	SSPC
Surveillance Tests	Pittsburgh, Pa.	About 300	0 - 3 years	1965-66-67-68	SSPC

TABLE A-2

BRIDGE PAINTS WITH RESISTANCE TO SALT BRINE—EFFECT OF VEHICLE COMPOSITION [a]

VEHICLE (PAINT NUMBERS)	RATING [b] FLOOR BEAMS	STRINGERS
Linseed oil (Paint G)	8.00	9.00
Phenolic (Paints E, I, J)	8.67	9.50
Vinyl (Paints A, B)	8.75	9.50
Chlorinated rubber (Paint C)	9.00	10.00
Coal tar (Paints K, L)	7.25	9.50
Asphalt (Paint M)	8.50	9.50
Phenolic/alkyd (Paints F, H)	8.75	9.75
Styrene-butadiene (Paint D)	8.00	10.00
Epoxy-amine (Paint N)	3.00	—
Epoxy ester (Paint O)	—	8.50

[a] Bridge 69 (Missouri Pacific Railway), 12-yr exposure, 20 test areas, blast cleaned.
[b] 10 = Perfect.

It is too early to draw conclusions on most of these series, except perhaps for the tests on the Golden Gate Bridge, involving 12 zinc-rich paints in comparison with several other systems. The tests were inspected in November 1968. The evaluations are summarized in Table A-3. This experience emphasizes (1) the great differences among well-known zinc-rich paints, (2) the need of finish coating for long-term protection in severe environments, and (3) the excellent effectiveness of properly finish-coated zinc-rich coatings.

TEST (3): PAINTING HAND-CLEANED STEEL

An evaluation is under way of paints especially formulated for the difficult and important role of protecting steel that is hand cleaned or power-tool cleaned.

Sixty-one specification paints and proprietary products were selected, based on past performance. Each paint was applied to 20 hot-rolled steel panels ranging from 0% to 100% in rust; these were exposed in industrial and marine environments. Results of the latest inspection are given in Tables A-4 and A-5. The first year's exposure showed the following:

1. As a class, the paints based on various linseed oil vehicles have given significantly better results than the others, although in many cases they were also slow in drying. Satisfactory results were also obtained with certain formulations of other types, including a phenolic/alkyd, a cumar (cumarone-indene) resin, epoxy esters, long-oil alkyds, chlorinated rubber, and certain phenolics. Poor results were obtained, on an average, with those paints that were designated as straight alkyds, fish oil paints, or with vehicle undetermined. Most synthetic vehicle primers were omitted from this evaluation because they are not recommended for use on hand-cleaned steel.

2. Among those tested, the best pigment combinations (in order) were: red lead/iron oxide; red lead/basic lead silico chromate; basic lead silico chromate/iron oxide; zinc dust and zinc dust/zinc oxide; and zinc chromate. These gave markedly better performance than those coatings that contain larger amounts of extenders or for which pigment content is undetermined or undisclosed. The combinations of red lead and iron oxide were outstandingly effective—much better than red lead alone, and far superior to iron oxide alone.

3. Paint life was a direct function of the dry-film thickness for any one type of coating.

4. A combination of rust and mill scale is the most difficult type of surface to protect.

5. The addition of only 1% of a special additive had a striking effect on the performance of a phenolic primer.

6. One thin unpigmented wetting oil pretreatment (meeting the general requirements of SSPC-PT 1-64) effected considerable improvement in primer performance.

7. This project, and several others, illustrate the importance of timely application of the second coat of paint, especially when the original surface preparation is marginal, the original primer of doubtful quality, the exposure severe, or the unexpected construction interval lengthy.

Although some types of vehicle and pigmentation were particularly effective, it was shown that a good primer can be formulated from a wide choice of raw materials. Skilled formulation is shown to be necessary because good performance cannot be guaranteed by selecting any one generic type of pigment and vehicle. The successes and failures so far in this exposure, however, indicate that a good structural steel primer used over hand-cleaned steel should have (1) adequate moisture resistance; (2) ability to penetrate surface imperfections and "wet" the steel; (3) adequate adhesion to steel, rust, and mill scale; (4) relatively low permeability to water, water vapor, and oxygen; (5) low content of water-solubles, yet have a slightly soluble inhibitive pigment; (6) flexibility to withstand temperature effects and minor rust expansion; and (7) ease of application and good film build.

TEST (4): SURFACE PREPARATION VERSUS DURABILITY

A 1966 report describes the first phase of a study which compares the performance of paint on steel with various common types of surface preparation. This first phase was concerned with water immersion, alternate immersion, and high humidity, using vinyl and phenolic paints. There was a marked difference between those methods which did and did not entail complete removal of mill scale. Blast cleaning to white metal resulted in slightly better performance than commercial blast cleaning. In every case, sand blasting was as good as, or better than, the equivalent degree of shot blasting or pickling. In this environment, vinyl paints performed much better than phenolics.

A parallel phase involves atmospheric exposure.

TEST (5): COMPARISONS OF PRIMER COMPOSITIONS

Each of the paints (with and without additives) was applied to six test panels fabricated with rivets, welds, and crevices. Surface preparations were blast cleaning, hand cleaning of intact mill scale, and hand cleaning of rusty

mill scale. One-, two-, and three-coat systems were evaluated in rural and marine environments.

Tables A-6 and A-7 show the average ratings of the two primer coats plus finish coat for the various pigment and vehicle types used. Linseed oil, epoxy and linseed oil/alkyd were the vehicle types that gave the best performance; basic lead silico chromate, straight and with iron oxide, gave the best performance of the pigment types.

Ratings on the blast-cleaned and mill scale surface were about the same, and both were better than ratings on rusty mill scale surface. As expected, all paints performed much worse in the marine exposure than in the semi-rural one. The wetting additive gave a noticeable improvement in the performance of the paints. In a single coat, brush-applied paints performed much more poorly than the spray-painted ones.

TESTS (6) AND (7): CAP TREE BRIDGE

Each of 66 selected paint systems was applied to the beam area on the underside of the deck structure at the shoreline of the Cap Tree Bridge—a low bridge over salt water (now named the Robert Moses Causeway). Half of

TABLE A-3

INORGANIC ZINC PAINT TESTS—GOLDEN GATE BRIDGE AND HIGHWAY DISTRICT

Area	Zinc-Rich Product	Date of Application	Dry Thickness Mils **			RATING* (10 = NO RUST)	
			Range	Average	Ratings Nov. 1967	Ratings November 1968	REMARKS
I	1	2-14-66	4 - 7	5	5- In 7+ Out	4+ Inside 6+ Outside	Inside badly rust spotted (blast damaged ?). Outside badly pin-point rusted.
II	2	2-23-66	2 - 4	3	9	8 General 6- Edges and Rivets	Flat areas good, but edges and rivets bad. Tiny rust blisters.
III	3	2-17-66	(1966) 1.5 - 3	-	9+ In 8.5 Out	8 Inside (E) 6 Outside (W)	Breaks through old rough spots. Rivets bad.
IV	4	2-18-66	3 - 7	5	8+	2 Inside 5 Outside	Edges, rivets, and some flat areas bad.
V	5	2-21-66	1 - 2 In 3 - 4 Out	3	8.5	5 - 6 Inside 5 - 6 Outside	Rust spotted. Thin looking.
VI	6	3-3-66	2 - 5	3	9	8.5 General 6 Edges and Rivets	Two coats.
VII	7	3-1-66	2 - 5	3	9	8.5 General 5 Edges and Rivets	Also reddish and discolored by water.
VIII	8 A	3-2-66	1 - 3	2	9	9 General 8 Edges and Rivets	Heavy salting. Discolored edges, but no rust.
IX	8 B	3-18-66	6 - 7	6	9.5	9+ General 8.5 Rivets 7 Edges	Heavy salting on sheltered side. (Needs special cleaning thinner.)
X	8 A	3-21-66	-	-	9	Same as VIII, but some edges rusted.	
XI	10	3-17-66	-	5	9+	9 General 8 Edges	Edges very bad in one place. Reported difficulty in cleanup.
XII	8 C	3-18-66	2 - 3	2.5	9(-)	6	Breaking through with many tiny blisters - flats and edges.
XIII thru XVI	8 A	3-21-66	1 - 3	2	9	9 General 8 Edges and Rivets	Heavy salting. Discolored edges, but no rust.

* For rust rating method, see Table E-7.

** Unless otherwise specified, dry film thickness is that measured by Elcometer in November 1967 (20 months after application). Some films showed lower measurment in 1966 and higher in 1968.

TABLE A-4

HAND-CLEANED STEEL TEST—EFFECT OF PIGMENT COMPOSITION

PIGMENT (PAINT NUMBER)	Coats of Paint ***	RATING **										Overall Rating
		Blast Cleaned		Wire Brush - Mill Scale		Wire Brush - Rusty Mill Scale		Wire Brush - Rusty		Average		
		Ind.	Marine	Ind.	Marine	Ind.	Marine	Ind.	Marine	Ind.	Marine	
RED LEAD (Paint Nos. 3, 4, 5, 7, 29, 31, 40, 41, 49, 58 and 60)	P	7.55	2.41	6.15	4.61	6.51	3.10	7.94	4.73	6.95	3.59	5.27
	P+T	9.41	3.34	8.96	5.68	8.11	4.15	9.30	6.09	8.77	4.68	6.73
ZINC DUST (Paint Nos. 8, 45, 46 and 55)	P	8.75	6.81	8.00	6.50	8.27	6.18	8.12	7.94	8.28	6.72	7.50
	P+T	9.50	4.92	9.50	5.33	9.00	6.46	9.50	7.92	9.30	6.22	7.76
ZINC CHROMATE (Paint Nos. 20 and 30)	P	8.00	1.25	7.62	6.37	7.12	2.50	7.50	4.00	7.47	3.32	5.40
	P+T	9.50	4.00	8.87	8.37	8.69	5.12	9.12	6.87	8.97	5.90	7.44
BASIC LEAD SILICO CHROMATE (Paint Nos. 38 and 57)	P	9.12	4.00	7.00	7.00	7.12	6.25	4.75	4.50	7.02	5.60	6.31
	P+T	9.50	4.50	9.37	6.00	9.37	5.56	9.50	3.62	9.42	5.05	7.24
ALUMINUM (Paint Nos. 6, 21 and 24)	P	8.09	1.67	5.83	2.17	5.66	2.50	7.67	4.00	6.59	2.56	4.58
	P+T	9.42	3.17	9.25	5.17	8.63	4.42	9.50	6.92	9.09	4.81	6.95
IRON OXIDE (Paints No. 12, 17, 48, 51, 54, and 61)	P	4.58	1.08	0.67	0.83	2.29	0.54	2.50	0.67	2.47	0.58	1.53
	P+T	6.80	1.96	7.55	1.83	6.97	1.42	8.00	1.75	7.27	1.67	4.21
RED LEAD/BASIC LEAD SILICO CHROMATE (Paint No. 9)	P	9.25	9.00	7.25	7.75	8.75	7.75	9.50	8.00	8.70	8.00	8.35
	P+T	9.50	7.25	9.50	4.00	9.50	7.50	9.50	9.00	7.50	7.05	8.28
RED LEAD/IRON OXIDE (Paint Nos. 2, 10, 11, 32, 34 and 36)	P	9.20	6.50	8.09	6.21	8.00	7.10	8.00	6.96	8.25	6.79	7.52
	P+T	9.50	7.05	9.25	7.75	9.08	7.75	9.34	7.79	9.25	7.63	8.45
ZINC DUST/ZINC OXIDE (Paint Nos. 33, 35, 37, 47 and 53)	P	7.65	4.30	6.75	3.60	8.15	4.78	6.85	4.20	7.51	4.33	5.92
	P+T	9.50	5.75	9.15	6.05	9.38	6.03	8.75	5.15	9.12	5.80	7.52
ZINC CHROMATE/ZINC OXIDE (Paint Nos. 18 and 39)	P	5.00	2.50	4.37	6.75	5.31	2.00	6.25	4.12	5.25	3.47	4.36
	P+T	9.50	5.75	9.00	8.12	8.12	4.00	8.00	5.62	8.55	5.50	7.27
ZINC CHROMATE/IRON OXIDE (Paint Nos. 14, 15, 16, 25, 28, 43, 50 and 52)	P	8.75	2.78	4.31	3.88	5.02	2.98	6.25	3.75	5.87	3.28	4.57
	P+T	9.31	2.94	8.95	6.13	7.14	3.53	8.39	5.00	8.20	4.23	6.21
BASIC LEAD SILICO CHROMATE/IRON OXIDE (Paint No. 13)	P	9.00	4.50	7.50	3.50	6.13	3.75	8.50	8.00	7.45	4.70	6.08
	P+T	9.50	5.00	9.50	7.50	9.13	5.50	9.25	8.50	9.30	6.40	7.85
MISCELLANEOUS PIGMENTS (Paint Nos. 19, 23, 42, 56 and 59)	P	7.31	4.25	7.31	5.44	7.35	4.50	7.81	3.62	7.43	4.46	5.95
	P+T	9.44	3.50	9.19	6.00	8.82	4.83	9.31	3.25	9.12	4.48	7.14
UNDETERMINED PIGMENTS (Paint Nos. 1, 22, 26, 27 and 44)	P	2.00	1.40	1.10	0.70	2.62	0.90	3.05	0.90	2.28	0.96	1.62
	P+T	7.95	2.30	8.00	2.80	7.77	1.97	8.70	1.90	8.05	2.19	5.12

* Thirty months marine and industrial exposure; 1220 panels, blast and wire brush surface preparation.

** Rating – 10 = Perfect.

*** P = Primer and T = Topcoat

TABLE A-5

HAND-CLEANED STEEL TEST—EFFECT OF VEHICLE COMPOSITION

VEHICLE (PAINT NUMBER)	Coats of Paint ***	RATING**										Overall Rating
		Blast Cleaned		Wire Brush-Mill Scale		Wire Brush-Rusty Mill Scale		Wire Brush-Rusty		Average		
		Ind.	Marine	Ind.	Marine	Ind.	Marine	Ind.	Marine	Ind.	Marine	
LINSEED OIL (Paint Nos. 9, 10, 11, 17, 31, 47, 53 and 57)	P	9.25	5.53	6.90	5.68	7.60	5.50	6.85	5.28	7.64	5.50	6.56
	P+T	9.43	6.56	9.32	6.56	9.45	6.30	9.50	6.34	9.44	6.41	7.83
PHENOLIC (Paint Nos. 4, 5, 21, 35, 40, 41, 58 and 60)	P	6.94	2.50	5.78	3.72	6.66	3.33	7.68	4.72	6.75	3.52	5.13
	P+T	9.43	3.75	9.15	5.19	8.35	4.70	9.24	6.00	8.92	4.87	6.88
ALKYD (Paint Nos. 1, 14, 23, 29, 33, 39 and 48)	P	4.07	1.00	3.68	2.00	3.82	0.97	4.79	1.96	3.84	1.38	2.61
	P+T	9.43	1.86	8.15	5.18	6.86	1.86	8.29	3.32	7.93	2.82	5.37
EPOXY (Paint Nos. 8, 18 and 28)	P	9.00	1.50	5.92	4.33	5.83	2.00	6.67	5.58	6.65	3.06	4.87
	P+T	9.41	3.50	8.84	6.33	6.75	3.58	7.33	5.67	7.81	4.53	6.18
VINYL (Paint Nos. 45 and 61)	P	8.88	7.25	6.25	4.50	5.00	4.94	4.25	3.75	5.88	5.07	5.48
	P+T	9.00	5.25	8.25	2.00	8.75	2.50	6.25	0.00	8.20	2.45	5.33
FISH OIL (Paint Nos. 12, 30, 52 and 54)	P	5.81	0.50	2.25	1.75	5.12	1.19	6.19	2.00	4.90	1.32	3.12
	P+T	8.13	1.87	8.81	4.00	8.07	2.94	9.25	4.44	8.45	3.24	5.85
CHLORINATED RUBBER (Paint Nos. 7, 20 and 46)	P	8.66	3.58	5.42	5.58	5.62	3.58	7.84	5.17	6.64	4.30	5.47
	P+T	9.50	4.84	8.41	6.59	7.41	4.12	9.08	6.00	8.36	5.14	6.75
THIXOTROPIC LINSEED OIL (Paint Nos. 49 and 56)	P	9.25	5.25	9.12	6.25	8.81	6.50	8.75	4.00	8.95	5.70	7.32
	P+T	9.50	5.75	9.50	6.25	9.50	6.50	9.50	3.75	9.50	5.75	7.62
LINSEED OIL/PHENOLIC (Paint Nos. 24 and 50)	P	9.12	4.88	7.25	5.75	7.19	5.44	7.13	5.00	7.57	5.30	6.43
	P+T	9.50	4.50	9.50	6.63	9.06	6.37	9.50	7.38	9.30	6.25	7.78
LINSEED OIL/ALKYD (Paint Nos. 2, 13, 15, 16, 25, 34, 37, 38, 43 and 59)	P	9.10	5.20	7.15	5.37	6.93	5.21	7.85	5.37	7.53	5.28	6.40
	P+T	9.40	4.47	9.20	6.37	8.67	5.31	9.12	5.94	9.02	5.48	7.34
LINSEED OIL/EPOXY (Paint Nos. 3 and 36)	P	8.50	1.75	7.25	5.00	7.56	4.75	8.00	7.37	7.77	4.72	6.25
	P+T	9.25	2.75	9.37	6.62	8.75	5.56	9.37	8.25	9.10	5.75	7.42
PHENOLIC/ALKYD (Paint No. 42)	P	8.25	4.00	7.75	6.00	7.75	5.50	8.50	5.00	8.00	5.20	6.60
	P+T	9.50	4.00	9.00	8.00	9.38	7.38	9.50	7.75	9.35	6.90	8.13
PHENOLIC/VINYL (Paint No. 51)	P	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.00	0.30	0.00	0.15
	P+T	2.00	0.50	7.00	1.00	5.88	1.00	7.75	1.00	5.70	0.90	3.30
MISCELLANEOUS VEHICLES (Paint Nos. 6, 19, 22, 32 and 55)	P	6.94	4.38	5.56	4.12	6.12	3.78	6.37	4.94	6.22	4.20	5.21
	P+T	9.50	4.88	9.25	4.75	9.03	5.25	9.44	5.82	9.25	5.20	7.23
UNDETERMINED VEHICLES (Paint Nos. 26, 27 and 44)	P	0.67	0.33	1.83	0.50	2.46	0.58	2.75	0.00	2.03	4.00	1.22
	P+T	6.92	2.16	7.76	2.66	7.88	1.87	8.16	1.17	7.70	1.95	4.82

* Thirty months marine and industrial exposure; 1220 panels; blast and wire brush surface preparation.

** Rating-10 = Perfect.

*** P = Primer and T = Topcoat.

TABLE A-6

COMPARISON OF PRIMER COMPOSITIONS—EFFECT OF PIGMENT COMPOSITION *

PIGMENT (Paint Number)	RATING								
	Blast Cleaned		Wire Brush-Mill Scale		Wire Brush-Rusty		Average		OVERALL
	Semi-Rural	Marine	Semi-Rural	Marine	Semi-Rural	Marine	Semi-Rural	Marine	AVERAGE
RED LEAD (Paint Nos. 1C, 2C, 8C)	9.50	7.00	6.33	3.00	7.50	3.33	7.78	4.44	6.11
ZINC DUST (Paint No. 5C)	9.50	0.00	7.50	0.00	8.50	0.00	8.50	0.00	4.25
BASIC LEAD SILICO CHROMATE (Paint No. 7)	9.50	9.00	8.50	8.00	9.00	7.00	9.00	8.00	8.50
RED LEAD/BASIC LEAD SILICO CHROMATE (Paint Nos. 5, 6)	9.20	6.80	7.00	5.00	7.90	4.40	8.03	5.40	6.71
RED LEAD/IRON OXIDE (Paint Nos. 1, 4, 3C, 4C, 6C)	9.64	7.09	8.22	3.89	8.41	3.11	8.26	4.70	6.73
BASIC LEAD SILICO CHROMATE/IRON OXIDE (Paint No. 3)	9.64	7.36	9.07	5.14	8.50	4.71	9.07	5.74	7.40
LEAD CHROMATE (BASIC)/ IRON OXIDE (Paint No. 2)	9.79	7.29	9.00	4.71	8.50	4.57	9.09	5.52	7.31

* Eight years exposure of 2 primer coats plus a finish coat. 360 panels, blast and wire brush surface preparation. Rating - 10 = Perfect.

TABLE A-7

COMPARISON OF PRIMER COMPOSITIONS—EFFECT OF VEHICLE COMPOSITION *

VEHICLE (Paint Number)	RATING								
	Blast Cleaned		Wire Brush-Mill Scale		Wire Brush-Rusty		Average		OVERALL
	Semi-Rural	Marine	Semi-Rural	Marine	Semi-Rural	Marine	Semi-Rural	Marine	AVERAGE
LINSEED OIL (Paint No. A, B, C, D, J, 1C, 2C, 4C, 5C)	9.71	6.94	8.86	5.39	9.03	5.10	9.20	5.80	7.49
PHENOLIC (Paint No. 8C)	9.50	7.00	3.00	0.00	6.00	0.00	6.17	2.33	4.25
ALKYD (Paint Nos. E, H)	9.58	6.50	7.58	3.33	7.41	2.00	8.19	3.94	6.06
EPOXY (Paint No. F)	9.63	6.88	9.00	4.25	8.75	3.75	9.12	5.76	7.04
LINSEED OIL/ALKYD (Paint Nos. 3C, 6C)	9.50	8.00	9.00	5.00	9.00	0.00	9.17	4.34	6.75
PHENOLIC/ALKYD (Paint Nos. G, I, L)	9.35	7.14	6.64	2.14	6.78	1.71	7.59	3.67	5.64

* Eight years exposure of 2 primer coats plus a finish coat. 360 panels, blast and wire brush surface preparation. Rating - 10 = Perfect.

each test area was commercial blast cleaned (SSPC-SP 6) and half was hand cleaned (SSPC-SP 2). All paint systems were brush applied. Many of the paint systems in this test were included in the less severe exposure on the Mid-Hudson Bridge, which is high over fresh water. (See Fig. A-1.)

Because of the severe exposure environment, most of the well-represented pigment and vehicle types are in fair-to-poor condition after 6 yr. Only one red lead primed system is still in good condition. The two epoxy paints and the one chlorinated rubber are giving excellent protection.

Because of the greater total film thickness, most new paint systems performed much better if applied over the previous sound paint than over blast-cleaned steel.

TEST (8): MID-HUDSON BRIDGE

The Mid-Hudson is a suspension bridge located high above fresh water (Fig. A-1). Each of the 44 test paint systems was applied to an area of approximately 10 sq ft on the top chord of a stringer, 12 ft above the deck surface, facing south. Half of each test area was hand cleaned (SSPC-SP 2) and half was commercial blast cleaned (SSPC-SP 6). All paint systems were brush-applied. Many of the paint systems in this test were included in the more severe exposure of the Cap Tree Bridge test. Tables A-8 and A-9 show the average rating for the various pigment and vehicle types used.

Because of the relatively mild exposure environment, most of the widely used general pigment and vehicle types have given a satisfactory performance for the past 6 yr. However, some of the paints which fell into the unknown or miscellaneous classification are giving a poor performance.

TEST (9): PAINTING GALVANIZED STEEL

This project was jointly sponsored by the Committee of Steel Producers of the American Iron & Steel Institute and the SSPC. Its purpose was to evaluate carefully selected trade sales paints of the type frequently used in painting of galvanized steel on guardrails, suspension cables, signs, portions of bridges, etc.

After 6 yr (in 1966) it was concluded that galvanized steel can be satisfactorily painted with zinc dust/zinc oxide paints, with some portland cement-in-oil paints, certain latex paints, and some of the special proprietary paints developed for this purpose. Chemical treatments used to prevent white rust stain are slightly detrimental to paint adhesion. Weathering before painting is helpful.

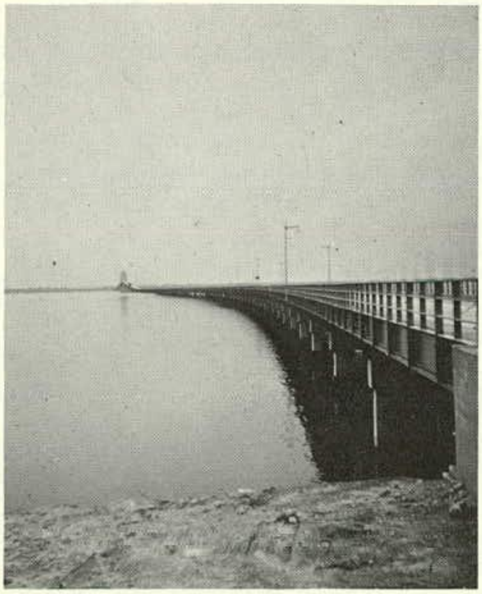
TESTS (10) AND (11): ZINC-RICH PAINTS

Tests have been undertaken in an effort to develop performance specifications that can be used for open-bid procurement of zinc-rich paints as an alternative to purchasing by proprietary name or composition alone. This becomes especially important because of the wide variations—from excellent to mediocre—that have been obtained with the numerous zinc-rich products available.

A composition specification tends to be overly restrictive, because good results have been obtained from widely different formulations of organic and inorganic types. Therefore, the SSPC is carrying out a series of accelerated tests under the direction of its zinc-rich advisory committee, with the cooperation of the International Lead Zinc Research Organization. In the meantime, inspections of series being undertaken by other SSPC members have been informative.

TEST (12): PAINTING WET OR COLD STEEL

Dr. William Wettach, chairman of the Corrosion Committee of the Federation of Societies for Paint Technology, in cooperation with the SSPC, has studied the effects of



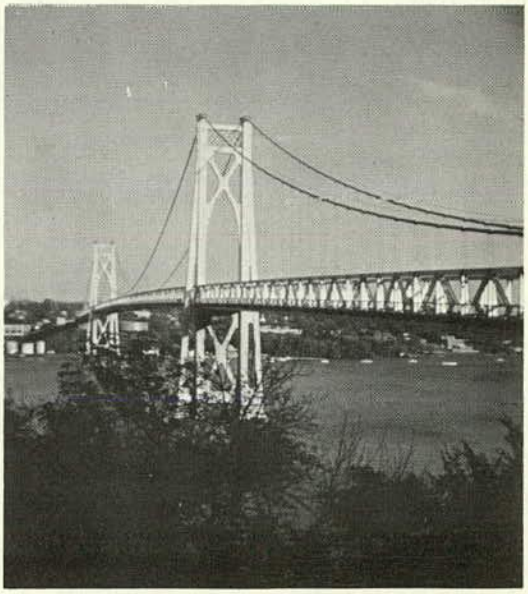


Figure A-1. Cap Tree Bridge (low over salt water) and Mid-Hudson Bridge (high over fresh water).

painting over cold and wet steel. A few of the conclusions reached after 31 months' exposure are:

1. Over intact mill scale at 25 F all paint systems performed very well.

2. Over rusty mill scale at either 25 F or 70 F primers gave only limited protection. If further coats were applied within 4 months, panels remained in good condition. Oil-base primers gave the longest protection and alkyds the shortest.

3. All primers applied over blast-cleaned steel surfaces were in much better condition.

4. Painting of wet, rusty mill scale, with most types of primers, resulted in worse performance than painting wet, tight mill scale.

5. Prompt application of intermediate and finish coats tended to avoid premature failure of primer.

TEST (13): PROTECTING LOAD-BEARING SURFACES OF BRIDGES

A 7-yr series of tests were made on a Chicago Great Western Railway bridge at Byron, Illinois, to evaluate paints and other materials for protecting the load-bearing surfaces of bridges. The test area consisted of the top flanges of the stringer girders directly beneath and between timber ties. Although these surfaces are peculiar to railroad bridges, they are similar in protective requirements to many highway bridge surfaces that are subjected to a combination of load bearing, de-icing salts, abrasion, greasy materials, moisture, and other contaminants.

All of the most effective materials required blast-cleaning surface preparation. The two most-effective coatings were metallizing and inorganic zinc silicate. Other coatings which performed well over blast-cleaned steel included the chlorinated rubber paint, a cold-applied coal tar mastic, and a zinc-dust paint. A cementitious paint, an aluminum-pigmented petroleum coating, an epoxy ester, and the control oil-base paint system gave fair protection over blast-cleaned steel, but failed completely over wire-brushed steel.

TEST (14): BRIDGE MAINTENANCE PAINTING

In June 1965, an inspection was made of the semi-experimental painting test on the Allegheny River Bridge of the Bessemer and Lake Erie Railroad. This large-scale maintenance painting test employed well-known paint systems of the oil-base and alkyd types frequently used on highway bridges.

In 1959, the bridge had been completely repainted using one touch-up coat, one intermediate, and one topcoat of aluminum paint. Six suitable paint systems were selected for comparison. For this test, the bridge was divided into six principal lengths. Complete data were kept on all costs, labor, paint composition, amount of all paints used, application properties, drying, film thickness, square feet per gallon, and costs of material and labor.

After 6 yr of exposure, each of these reputable paint systems is still in good condition. On several of the spans, the single coat of aluminum paint is beginning to wear through, but the underlying coats are still in good condition. The following observations were made:

1. Slight rust blistering occurred on horizontal surfaces such as the tops of the bottom flanges and chords that are exposed to the effects of weather, debris, dust, and falling ballast.

2. The topcoat was thin in several places, on the members exposed to sunlight, prevailing winds and weather. (Application of a second coat of aluminum paint had been

TABLE A-8

MID-HUDSON BRIDGE PAINT TEST—EFFECT OF PIGMENT COMPOSITION *

PIGMENT (PAINT NUMBER)	** RATING
Red Lead (Paint Nos. 17, 21, 28, 40)	7.50
Zinc Dust (Paint Nos. 29, 31, 34, 41)	7.75
Aluminum (Paint Nos. 18, 23)	8.00
Red Lead/Zinc Oxide (Paint Nos. 6, 10, 11, 12, 13, 14, 19)	7.28
Red Lead/Iron Oxide (Paint Nos. 4, 5, 22, 25, 26, 30, 39, 43)	7.75
Zinc Dust/Zinc Oxide (Paint Nos. 33, 36)	7.50
Zinc Chromate/Iron Oxide (Paint Nos. 3, 16, 32, 35, 37, 38)	7.33
Basic Lead Silico Chromate/Iron Oxide (Paint Nos. 15, 20)	7.50
Miscellaneous Pigments (Paint Nos. 2, 42)	8.50
Undetermined Pigments (Paint Nos. 1, 7, 8, 9, 24, 27)	6.00

* Six years mild exposure high over fresh water; 44 test areas; blast and wire brush surface preparation.

** Rating - 10 = Perfect.

deferred for 3 yr because of the unexpectedly good performance.)

3. Some parts are subject to concentrated corrosion and are difficult to protect with paint. Examples are the badly rusted rivet heads on the flat top chords where water can collect and where the pigeons can roost. Other difficult-to-protect places include the crevices of chord members, the interface between the tops of the T-flange and the concrete deck. Brittle paint tended to have poor adhesion to the burnished rivet heads.

4. This test demonstrated that, with good surface preparation and application, excellent corrosion protection and appearance can be obtained in maintenance painting with any one of several reputable paint systems in a typical urban high river bridge environment.

TEST (15): PAINTING STEEL BRIDGES FOR MILD EXPOSURES

Cooperative Santa Fe Railway—SSPC bridge paint tests were inspected in July 1965. After 13 yr of exposure in a mild environment near Kansas City, Kansas, several typical kinds of well-known oil-base and proprietary coatings gave satisfactory performance. In particular, a standard two-coat Santa Fe conventional red lead linseed oil base paint system was in almost perfect condition, either with the standard primer or with a special proprietary primer. A two-coat proprietary asphalt system was nearly as good. Coatings systems which are still in fairly good condition include a one-coat proprietary asphaltic coating and a two-coat cementitious paint system. A non-hardening grease-type mixture has gradually worn away over the years and is now completely gone in all weather-exposed locations. Serious rusting was confined to tops of bottom flanges, a condition which was prevented by the better coatings, but might also be improved by standard sloped flanges.

TESTS (16) AND (17): WEATHERING STRUCTURAL STEEL BEFORE PAINTING

Two bridge painting tests were undertaken in 1958 and inspected in August 1965 to compare the performance of paint applied in the shop versus that applied in the field after structural steel has been allowed to weather. The first was on the Great Northern Railway and the second on the Pennsylvania Railroad. After the first 7 yr of exposure, most parts of both test bridges were in excellent condition, regardless of whether the paint was applied to hand-cleaned steel in the shop, or to hand-cleaned or sandblasted steel which had been weathered in the field before painting. Low surface temperature during application in this case apparently did not adversely affect the shop-painted portion.

Based upon this inspection, it is not anticipated that any appreciable amount of touch-up painting will be required for several years. It is therefore concluded that, for relatively mild exposure of this kind, many years of protection can be obtained by any one of the five good oil-base shop primers used in moderate environments, as long as they are properly applied over a conscientiously prepared surface.

TESTS (18) AND (19): PAINTS FOR WATER IMMERSION

Paint systems in this surveillance test are those developed for protection of steel which is immersed in water, alternately immersed, or exposed to high humidity. Each system was applied to two near-white blast-cleaned panels according to the manufacturers' recommendations.

TABLE A-9

MID-HUDSON BRIDGE PAINT TEST—EFFECT OF VEHICLE COMPOSITION *

VEHICLE (PAINT NUMBER)	** RATING
Linseed Oil (Paint No. 19)	8.00
Phenolic (Paint Nos. 33, 35, 40)	7.67
Epoxy (Paint Nos. 15, 17)	7.00
Vinyl (Paint No. 31)	8.00
Fish Oil (Paint No. 3)	8.00
Chlorinated Rubber (Paint No. 34)	7.00
Linseed Oil/Alkyd (Paint Nos. 2, 4, 5, 6, 20, 22, 25, 26, 32, 36, 37, 38, 43)	7.85
Linseed Oil/Epoxy (Paint Nos. 21, 30)	7.00
Phenolic/Alkyd (Paint No. 41)	8.00
Miscellaneous Vehicles (Paint Nos. 16, 23, 29, 42)	7.50
Undetermined Vehicles (Paint Nos. 1, 7, 8, 9, 10, 11, 12, 13, 14, 18, 24, 27, 39)	6.70

* Six years mild exposure high over fresh water; 44 test areas; blast and wire brush surface preparation.

** Rating - 10 = Perfect.

The vinyl and phenolic/vinyl systems are performing well; the chlorinated rubber systems are producing average results; the metallized zinc and aluminum systems are not performing so well. Two coal tar epoxies and one epoxy are in excellent condition. An asphalt system is performing just below average, while a Gilsonite/asphalt and an airless vinyl are performing poorly. Performance of another airless sprayed vinyl system, a urethane system, and a fish oil system is about average.

TEST (20): PAINTS FOR WATER IMMERSION

To compare some of the best coatings systems for water immersion, a 14-yr, three-phase field service test of paints was carried out, using a large watertank interior at Ambridge, Pennsylvania. Throughout this test, the SSPC vinyl paint systems, and variations thereof, gave outstanding performances; good performance was obtained over steel that was prepared by sandblasting, grit blasting, shot blasting to commercial grade or brush-off grade. Neither the use or non-use of wash primer pretreatment or minor differences in formulation of the various vinyl coatings provided any essential differences in performance.

Other systems that have been successful so far include (sealed) metallizing with zinc or aluminum, inorganic zinc silicates, certain epoxies, and certain zinc-dust paints.

It is indicated that these vinyl systems will continue to give good service with a minimum of maintenance even beyond the 14-yr life they have already demonstrated.

TEST (21): TEMPORARY COATINGS

A project was undertaken to evaluate 34 thin, clear coatings to protect pre-blast-cleaned steel between the time of shotblast cleaning and painting. A few promising products with the necessary clarity, drying rate, cost, weldability, and length of protection are being investigated for repaintability. Wash primer qualifies on all counts except clarity.

TEST (22): SURVEILLANCE

The SSPC carries out comparison tests with a cross-section of the new products developed by the industry. Their success is measured against that of established products whose performance on structures has been well documented. Although results with this wide range of materials do not lend themselves to brief summation, they do serve as a useful guide.

INTERCORRELATION OF PAINT TESTS

A punch-card method has been adopted for correlating numerous results of paint systems evaluations in outdoor exposures. This approach has been found necessary because of the tremendous amount of data that must be considered.

The initial key-sort cards have been prepared, beginning with some of the exposure tests, and can be expanded to include other reliable field and laboratory experience. Data will continue to be confined to those tests that the SSPC believes to be verifiable and meaningful. Each exposure of each paint system is entered on a separate card, which is coded and notched to represent the basic variables of the correlation. These variables include the type of vehicle, pigment, exposure environment, surface preparation, initial surface conditions, method of applying paint, and the type of test.

OVERALL CONCLUSIONS

A pattern emerges from these exhaustive tests, leading to certain conclusions regarding good practice, pigmentation, and vehicles. Each series of tests is directed toward a particular type of problem, exposure, or application, but some generalizations can be made concerning trends which underline all of the experimental findings:

Any one of several proven paint systems achieved effective protection for several years, provided that good surface preparation and careful application were carried out under careful supervision and inspection.

In normal environments, good paint life has usually been obtained over hand-cleaned steel on panels, in field tests, and on structures, if good oil-base paint systems are properly used.

In severe environments, such as those involving salt water, constant high humidity, or chemicals, it is advisable to blast clean and apply a synthetic paint such as zinc-rich, vinyl, chlorinated rubber, epoxy, etc., as recommended in this report.

Even in milder environments, scale removal by blast cleaning is effective in obtaining better appearance, longer life, and insurance against mill scale lifting. Blast cleaning, however, offers its own challenges in obtaining profiles which can be properly coated with 3 to 7 mils of paint, avoiding recontamination of surface, and in proper choice of abrasive.

Paint film thickness and uniformity correlate directly with paint performance.

Pigmentation of the primer plays an especially important role in determining performance of paint systems, particularly those based on linseed oil or long-oil formulations. Some trends are evident concerning pigmentation (see Table A-10):

1. In many, but not all, of the organic and inorganic binders, zinc-rich pigmentation gave good barrier and scratch protection in very severe environments, as well as in milder ones. Its galvanic protection of badly damaged areas, however, seemed to be limited to immersion or very wet environments.

2. In all tests, the red lead/iron oxide performed better than straight red lead (up to 25% iron oxide).

3. When combined with iron oxide, the basic lead silico chromate was equivalent to red lead (less chalking, but may require slightly better surface preparation due to alkyd content).

4. Tribasic lead phosphosilicate was equally effective, and offers a white or colorless primer. Barium metaborate also showed promise.

5. Zinc dust/zinc oxide pigmentation was very effective over galvanized steel as well as hand-cleaned or blast-cleaned steel.

TABLE A-10

RELATIVE PERFORMANCE OF PIGMENT TYPES IN VARIOUS PAINT TEST INSPECTIONS, 1965-1967

	PERFORMANCE				
PIGMENT TYPE	BRINE-RESISTANT BRIDGE PAINTS	HAND-CLEANED STEEL TEST	WETTING ADDITIVE TEST	MID-HUDSON BRIDGE TEST	ROBERT MOSES BRIDGE TEST
Red lead	Good to poor	Fair	Poor	Good	Poor
Zinc dust (or zinc-rich)	—	Good	Poor	Good	Fair
Zinc chromate	—	Fair	—	—	—
Basic lead silico chromate	—	Fair	Good	—	—
Aluminum	Good	Fair	—	Good	Fair
Red iron oxide	—	Poor	—	—	—
Red lead/zinc chromate	Good	—	—	—	—
Red lead/basic lead silico chromate	—	Good	Fair	—	—
Red lead/zinc oxide	—	—	—	Fair	Fair
Red lead/red iron oxide	Good to fair	Good	Fair	Good	Fair
Zinc dust/zinc oxide	—	Fair	—	Good	—
Zinc chromate/zinc oxide	—	Fair	—	—	—
Zinc chromate/red iron oxide	Fair	Fair	—	Fair	Fair
Basic lead silico chromate/ red iron oxide	—	Fair	Good	Good	Fair
Lead chromate/red iron oxide	—	—	Fair	—	—

6. Zinc chromate primers showed excellent rust-prevention properties, but tended to give shorter-term protection, and could not be exposed by themselves for long periods in oil-base vehicles, perhaps because of their stability.

7. In well-formulated paints, some unusual combinations of pigmentation gave good results, including tribasic lead phosphosilicate, red lead/basic lead silico chromate, and aluminum with inhibitor added.

8. In preliminary tests, basic lead silico phosphate silicate and barium metaborate have been at least equivalent to all the above, but have not been exposed long enough for final conclusions.

9. Primers having a high percentage of inerts, extenders, and undisclosed pigmentations tended to be markedly poorer than any of those mentioned above, which used recognized inhibitive pigmentations.

10. Choice of primer pigmentation appeared to be less critical in the synthetics, such as vinyls, where vehicle composition appeared to be the controlling factor. Even here, however, an inhibitive pigment tended to offer a safety factor when barrier protection was insufficient.

Vehicle composition is critical in all types of exposures. Table A-11 generally summarizes the relative performance of paints according to generic vehicle composition. This table should be regarded only as a guide; the project reports summarize more completely the tests and conclusions. Because it is inadequate to discuss vehicle composition solely in terms of broad generic types (such as vinyl, and epoxy) the following conclusions are based upon the best formulations of each type that was evaluated:

1. In normally dry atmospheric service, the linseed oil or linseed oil/alkyd were equivalent to any of the other vehicles.

2. In prolonged salt brine exposure, properly formulated vinyls, chlorinated rubber, and asphalt mastics have been excellent. The early epoxies and the various phenolics were variable.

3. In water-immersion tests, the vinyls have had the most consistently good performance for the past 14 yr. Some of the coal tar epoxies, coal tars, some of the chlorinated rubber, and sealed metallizing were also excellent, but have had shorter exposures.

4. In zinc-rich paints, a wide range of vehicles gave good performance, including both organic and inorganic types. Within each type, however, there were others which showed considerably poorer performance.

5. High-build coatings, having a low percentage volatile and often a thixotropic vehicle, tended to give good performance in proportion to their film thicknesses. This class includes a new type of thixotropic linseed oil aluminum topcoat in atmospheric environments and epoxy for severe environments. These coatings are very promising because of low application costs, but results to date have been incomplete.

With most types of paint, best results were obtained with specification products whose composition was well-known. This applies to oil base, alkyds, vinyls, coal tar, coal tar epoxies, and asphalt. Here, some further proprietary improvements could be made, sometimes within limits of the

TABLE A-11

RELATIVE PERFORMANCE OF VEHICLE TYPES IN VARIOUS PAINT TEST INSPECTIONS, 1965-1967

VEHICLE TYPE	PERFORMANCE					
	BRINE-RESISTANT BRIDGE PAINTS	HAND-CLEANED STEEL TEST	WETTING ADDITIVE TEST	MID-HUDSON BRIDGE TEST	ROBERT MOSES BRIDGE TEST	WATER IMMERSION TEST
Linseed oil	Good to fair	Fair	Good	Good	Poor	—
Phenolic	Good	Fair	Poor	Good	Fair	Poor
Alkyd	—	Poor	Fair	—	Fair	—
Epoxy	—	Fair	Good	Fair	Good	Good
Vinyl	Good if blast cleaned	Fair	—	Good	Poor	Good
Fish oil	—	Poor	—	Good	Poor	Fair
Chlorinated rubber	Good	Fair	—	Fair	Good	Fair
Thixotropic linseed oil	—	Good	—	—	—	—
Coal tar	Fair	—	—	—	—	—
Asphalt	Good if blast cleaned	—	—	—	—	—
Linseed oil/phenolic	Poor	Fair	—	—	Fair	—
Linseed oil/alkyd	—	Fair	Fair	Good	Fair	—
Linseed oil/epoxy	—	Fair	—	Fair	Fair	—
Phenolic/alkyd	Good	Good	Fair	Good	Fair	—
Phenolic/vinyl	—	Poor	—	—	—	Good
Epoxy/coal tar	—	—	—	—	—	Good

specification. On certain other types, however, differences in performance could not be correlated directly with known composition. This is particularly true of the zinc-rich paints where a wide variety of vehicles have been successful, and an equally large number have been difficult to apply and ineffective in performance. For this reason, a concerted effort should be made to develop performance specifications for coatings of these types.

APPENDIX B

PRACTICES OF OTHERS WHO PAINT STEEL

Some of the practices of the 50 U.S. state highway departments and AASHO in painting of structural steel are described in *NCHRP Report 74B*. The useful experiences of others who specialize in painting structural steel, as obtained from interviews, inspections and questionnaires are described in this appendix.

SOME PAINTING PRACTICES OUTSIDE THE U.S.

English Painting Practices

Trends in painting of highway structural steel in England differ considerably from those in the U.S., as reflected in contacts with the British Iron & Steel Research Institution, in correspondence with the British Research Institute, and in the British literature.

A meeting was held with Dr. R. R. Bishop, who is in charge of a survey of painting of structural steel for the Road Research Laboratory, Ministry of Transport, in England. His program began with a survey in 1964 and 1965 on the condition of paint in common use in Great Britain. The committee chose 11 bridges built since 1958 so as to obtain as much detail as possible on surface preparation and on the coatings used. The entire history and performance of each were diligently investigated, and some excellent conclusions were drawn. It was also shown that even under these ideal investigatory conditions, many uncertainties still remain in determining (1) what types of surface preparation were actually used a few years ago; (2) the details of application; (3) the maintenance history of the bridges; (4) the actual performance of the coatings; and (5) the explanation of seeming irregularities. There-

fore, corrosion tests of referenced painting specimens and test areas at selected bridge sites were planned as the next step in this excellent survey.

Full-scale tests are being initiated on new bridges, to compare new systems with the British standards (two coats of red lead in oil, and two coats of micaceous iron oxide phenolic).

Zinc spray application is widely used in Great Britain, perhaps because of the many severely humid exposures. Because of the cost of this method, however, other protective systems (including epoxies, zinc-rich, and chlorinated rubber) are being considered and tested. Whenever possible, the paint companies will supply these as specification products, with the provision that the formulation can be disclosed publicly in 5 yr.

The ratio of labor/material is only 3/1 in Great Britain, versus 10/1 in New York. Pre-blast cleaning before fabrication is used in the United Kingdom, especially in shipbuilding. Formerly, a thin coat of zinc-dust paint had been applied to the newly cleaned surface, but (partially due to objections of the welders' union) an especially durable one-package wash primer is now used.

Considerable work is being done to determine the best anchor pattern profile for paint.

Metallizing has been found to cost about three times as much as grit blasting and painting.

A conference was held with Dr. R. W. Wilson of Shell Research Limited (in Chester) on July 19, 1966. This meeting was concerned mainly with English surface preparation practices, beginning with a review of the proposed British standard specification for surface finish of blast-cleaned steel for painting. The specification recognizes four grades that correspond approximately to those of the SSPC. It also recommends methods for specifying surface roughness.

Traces of oversize grit were found to result in "rogue peaks" which drastically affect paint performance. Many paint firms now do their own surface preparation and offer a 5-yr guarantee. Shot blasting is usually used in place of grit or sand, except on old ships. High humidity increases painting costs in Great Britain as compared to those in the Mediterranean.

Japanese Painting Practices

An interview was held with two representatives of Kansai, the largest paint company in Japan, which supplies considerable paint for highway and railroad use.

The Japanese National Railway and the central government highway department use the best available steel-painting practices, but the local highway departments apparently operate on a very low budget.

Blast cleaning and the use of synthetic paints is apparently more widespread in Japan than in the U.S. Nozzle sandblasting is often carried out before fabrication or immediately thereafter, but the weld areas are later recleaned by wire brushing. Considerable steel is also shipped and erected before blast cleaning and painting (as in Missouri). The smaller fabricators often are not equipped to blast-clean before fabrication.

One serious Japanese highway painting problem is primer deterioration before the second coat of paint is applied, a problem often mentioned by U.S. fabricators. Paint film thickness is specified in Japan, but its measurement presents problems.

Swedish Painting Practices

Just prior to the initiation of this project, interviews were held with two members of the Swedish IVA Corrosion Committee who made separate visits to the U.S.

In surface preparation, improved tungsten carbide scrapers have effected much improvement in performance, and samples were sent to the SSPC. Tests show that roller application is best because of the somewhat thicker coat. Spray application is also superior to brush, but requires more rigid inspection in the field. Swedish test work showed alkyd vehicle to be preferable to linseed oil, even over hand-cleaned steel. Red lead was found superior to zinc chromate.

In best surface preparation, the sequence was as follows (from worst to best): (1) no surface preparation; (2) light wire brushing; (3) brush-off blast cleaning; (4) flame cleaning; (5) medium wire brushing; (6) thorough wire brushing; (7) shot blast cleaning (with cut wire); (8) commercial blast cleaning; (9) pickling; (10) white metal blast cleaning. This work was amply illustrated with photographs.

BRIDGE AND TURNPIKE AUTHORITIES

Through the cooperation of the International Bridge, Tunnel & Turnpike Association, questionnaires were sent to their members, and 19 interesting returns were obtained. In addition, some valuable inspections were made involving the Robert Moses Bridge, the Chesapeake Bay Bridge, the Rickenbacker Causeway, and the Mid-Hudson Bridge.

About 70% of the respondents prepare the surface by hand cleaning and 30% use blast cleaning or other methods. Environments, annual costs, frequency of repainting, and frequency of inspection all varied too widely to permit any broad generalizations. Most primers consisted of some type of red lead in linseed oil; the color of the finish coat was evenly divided between aluminum and other types. Five of the 19 respondents did not know the type of paint systems originally used on their bridges. (As a result of this questionnaire, a test program has been undertaken which includes an evaluation of zinc-rich paints, vinyls, epoxies, coal tar epoxies, colored aluminum, and silicone alkyds.)

The guardrails of most authorities were usually protected with a red lead primer and aluminum or white topcoat, which are repainted on an average of every 3 yr. The maintenance costs average about 15 cents per foot of guardrail, and replacement is usually because of impact, rather than corrosion.

One of the many interesting inspections was that of the Rickenbacker Causeway (Miami, Florida) on which a large number of paint systems were tested under very adverse conditions. Under the difficult application conditions which originally prevailed, it was decided that a low-cost petroleum base non-hardening coating was as satisfactory as any

of the others tested. On the Causeway, an average life of about 2 yr was obtained at 300 sq ft per gallon, at $2.00 per gallon, or at a cost of less than 0.5 cent per square foot per year. In such locations, however, some section may be lost due to gradual rusting underneath this type of coating.

RAILROADS

The painting of railway bridges has much in common with that of highway bridges and much can be learned from inspection. Although railroads do not use large amounts of de-icing salts, large amounts of salt are spread along the structures by the constant dripping of salt brine from refrigerator cars. Because of the applicability to highway painting problems, inspections were made of SSPC bridge-painting tests which had been started cooperatively with various railroads some 5 to 15 yr ago. Results are described in Appendix A, including work done on the Missouri Pacific, Santa Fe, Pennsylvania, Chicago Great Western, Great Northern, and Bessemer & Lake Erie railroads.

Interviews with representatives of three railroads indicated that they are doing no normal painting whatever on the great majority of bridge surfaces, but depend upon non-hardening grease type of coatings. Although these have a shorter life than ordinary paint, they are very inexpensive, easily applied, and reportedly require little surface preparation. However, they present problems in slipperiness, difficulty of proper inspection, and require frequent maintenance.

Current trends in railroad painting practices were discussed with W. L. Short, representing the American Railway Bridge & Building Association, and F. P. Drew, representing the Association of American Railroads. In 1965, Mr. Short issued a very complete report on painting of railroad bridges.

Railroad inspections included a visit to the Savannah River Bridge of the Seaboard Air Line Railroad Company, which is immediately in the path of heavy fog and fumes from a paper plant, resulting in a very highly alkaline wet bridge surface for many hours each day. Originally painted with a proprietary asphaltic mastic, this bridge was subsequently repainted with an amine adduct epoxy system, and was the subject of many bridge paint tests. The most difficult part of this repainting job was the removal of the previous heavy coat of mastic by blast cleaning. The lift-bridge portion was badly damaged in December 1966, and repainted with a coal tar epoxy paint.

A second bridge inspected on this railroad crosses the Altamaha River near Brunswick, Georgia; the previous paint had been badly eaten by brine drippings. The floor system was repainted with a coal tar epoxy, and the paint was in excellent condition after 4 yr.

Interesting case histories were found on the railroad portion of the Huey Long Bridge on the New Orleans Public Belt Railroad in New Orleans, inspected in February 1966. The bridge manager's policy is to spot-clean (blast-clean when necessary), prime, and topcoat only those portions of the bridge that need it. This practice results in spottiness, but prevents an overly heavy coat being built up just for the sake of appearance. Therefore, a long-oil finish coat which weathers away is preferred to a synthetic type which does not. Owing to the constant drippings from refrigerator cars on the turns in this bridge, it has been an excellent accelerated exposure site for many types of paint. Materials on test include a large range of epoxies, most of which the railroads considered unsatisfactory. The general impression was that the fish oil proprietary paints are in fairly poor condition. Metallized aluminum and zinc (15 mils measured) are in good condition. The basic lead silico chromates generally were in good condition after 2.5 yr.

An aluminum grease paint (prepared by mixing SSPC-Paint 101 with proprietary petroleum-base mixture) had protected the tie plates, bolts, and fastenings very well. It stays in a soft condition. A straight asphalt material, however, is in very poor condition, either with or without aluminum pigmentation.

Several other synthetic paint systems are in rather poor condition, although it was not always possible to know the exact conditions of application and exposure. In general, the unpainted stainless steel plates were intact; one type of aluminum plate delaminated, whereas another alloy was in very good condition when inspected. Two sets of unpainted high-strength low-alloy steel panels had been in very poor condition. The modern wrought-iron sample was badly corroded, although the wrought-iron sample made in 1869 was better.

Two years earlier, widespread cracking off of thick paint accumulation occurred on this bridge during a rapid icing condition. Heavy, smooth mill scale, 25 yr old, which was exposed by this condition had begun to rust only after a 2-yr exposure.

The plans and specifications of the Canadian Pacific Railway were reviewed with regard to hot galvanizing, metallizing, and the use of inorganic zinc-rich coatings. Extensive tests of all of these systems are under way.

CONSULTANTS IN PAINTING OF STEEL

Conferences, meetings, and interviews were held with all of the available consultants who specialize in subject matter related to the painting of structural steel.

Consultant A, who recently has been closely concerned with repainting of vinyls of a large bridge in a highly industrialized area, emphasized the importance of inspection. Perhaps more than any other factor, the selection, training, supervision and proper reimbursement of the inspector is the key to good paint performance. In addition, the inspector needs better instrumentation, a clear guide, and a meaningful set of specifications.

Consultant B emphasized that blast cleaning to remove mill scale will eliminate most paint failures. He believes that this investment in surface preparation can be best protected by application of a zinc-rich paint, which should be overcoated in severe environments involving humidity, chemicals, and the like. Differences in surface preparation overshadow most differences in the type of paint used. He believed that profile depth in blast cleaning was very important, and worked with the SSPC toward the development of a device for field measurement of profile.

Primed steel should not be allowed to stand for long periods at the erection site before additional coats are applied. Application problems with zinc-rich can be avoided by familiarity; there is a tendency to settle; special hot spray techniques are required; public zinc-rich specifications are badly needed.

Consultant C emphasized the need for greater uniformity and clarification of highway paint specifications. For most highway applications, hand cleaning is adequate, followed by application of a good linseed oil primer. Blast cleaning in the fabricating plant can be less expensive than proper hand cleaning. Pre-blast cleaning before fabricating can result in poor adhesion; surfaces should be recleaned unless an oil-base paint is used. Blast-cleaning rates for T-1 steel and high-strength low-alloy steel tend to be much lower and more expensive than for ordinary carbon steel. Zinc-rich paint systems deserve further attention, but the consultant tended to favor epoxy for severe applications. For the latter, bids vary widely, from $50 to $100 per ton of steel.

Consultant D had just completed a survey of plants throughout the U.S. to determine the type of paint which has yielded the longest life. The case histories showed that vinyls far outlasted any other type of paint, with many applications of 10 yr of performance or more in severe environments.

Consultant E believed that a statistical approach should be used to determine which paint, surface preparation, etc., has yielded the best performance on bridges with equivalent environments throughout the country. In addition, he felt that further attention should be given to special weather conditions (such as extreme cold) and to protection of bearing surfaces, expansion rollers, suspension cables, underwater steel, and buried steel.

In this survey, the considered opinions of most of the specialists in the various phases of painting structural steel were taken into consideration.

PAINTING CONTRACTORS

One contractor, who specialized in painting steel, uses a variation of brush-off blast cleaning (SSPC-SP 7), particularly in maintenance work. "Shower blasting" enables him to discover loose-paint areas where blasting to bare metal is essential. If the paint is sound, there is no need to remove it. He then prefers an application of a complete prime coat, rather than spot primer, to cover defects not visible to the naked eye. He sees considerable merit in blast cleaning in the field ($40 per ton for surface preparation and three coats) instead of in the shop. Otherwise, two shop coats are needed or the steel will be in poor condition even before it is erected. Field cleaning is believed to have increased paint life from 6 yr to 10-12 yr.

Records tend to show better results by brush application. Unions will not permit spraying red lead. In blasting off old red lead paint, extreme care should be taken that air-mask inlets are upwind from the dust and that a good filter is used.

Another contractor, who specializes in cleaning steel for industrial plants, offers a guaranteed maintenance cost with annual inspection and touch-up. He is concerned with the differences in sand-blasted steel versus that shot-blasted in the shop, especially the suitability of the latter for zinc-rich paints. He uses high-pressure water blast for maintenance work to remove loose paint and chalk. This is usually followed by dry wire brush and painting the same day. His greatest problems are poor-quality shop coats, specifying overly thick films, and pinholing on one-coat high-build paint systems.

PLANT MAINTENANCE ENGINEERS

Maintenance of outdoor plant structural steel has much in common with maintaining highway steel in severe environments. An operator of major radar missile-tracking stations throughout the world finds that it is economical and essential to uninterrupted operation that no expense be spared in initial surface preparation and paint. He favors white-metal blast cleaning and shop application of a full system such as topcoated zinc-rich, or a vinyl system.

A visit was made to the operator responsible for maintenance of the Cape Kennedy Air Force Missile Range Stations. This contractor uses a modified near-white surface preparation specification, referring to SSPC-Vis 1 Photographic Standard B Sa 3 (white metal) and stating that 90% of the surface shall look like this and the remainder shall . . . etc.

Here, painting is required on the same day as surface preparation. Von Arx needle guns are used on some areas before touch-up. Currently the contractor favors painting of faying surfaces of high-strength bolted joints, reasoning that the risk from corrosion is greater than the risk of slippage.

Much of the experience obtained throughout the country in the protection of petroleum refineries has some relevance to the painting of highway steel. To survey some of this experience, a questionnaire was submitted to 90 petroleum engineers throughout the country who are responsible for maintaining steel tanks, plants, and other structures, exposed to a wide variety of climates and atmospheres. This questionnaire was submitted to the American Petroleum Institute's Committee on Refinery Equipment, and the Subcommittees on Corrosion, and on Production.

Both refinery and production painting practices had much in common with painting of other steel structures. There is, however, a greater use of synthetic coatings, in addition to the usual alkyds, including zinc-rich (both organic and inorganic), vinyls, catalyzed epoxies, coal tar epoxies, and silicones. Surface preparation is almost equally divided between blast cleaning and other kinds. Paint application is almost equally divided between the conventional spray, brush, roller, and airless spray. Many refineries average 8 yr or more of paint life. More than half have a painting bill of more than $500,000 per year.

For further information on epoxy paints (which have been used to a limited extent in highway applications) a questionnaire was submitted to 200 epoxy paint users throughout the country. Replies are believed to represent a cross-section of well-informed users, manufacturers, maintenance engineers, and corrosion engineers involved in protecting plants, bridges, and other steel structures. Some of

the results were as follows:

1. Polyamide epoxy is preferred somewhat over the polyamine or the polyamine adduct; most results were reported as excellent or good.

2. Most users felt that either a guide or a performance-composition specification is needed for intelligent purchasing.

3. Except for specialized severe requirements, good reports were obtained, emphasizing need for good application.

Ninety-three comments were received on specific experience and desired improvements.

STEEL FABRICATORS

Many of the steel fabricators interviewed have developed a capability for blast cleaning all or a part of their structural steel production. Some of the larger shops have installed rotary blast-cleaning equipment, through which most of the plates and structural shapes are routinely passed before fabrication is begun. Those who can afford the space and money have found greater uniformity in painting, as well as cleaner steel and fewer weld rejections. The out-of-pocket charges can be low inasmuch as the principal expenses consist of amortization, interest on investment (real estate and equipment), maintenance, and other charges directly related to fixed investment.

A single coat of primer, some fabricators find, is erroneously expected to protect steel work for an indefinite period. Another problem is counteracting the temptation to use fast-drying synthetic resin primers on hand-cleaned steel surfaces. Because these products have poor ability to wet the surface, premature failures often result. Other difficulties were attributed to the lack of good inspection in field painting, resulting in thin, uneven paint films.

At present, contact surfaces of high-strength bolted joints are not ordinarily painted, but the possibility of using suitable protection will be under intensive study.

The American Institute of Steel Construction is providing guidance on practices on many matters, such as proper use of high-strength low-alloy steels, design to minimize corrosion, and maintenance.

U.S. GOVERNMENT AGENCIES

Informal interviews were held with representatives responsible for the painting of structural steel for such agencies as the Bureau of Public Roads, Bureau of Ships, Bureau of Yards and Docks, Air Force, Corps of Engineers, Maritime Administration, General Services Administration, and NASA. Two conferences were also held with the contractor preparing a Defense Department painting manual to be used by the Army, Navy, and Air Force. Conclusions and recommendations are incorporated in this report.

SSPC SEMINAR

Two discussion periods on highway structural steel painting problems were attended by approximately 40 SSPC Research Committee members, including highway engineers, steel producers, fabricators, contractors, raw material suppliers, paint manufacturers, corrosion engineers, government representatives, maintenance engineers, and others specializing in the painting of structural steel.

These discussions confirmed or modified many of the recommendations from this study, and called attention to concepts that might otherwise have been overlooked, including (1) the great difficulty or impossibility of obtaining meaningful historical information on existing bridges; (2) the need for much more than a 1-yr study, which would leave many questions unanswered; (3) the value of suggesting fruitful areas for further research; (4) the possibility of a statistical evaluation of a large number of paint systems on new bridges; (5) the occasional need to purchase within-the-state materials; (6) the need to uncover failures as well as good case histories; (7) the existence of critical areas under leaking joints; (8) problems resulting from increased use of de-icing salts; (9) adaptation of the *Steel Structures Painting Manual* for highway use; (10) the impracticality of having 75 different primers in use by the states; (11) the need for an impartial agency for information; and (12) the need of supporting recommendations by case histories.

Many specifications writers are not versed in paint and should benefit by case histories, interviews, and basic data obtained on a survey of this kind.

APPENDIX C

PAINT FILM THICKNESS MEASUREMENT

IMPORTANCE

A critical review of the painting of highway structural steel showed that the film thickness is frequently more important than the types of coating selected. Thickness is a direct measurement of the total quantity of solid protective barrier purchased, and directly related to the adequacy of application. Furthermore, the increased use of blast clean-

ing has introduced an unknown effect on the amount of paint required to provide a given measured film thickness, on the optimum thickness required, and possibly on the measurement procedures. At the same time, if these effects were more thoroughly understood, blast cleaning could make film-thickness specification a more practical requirement.

Because there was a dearth of information on the proper measurement of film thickness and the effect of profile on paint consumption, a small extension in time (within the funds already appropriated) was requested and approved in order to investigate these film-thickness effects.

An intensive investigation of film thickness was not necessary or possible in the time available. It was hoped, however, that immediate needs could be answered, and a basis provided for future studies that might be advisable.

INSTRUMENTS TO MEASURE FILM THICKNESS

The most commonly used instruments of measuring dry paint film thickness on steel—the Elcometer, the Mikrotest, and the General Electric (G. E.) thickness gages—are all based on an electromagnetic induction principle. Some states and other users employ the roller or prong gages to measure wet film thickness at a time in the painting schedule when any deficiencies can be promptly and inexpensively corrected. Unfortunately, the wet thicknesses cannot be rechecked later for verification under a contract. (Wet thickness was found to have another serious defect, as described herein.) The Tooke gage also effectively measures paint film thickness. Its use involves scratching through the paint film at an oblique angle and examining the resultant section under magnification. Figure C-1 shows some of the commonly used gages.

Paint consumption, accurately measured, also indicates with considerable precision the thickness of wet or dry film applied over a smooth surface. Although it is useful to the user and to the researcher, this method cannot be considered amenable to normal inspection procedures.

A number of other instruments are used less frequently for the measurement of paint film thickness on iron or steel; these were not investigated. They include the Beta-ray back scattering device; the Tinsley gage (magnetic); the eddy current method; the inductance method; the Gardner gage; the Pfund gage; and the penetration gages. The Beta-ray back scattering device and the eddy current instruments tend to measure the weight of coatings rather than their thickness. They usually require separate calibration for coatings of different compositions, or even for different methods of application.

Methods that were used merely for comparative purposes included weight of film; micrometer measurement of steel before and after painting; stripping of film; and the scotch-tape peeling method. These methods were used chiefly in the laboratory portion of this project.

RESEARCH PLAN

In this preliminary investigation, no attempt was made at an exhaustive study of all phases of film-thickness measurement. Instead, effort was concentrated on obtaining tentative answers to a few practical questions which must be answered as a part of any definitive recommendations on the use of protective coatings for steel. These include the following:

1. What is the effect of paint film thickness upon paint durability?
2. What is the effect of surface profile upon paint consumption?
3. What is the true relation between wet and dry film thickness?
4. What are some of the advantages and disadvantages of the film-thickness measuring devices?
5. What are the proper methods of using these devices?

EFFECT OF THICKNESS ON PAINT LIFE

Perhaps the most remarkable data on the effect of thickness on paint life is that developed in 1968 on a study jointly reported (published June 1969) by the Federation of Societies for Paint Technology and the SSPC. One of the results of this study is illustrated in Figure C-2, which shows paint life as a function of coating thickness for two paint systems—an oil base and an alkyd. From this it is evident that each additional mil of paint thickness added, on the average, 20 months of useful life to each paint system in each of three widely different environments. In addition, this study indicated the existence of a critical threshold of paint film thickness necessary for long life for any one paint system in any given environment.

This and other studies tend to emphasize the importance of obtaining proper paint film thickness and the necessity of having reliable methods for measuring it.

PROFILE DEPTH VERSUS PAINT CONSUMPTION

The Problem

Each of the modern synthetic paint systems requires its own type of surface preparation, frequently by blast cleaning, to a given depth of profile. This study attempted to determine the order of magnitude of the additional amounts of paint required to fill in various typical profiles obtained by grit blasting with G18, G40, and G80 steel grit, comparing these with the theoretical consumption and the consumption over smooth surfaces.

Techniques

A complete weight balance and a paint solids balance were made on all painted panels (using a special Seederer Kohlbusch balance) before application, during drying, and after curing.

Profile measurement was made by a special technique developed by the SSPC in which peaks and valleys were measured to the nearest 1/100 mil (microscopic method) with only 0.25 mil traverse between readings. The trace provided by this method is considerably more detailed and accurate than that provided by the usual stylus type of instrument.

Measurements were made to indicate the order of magnitude of extra paint required to achieve a given paint

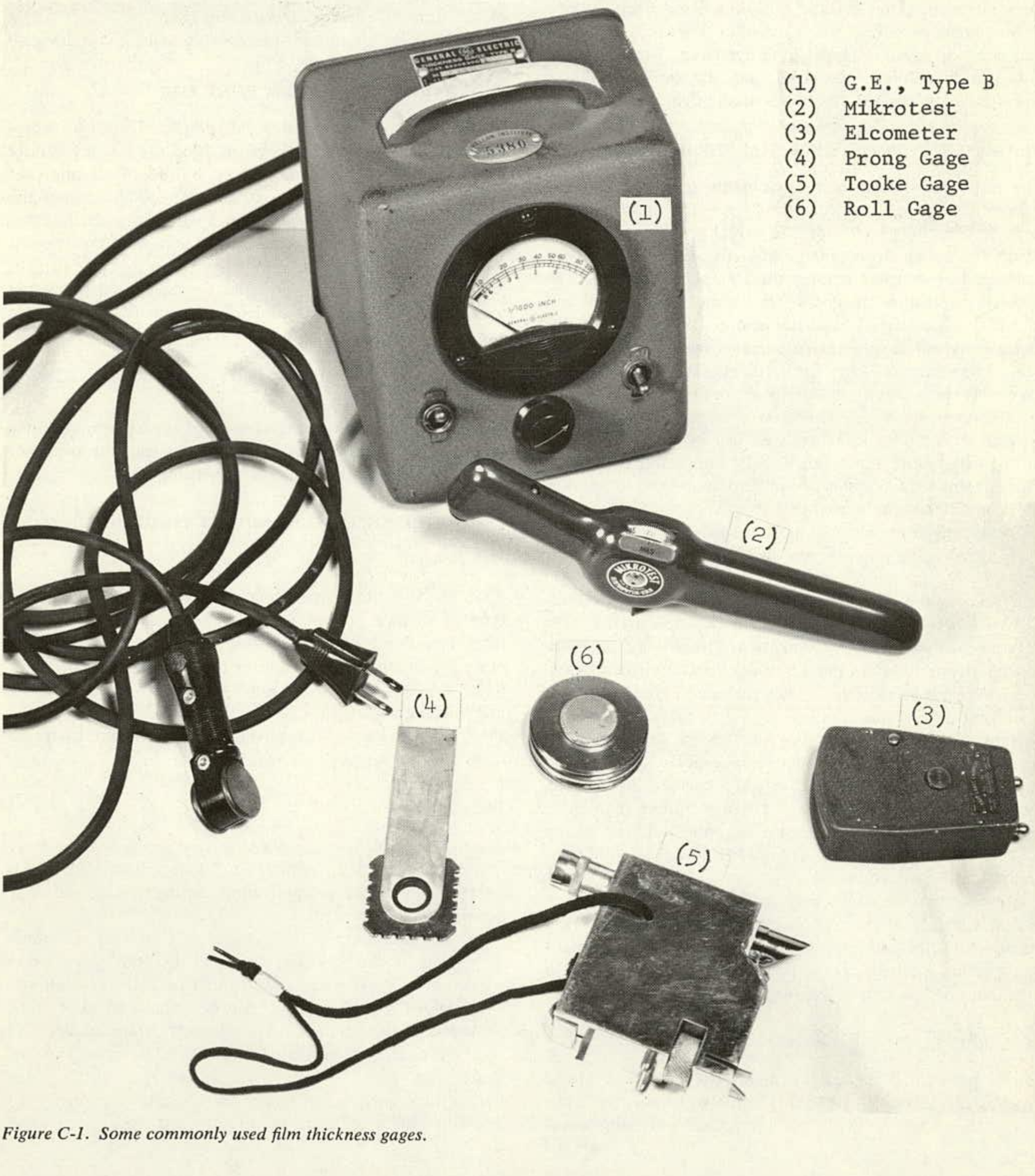


Figure C-1. Some commonly used film thickness gages.

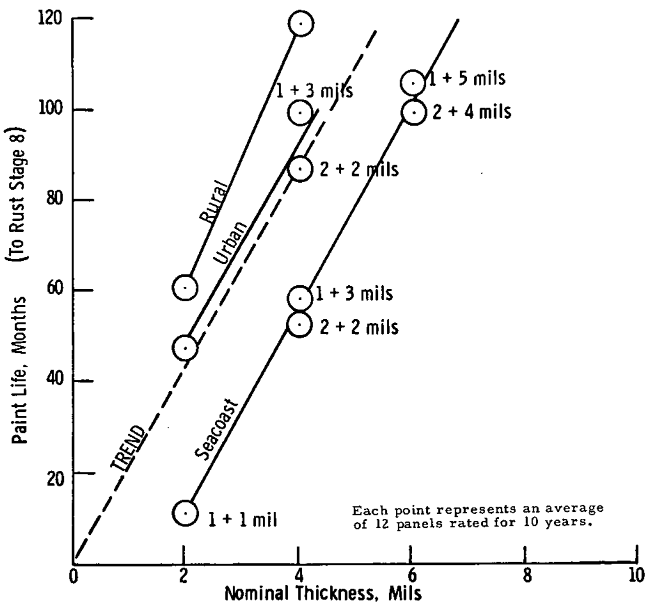


Figure C-2. Average paint life vs thickness (oil and alkyd paints).

film thickness over blast-cleaned steel, in comparison with the amount required to achieve the same film thickness on a smooth surface.

Twelve 4 in. x 12 in. x ¼ in. steel panels were used in this test. Panels 1, 2, and 3 were smooth steel with a maximum profile of less than 0.1 mil. Panels 4 through 12 were standard intact mill scale carbon steel.

Each panel was weighed on an analytical balance to 1 milligram. Next, panels 4 through 12 were grit blasted to white metal at 90 psi: G80 grit was used on panels 4, 5, and 6; G40 on panels 7, 8, and 9; and G18 on panels 10, 11, and 12.

Panels 4 through 12 were weighed again to determine the amount of steel lost due to blast cleaning. Next, all panel thicknesses were measured with a micrometer, averages being taken over the entire surface. All of the panels were then painted with the same paint (SSPC-Paint 1-64, "Red Lead and Raw Linseed Oil Primer") and left to dry. After a 1-week drying period they were weighed and their thicknesses were measured again. The theoretical thickness was calculated as follows:

$$T_T = W/(A \times D) \qquad \text{(C-1)}$$

in which

T_T = theoretical paint thickness;
W = weight of paint on panel;
A = area painted; and
D = density of the paint.

The amount of paint lost because of the profile can be found by

$$V_L = (T_T - T)\,A \qquad \text{(C-2)}$$

in which

T = actual paint thickness; and
V_L = volume of paint lost due to profile.

Results

It was found that the amount of paint that would give a film thickness of 2.7 mils on a smooth surface would result in a measured film thickness (above the peaks) of only 1.5 mils on a grit-blasted surface (G80 grit).

Figure C-3 shows that 1 to 3 gal of paint are required to fill in the valleys of grit-blasted steel per 1,000 sq ft of surface, resulting in substantial additional cost beyond that which would be required on smooth steel. Still greater losses occur if coarser grit is used, as shown in Figure C-3. (It is believed that the loss in thickness would be somewhat less if medium or fine sand were used. This effect should be measured.)

WET VERSUS DRY FILM THICKNESS

The Problem

Some states specify wet film thickness because it allows prompt correction of any oversights, defects, or deficiencies during the course of the shop or field painting. Like the electromagnetic methods, the wet measurements tend to show the thickness above profile peaks.

Although time precluded the writing of an extensive report on the relationship between wet and dry film thickness, it was possible to obtain some guidance in the selection between these two basic methods of specifying the amount of paint to be applied.

Techniques

The object of this test was to determine the correlation between wet and dry film thicknesses of paint on steel surfaces.

Two different types of paint were used: SSPC-Paint 106 (Black Vinyl), 47% solids by volume; and SSPC-Paint 104, Type I (White Alkyd), 13% solids by volume.

Each paint was used on two different panels. The method of procedure of this test was as follows:

1. Two steel panels of known surface area were cleaned with solvent and weighed on an analytical balance.
2. A cup of thoroughly mixed paint and the brush to be used in the test were weighed.
3. Paint was brushed on one of the panels, and the cup and brush were weighed again.
4. After 1 min the panel was weighed, with successive weighings at 6, 10, 20, 30, 60, and 120 min.
5. This procedure was carried out on each paint.
6. Calculation: If the percentage of volatiles and the density of the volatiles in the paint are known, the contribution of the volatiles to the wet film thickness at any time is found by the equation:

$$T_V = \frac{W_V}{A\,D_V} \qquad \text{(C-3)}$$

in which

T_V = wet film thickness due to volatiles;
W_V = weight of volatiles;
D_V = density of volatiles; and
A = surface area of painted panel.

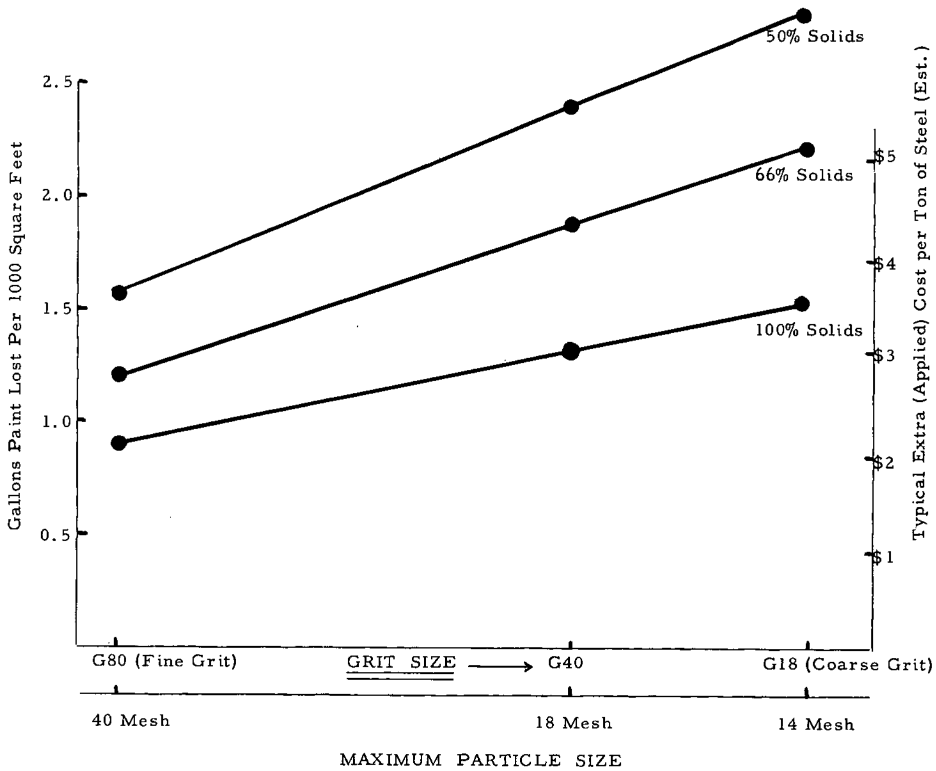


Figure C-3. Estimated paint required to fill in valleys of blast-cleaned steel.

The wet film thickness at any time during drying is obtained by adding the contribution of the solids and volatiles together.

Results

Wet film thickness began to drop sharply immediately after application, and thereafter approached the dry film thickness during the next period of minutes or hours. For the first hour the measured wet film thickness, T_W (mils), of the vinyl paint decreased rapidly with time, θ (min), according to the following approximate relationship:

$$T_W = 6.7 \text{ mils} - 3.4 \log \theta \qquad \text{(C-4)}$$

Thus, an initial wet thickness of about 10 mils decreased to less than 7 mils the first minute, and less than 4 mils in 10 min. After 60 min, the wet film thickness had dropped to 1.3 mils, which was approximately equal to the dry thickness. Further shrinkage appeared to be negligible.

Within the time range of 0.1 min to 100 min, the rate of reduction in paint film thickness for the oil-base paints was much lower than for the vinyls, as indicated by the following:

$$T_W = 3.6 - 0.8 \log \theta \qquad \text{(C-5)}$$

Therefore, wet film thickness correlates well with dry film thickness only for the first few seconds and on films that have little or no volatile thinner, in which case the following conversion is used:

$$T_W = T_D(100/V) \qquad \text{(C-6)}$$

in which

T_W = wet film thickness;
T_D = the desired dry film thickness; and
V = percentage solids by volume.

It was found, however, that this simple formula is seldom accurate with the majority of structural steel coatings, which contain appreciable amounts of highly volatile thinners that evaporate rapidly from the wet film. By the time the wet film thickness gage is read—a few seconds or minutes after application—much of the thinner has exaporated, giving a thickness reading somewhat intermediate between the original percentage solids and 100% solids. Furthermore, additional thickness change is believed to occur during the drying or curing process.

Further work should be done to establish whether there is a way of obtaining an immediate film-thickness measurement which is meaningful and not misleading.

TYPICAL CALIBRATION CURVES

Calibration curves were prepared for randomly selected models of the three most frequently used magnetic dry film thickness gages—the Mikrotest, the Elcometer, and the G.E.

The curves shown in Figure C-4 were prepared by using shims of known thickness. The Mikrotest is factory precalibrated, and was found to have its most accurate readings in the 5- to 6-mil range. For comparison, the other two gages were therefore calibrated in this range. Both the

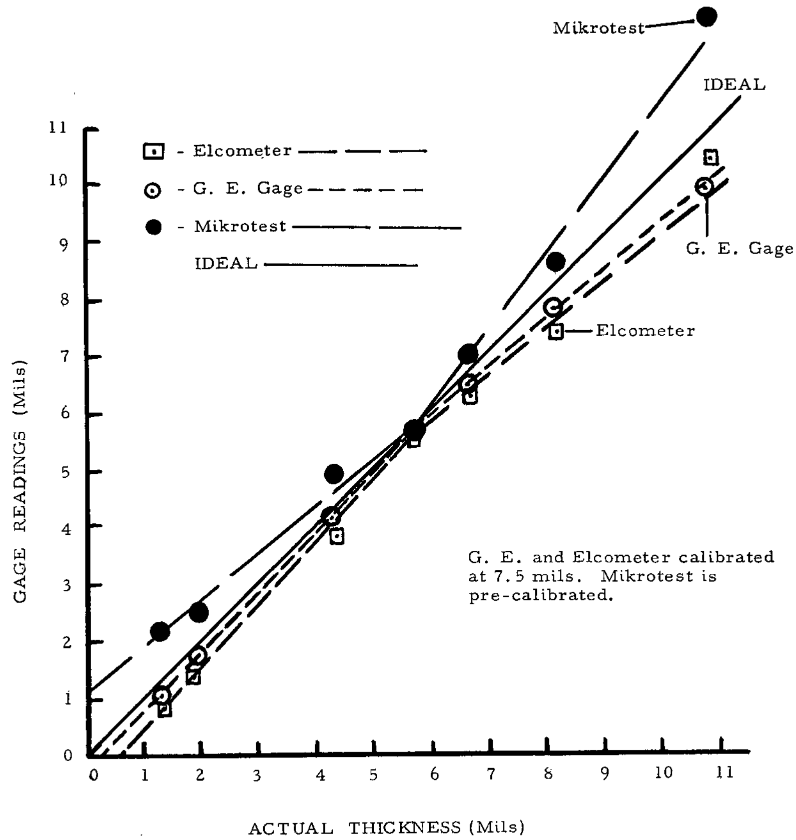


Figure C-4. Calibration of some magnetic dry film thickness gages.

Elcometer and the G.E. were found to have essentially a straight-line calibration curve, whereas the Mikrotest did not, thereby introducing an error when several Mikrotest readings are to be averaged.

The pre-calibrated Mikrotest readings were high at both the thin and thick film ranges. The other two can be calibrated to read relatively accurately in any given range, but they require a "zeroing" procedure which some operators consider tedious. (The Mikrotest can also be recalibrated to read accurately in the high or low range, but this is difficult.)

Another disadvantage sometimes cited is that the Mikrotest tends to give erroneous readings if any vibration is present (as on bridges), or if the operator's hand is unsteady. However, it is occasionally claimed that some operators have been unable to obtain reproducible duplicate readings using the Elcometer.

With most of the instruments calibrated on a blast-cleaned surface, the test measurement subsequently obtained was generally thickness of coating above the high point of the blast pattern and was not the same as the reading obtained if the same amount of liquid paint was applied to a smooth non-blasted surface.

This preliminary work indicated that electromagnetic film gages, if properly calibrated with a shim, tend to read the thickness above the peaks. Within normal ranges, other factors such as the steel thickness, steel composition, and coating composition have only minor influences on thickness measurements, compared with the effect of surface profile, zeroing procedure, and under-film rust, particularly in measuring films of 1 mil or more in thickness, as customarily used on structural steel.

Because there have been some deviations between instruments of the same type, further work should be done to spot-check a large number of instruments of each type.

The Elcometer has the advantages of compactness, ruggedness, and simplicity. However, like other valuable gages it requires careful calibration. Complaints have been received of low readings due to unwanted penetration of electrodes into soft films. It is believed that this instrument tends to give a film-thickness reading about equal to paint thickness over the great majority of peaks of the profile.

The G.E. Type B gage requires a 110-volt current source and warm-up period. It tends to include in its measurement some portion of the film below the maximum profile. Wet film thickness gages also tended to indicate the thickness over the great majority of the peaks of the profile. The micrometer method in the *Steel Structures Painting Manual* (Vol. 1, p. 139) is usually applicable only in the laboratory or on small pieces, whereas the scotch-tape method is applicable only to coatings which can be removed from the surface with tape.

PROPER USE OF THICKNESS GAGES

Some information on the proper use of thickness gages is available from existing sources, particularly the SSPC *Manual* (Vol. 1, pp. 122-124, 139). Considerable information is available from the manufacturers, ASTM committees, the experiences of the individual states, and SSPC members who must use these methods regularly.

Instructions are given here for use of the six principal types of film-thickness gages commonly used:

1. Tooke gage (scratch type).
2. Elcometer (magnetic).
3. G.E., Type B gage (magnetic).
4. Mikrotest gage (magnetic).
5. Roll gage (wet thickness).
6. Prong gage (wet thickness).

Dry film thickness gages fall into two broad classifications:

1. Non-destructive.—Two principal gages of this type are (1) the magnetic type described herein (used only to measure non-magnetic coatings on ferrous substrates); and (2) the electronic or eddy current type (used on any substrate, provided that either the substrate or the film is metallic). With the non-destructive-type gages, film thickness can be measured without harming the film.

2. Destructive.—These gages are so termed because the film must be broken to make measurements.

Tooke Gage

The Tooke gage (Fig. C-5) is an invaluable aid in a wide variety of coatings problems, particularly in the inspection of multi-coat paint systems. Because it is a scratch-type gage, it is slightly destructive, and the coating must be repaired after its use.

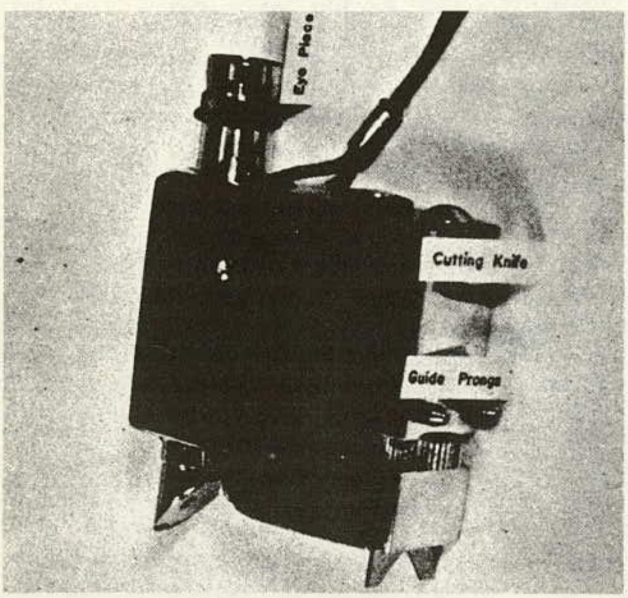


Figure C-5. Tooke gage.

Scratch-type gages operate on the principle of cutting the coating film at a predetermined angle, normally 45°; magnifying the view of the cut; and comparing the cut edge of film to a calibrated scale viewed in the eyepiece. For 45° triangles (as shown in Fig. C-6), A is equal to B. The thickness of the prime coating therefore can be determined by measuring the length of B.

To determine film thickness with the Tooke gage, place it on the surface so that the cutting edge or knife and the two guide probes are in contact with the surface. Press the cutting edge into the coating until the cutting edge touches the metal substrate and pull the gage to produce a cut, ½ to ¾ in. long, in the coating. Maintain continuous three-point surface contact while cutting. Remove the instrument and place it on the surface, with the viewing piece over the cut. Turn on the viewing light. View the cut through the eyepiece. Adjust the focus with the focus knob. Locate the gage so that any long line of reticle coincides with the top, left edge of the cut. Count the number of divisions from the left edge of the cut to where a division appears to coincide with the lower surface of the paint film being measured. The number of divisions counted will equal the film thickness in mils. After the thickness is determined, turn the viewing light off and repair the cut in the coating.

The Tooke gage is an indispensable tool when multiple coats at specified thickness are used because the thickness of each coating can be determined, provided there is a color contrast between coatings. The Tooke gage also provides a visual means for verifying the accuracy of other types of dry film thickness gages.

Elcometer Gage

The Elcometer gage is for use only on ferrous (iron and steel) surfaces and measures the thickness of non-magnetic coatings which have been applied over the bare material. In cases where metallic coatings of non-magnetic material have been applied (for example, galvanized iron), the gage will include the thickness of non-magnetic material with paint thickness. In such cases as painting galvanized iron, the gage is first used to establish the average thickness of zinc prior to painting; this thickness of non-magnetic metal (zinc in this case) is then subtracted from all gage readings made on paint films applied over the galvanized iron.

Before this meter is used it should always be calibrated in the following manner. Place brass shims of known thickness, approximately equal to that of the expected film thickness, on an uncoated base of similar type and thickness as will be met on the job. Holding the instrument at right angles to the surface, place the two contact spheres firmly on top of the shim and depress the pointer locking button. Set the scale pointer to the correct reading by rotating the zero adjusting knob, while keeping the pointer locking button depressed. Release this locking button before removing the instrument from the surface. This method is more accurate than setting the meter to zero on a bare base. It also tends to eliminate errors due to profile depth of blast-cleaned steel.

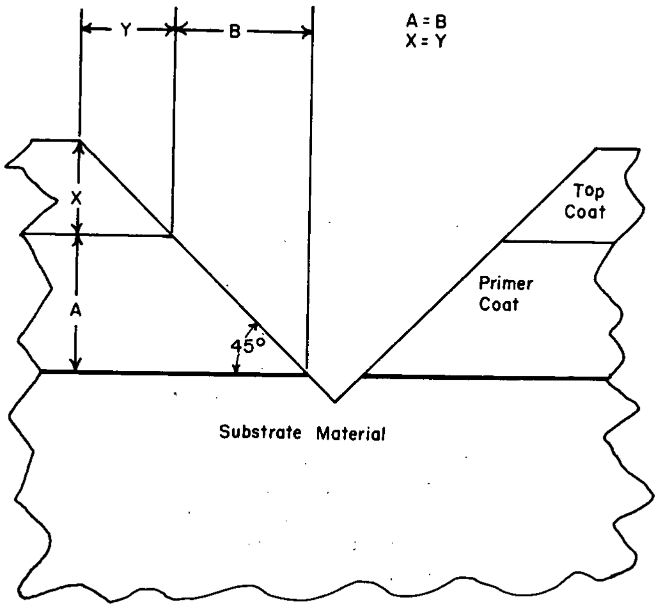


Figure C-6. Cut made by Tooke gage.

When this calibration has been made, the meter is ready for use. Place the spherical tips on the surface to be measured and depress the pointer locking button. When the pointer comes to rest, release the pointer locking button and read the appropriate scale (usually the black scale, which reads in mils). The needle motion can be damped, increasing the speed with which the needle comes to rest, by repeatedly depressing and releasing the pointer locking button.

The meter can be used in any position, so long as the contacts are at right angles to the surface. Measurements can be made after a little experience when the scale is obscured from view, because the pointer locks at scale reading and can be brought into position for reading.

Small pieces, coated on one side or both, should be placed on a soft iron plate for readings.

If the base is magnetized, or when using instruments scaled above ¼ in., take the average of two readings at the same point, the second taken after turning the meter through 180°.

Like any precision instrument, this gage will be damaged by dropping. Avoid depressing the pointer button except when calibrating or taking measurement, because the pointer will fly against limit stops when no magnetic circuit exists between spherical tips.

Keep the gage clear of any strong magnetic fields at all times. Never lay the gage on a metal bench, shelf, desk, transformer, or machinery, or near other sources of strong magnetic fields. This will ruin the gage.

When calibrating the Elcometer, it is recommended that the operator use a calibration shim within 50% of the target value. For example, use a 0.002-in. (2-mil) shim when calibrating the gage for use on films ranging from 0.001 to 0.003 in. (1 to 3 mils).

The Elcometer will measure erratically over hard tempered steels that retain induced magnetism, and over nickel. It will not measure at all over stainless steel.

G. E. Gage

The Type B General Electric thickness gage consists of a gage head, a control unit, and suitable leads. It is used primarily for measuring the thickness of paints, enamels, heaving platings, bearing linings, and other non-magnetic coatings on magnetic steel parts. The standard scale range of this gage is 0.0001 to 0.100 in. However, it can be supplied with a special scale range which is extended to 0.3000 in. for non-metallic coatings only. For metallic coatings, the range can be extended to a value somewhere between 0.1000 and 0.300 in., depending upon the resistivity of the metal.

Because the magnetic field set up by the gage head spreads out beyond the poles, a surface area somewhat larger than that necessary to support the gage head is required. If the area is not large enough, or if the gage head is placed too near the edge of the surface, errors in reading may be encountered.

Certain steel base materials may exhibit a "grain effect" magnetically. If the gage head is so placed on the surface that its axis is parallel to the direction of the grain (i.e., the direction in which the steel was rolled), the reading may be different from that obtained when the axis of the gage head is at right angles to the grain. This effect is usually negligible, but, where it is noticeable, it can be reduced by using the gage head in the same position on both the reference sample (on which the gage is adjusted) and the coated part.

After a warm-up period of approximately 15 min, the gage is usually adjusted to the base metal as follows:

Select the proper scale range for the estimated thickness by using the scale-selector switch. Insert the standard nearest the estimated coating thickness between the uncoated specimen and the gage head. Adjust the rheostat until the instrument pointer indicates the known thickness of the standard. The gage is ready for use and will have a range of ± 50% of the value of the thickness standard used to calibrate the gage. For example, if a 6-mil standard is used to calibrate the gage, the resulting range will be 3 to 9 mils. It should be readjusted if the scale range is changed.

If the magnetic properties of the coated and uncoated specimens are different, or if an uncoated specimen is not available, the gage can be adjusted as follows:

After the proper scale range has been selected, place the gage head on the coating and note the instrument reading. Insert a suitable thickness standard between the coating and the gage head. If the new reading of the instrument is not equal to the original reading plus the thickness of the standard, adjust the rheostat until the instrument indicates the anticipated value of coating thickness plus standard. Repeating this procedure two or three times will adjust the gage correctly for the particular base metal.

The standard scale can be used with any of the following base metals, provided a correction curve is used: high-carbon steel, alloy steel containing nickel or chromium, low-carbon steel less than 0.010 in. thick, or surfaces where the radius of curvature is less than 3 in. if concave, or 1.5 in. if convex.

Mikrotest Gage

The Mikrotest gage (Fig. C-7) is a permanent magnet-type, magnetic, non-adjustable gage. The Mikrotest utilizes one contact probe and measures the magnetic flux between this probe and a ferrous substrate by means of a balanced mechanism. Because of this balanced mechanism principle of operation and permanent calibration, an uncalibrated Mikrotest will produce accurate measurements only for coatings on smooth steel. Surface irregularities and surface preparation will influence the accuracy of thickness measurements.

Film thicknesses for coatings on smooth steel are measured as follows:

1. Turn dial to maximum reading.
2. Place contact probe on surface to be measured and depress pin in handle.
3. Slowly and as continuously as possible, rotate dial toward decreasing thickness (clockwise) until magnetic contact breaks. At this point, a click will be heard and pin will drop. The coating thickness can then be read on the dial indicator.

For coatings on rough steel, such as sandblasted steel, the Mikrotest must be corrected for accurate measurement as follows:

1. Locate an uncoated area or produce such an area by removing coating with stripper or by subjecting a similar piece of steel to like surface preparation.
2. Place a shim of known thickness (approximately the same thickness as that of coating to be tested) on uncoated area.
3. Make film-thickness measurement of shim according to procedure for smooth metal.
4. The difference in shim thickness and Mikrotest reading is the correction factor for the chosen film thickness. For example, if a 3-mil shim is used and the Mikrotest indicates 3.75 mils, subtract the difference (0.75 mil) from Mikrotest reading to obtain correct thickness.

Caution: because the Mikrotest gage is permanently calibrated, it should be checked periodically for accuracy when used on smooth steel by using the procedure outlined for sandblasted steel.

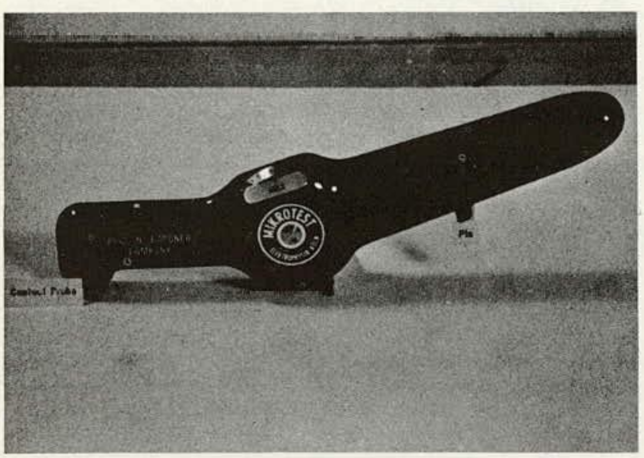


Figure C-7. Mikrotest gage.

Roll Gage

The roll-type gage has three tracks or bearing surfaces machined on the cylindrical surface (see Fig. C-8). The outside tracks form a reference plane with the substrate. The inside track is so machined that its relation to the outside tracks forms a cam. At one point, all three tracks are in the same plane, which becomes the reference point of no film thickness. Exactly opposite from the zero point, the plane of the inside track is at its greatest distance from the plane formed by the outside tracks. This distance is equal to the maximum, measurable film thickness. Recesses are machined on each side of the inside track to minimize change in coating thickness caused by carry over or flow of paint caused by track movement. Owing to the geometric relation of the tracks, two identical measuring sides are available. The distance in thousandths of an inch between the planes formed by the outside tracks and the inside track is stamped on the side at approximate intervals. Roll-type wet film gages are available in various film-thickness ranges.

To determine wet film thickness with the roll-type gage, place the point of the gage registering maximum film thickness adjacent to the surface. Holding the gage between thumb and one finger, roll the gage along the substrate until the point of gage reading zero is adjacent to the surface. Maintain the outside tracks firmly against the substrate surface during the rolling process. Remove the gage from the surface and observe the point at which the inside track began to continuously pick up paint. This point indicates the wet film thickness. Calibration figures on the side of the gage show film thickness in mils. On curved surfaces, roll the gage along the curvature.

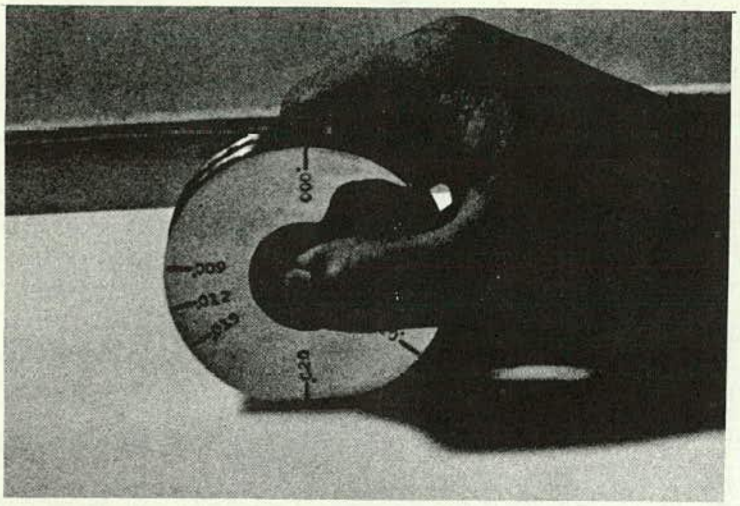
Remove all paint from the gage after each measurement by wiping with a soft rag or paper towel. During measurements, the inside track must be free of oil, grease, and similar materials that will hinder the adherence of paint to the track. Because the outside tracks are close together, wet film thickness determinations with the roll type gage are quite accurate.

Prong Gage

The prong-type gage (one kind is shown in Fig. C-9) is quicker and easier to use than the roll-type gage, but it usually is not as accurate for films below 6 mils. Excessive distance between the outside (reference) prongs limits the effectiveness of the prong-type gage when used for thin films.

The two outside prongs form a reference plane. The inner prongs are machined to various distance variations from this reference plane. The distance or gap between the prongs and reference plane is marked on the prongs in either mils or thousandths of an inch.

To determine wet film thickness with the prong-type gage, hold it firmly by the handle. While maintaining the gage perpendicular to the surface, press both side prongs firmly against the substrate. Maintain the gage perpendicular to



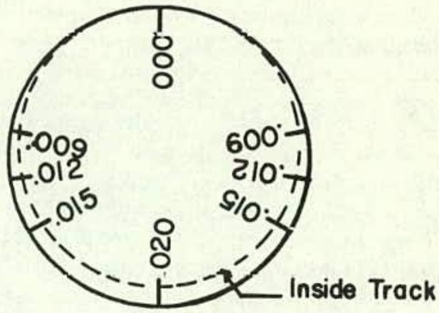


Figure C-8. Roll gage.

the surface during removal. Observe the tips of the measuring prongs. If the face of a prong is partially coated with paint, the marking on that prong indicates the thickness of the coating. If a prong is completely coated and the next prong is not coated, the thickness lies between the thicknesses indicated by these two prongs. An uncoated prong between coated prongs indicates poor technique or non-uniform film thickness. Presence of oil, grease, and similar materials that hinder adherence of coating to the gage will cause erroneous readings. If all the prongs are coated, switch to a higher-scale gage. If none of the prongs is coated, switch to a lower-scale gage. Be sure to remove paint from the prongs after each measurement.

On curved, cylindrical surfaces, the prong-type gage must be so placed that its major axis is at right angles to the curvature.

NEED FOR FURTHER WORK

Many states omit all film-thickness requirements from their specifications because they are not satisfied that available gages are reliable, or that their proper use can be justified.

Some errors encountered by the SSPC have been traced to pressure on a newly dried film tending to give too low a reading. An error also can result from the manner in which the shim is oriented on the test surface when zeroing the instrument. An error is inherent if the instrument is zeroed on de-scaled steel and used to measure paint film thickness over mill scale. An even greater error is traceable to calibration of the instrument over smooth steel and subsequently measuring the paint film thickness over blast-cleaned steel. For each instrument, the number of readings that are necessary to obtain a sufficiently accurate average on various types of steel should be indicated.

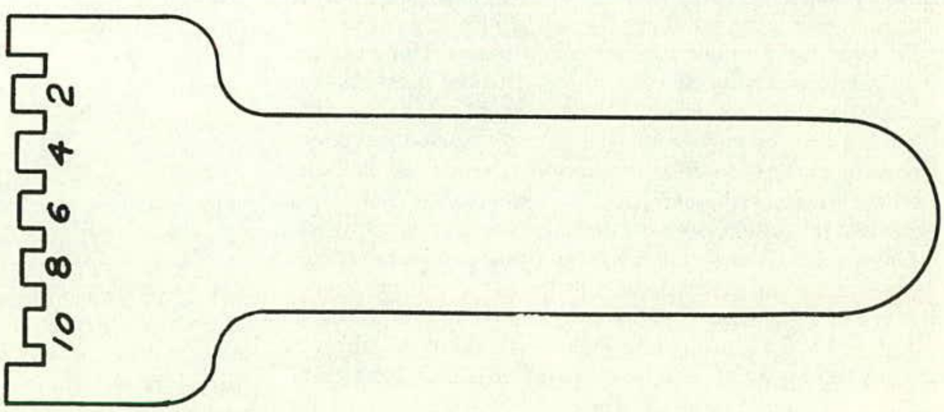


Figure C-9. Prong gage.

It is proposed that further work be done on aspects of the proper use of the principal instruments. Several of the limitations and peculiarities of existing instruments, as described and illustrated in this chapter, suggest such work, including the following:

1. It is recommended that a specification similar to the SSPC surface preparation and paint application specifications be considered. In spite of the limitations of present instrumentation, it is believed that film-thickness measurements can be made sufficiently reliable to warrant their inclusion in this type of specification. Such standards, guides, or specifications are necessary to insure that all concerned have a proper understanding of the limitations and proper use of these devices.

2. Additional information should also be presented on other aspects. For example, it is important to know (1) how to allow for the effect of mill scale (particularly with electromagnetic gages); (2) how to avoid edge effects during measurements; (3) how to recognize and compensate for possible residual magnetism from welding, power lines, etc.; and (4) what allowance must be made for existing profile depths, as well as the effects of surface cleanliness.

3. Statistically significant numbers of each type of commercial gage should be calibrated to determine the expected accuracy and reliability of each.

4. Further information should be developed on the effect that other types of roughness due to sandblasting, shot blasting, and hand cleaning have on paint consumption.

5. Further guidance is needed on what techniques, if any, can be developed to make wet film thickness meaningful.

6. Further data are needed on the effect of paint film thickness upon paint life.

These means for improving the use of present gages are relatively straightforward and vitally important. Such a study should result in improved painting quality and effectiveness of inspection, and lower costs.

APPENDIX D

COSTS—EVALUATION OF PAINTING ALTERNATIVES

PAINTING COSTS—A NEW APPROACH

Many attempts have been made to adapt theoretical cost analysis techniques to the problem of choosing among alternate paint systems for the protection of steel structures. Among these are the discounted cash flow approach, capitalized cost method, pay-back time, calculated risk, net present value of alternative costs, return on incremental investment, and equivalent uniform annual cost.

Among conventional methods, one of the simplest and best adapted to paint problems is shown in Figure D-1. Cumulative costs per unit area are plotted against elapsed time for the presumed life of the structure (for example, 30 yr) to compare the costs of two or more paint systems. This hypothetical example illustrates how, in a certain Zone 2 type of environment, it is more economical to use a deluxe paint system (for example, topcoated zinc-rich over blast-cleaned steel) than a cheap paint system, even though the initial cost of the latter is considerably less. Unfortunately, such comparisons usually are drawn after the experience has been obtained.

Another method of obtaining paint costs is shown in Figure D-2. Curve B is calculated to show the effect of paint life on paint costs for a paint system of "moderate" quality (oil-base paint system over carefully hand-cleaned steel). This curve can be drawn with no knowledge of actual paint life, if only the unit cost per square foot of paint, painting, and repainting is estimated for a given locality. As illustrated, this cost will decrease as the assumed paint life increases from 2 to 15 yr, or anything in between for the entire life of the structures (for example, 30 yr).

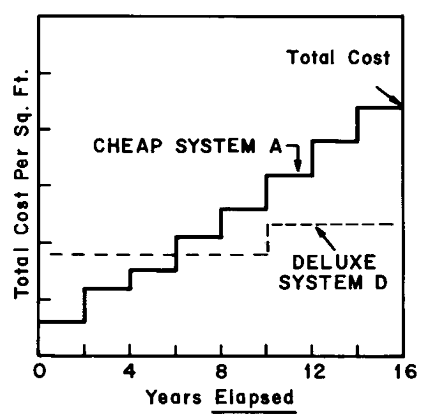


Figure D-1. Cumulative paint cost vs time (in typical Zone 2).

Similar curves, A, C, and D, could be estimated for other types of coatings, based upon the known costs in a particular market area for surface preparation, paint application, and cost of paint (Fig. D-3). Curve A could represent a very cheap system, B an oil-base system over hand-cleaned steel, C a vinyl system, and D a zinc-rich with vinyl finish coat.

Once drawn up, such a set of curves can be useful in choosing the most economical paint system for each zone. For example, assume that "moderate" paint system B is being used, and that an average paint life of 11 yr is being obtained (for example, in a dry rural or urban atmosphere —Zone 1). The horizontal line indicates that a lower cost can be achieved with system A only if it shows a paint life of at least 8 yr. System C would have to show a paint life of at least 15 yr to be comparable in cost, whereas system D does not appear to be economical even if it never requires repainting.

Note, however, that the choice of paint system D could be easily justified over B in a typical Zone 2, provided that the latter was achieving a paint life of 5 yr or less, compared with 8 yr or more for the deluxe paint system D.

These cost curves are illustrative only, because the prices of material and labor will vary from one place to another. To be accurate in comparing widely different methods of protection (for example, conventional paint vs low alloy steel or vs galvanizing), the time value of money should be taken into consideration. The plotted costs should then be expressed on the basis of net present value by capitalized cost, because expenditures at some distant date can be met by setting aside a smaller sum of money today at the assumed interest rate.

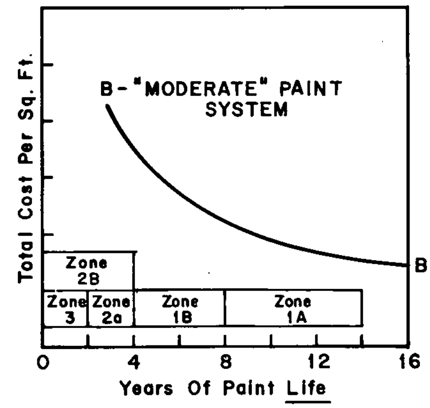


Figure D-2. Cumulative paint cost vs paint life (one paint system).

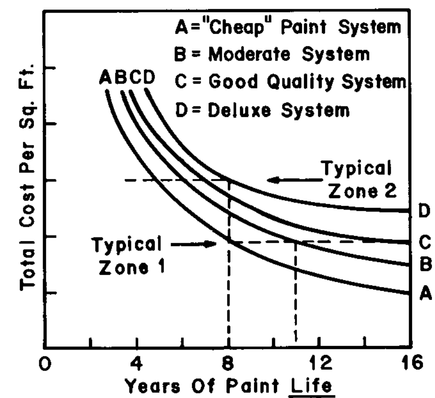


Figure D-3. Cumulative paint cost vs paint life (several paint systems).

APPENDIX E

RECOMMENDED PAINT SYSTEMS

The term "paint system" includes surface preparation, pretreatment, paint application, paint thickness, primer, intermediate coat, and finish coat.

Several important factors should be considered before selecting one or more coating systems for highway structural steel. Until recently, the choice was much more limited, because blast cleaning or pickling, which almost all of the synthetic paints require, were not widely available. During the past generation, the growth of better synthetic paints and the difficulty of getting good hand cleaning have made descaling a more common practice. However, descaling by blast cleaning is not a panacea, and many states that have studied the problem continue to use hand-tool cleaning or power wire brushing.

Table E-1 shows that the relative rate of corrosiveness of atmospheres in which highway structures are located can vary by a thousand-fold.

MILD ENVIRONMENTS

Most bridges in the U.S. are located in mild atmospheric rural or urban environments where good paint life can be obtained over properly hand-cleaned or power-tool-cleaned steel. When the latter methods are used, a linseed oil base paint system is recommended (see Table 3). Some of the alternate types of oil-base primers, intermediates, and topcoats are further discussed in Figure E-1, which is based upon SSPC-PS 1.00. Compositions of the most commonly

used primers are given in Table E-2. Figure E-2 is an example of a typical oil-base system (SSPC-PS 1.01, giving paints, surface preparation, application, film thickness, etc.).

The test work of the SSPC and others has indicated that a 75/25 combination of red lead/iron oxide has excellent weathering characteristics. Recent tests by SSPC and many of the states have shown that basic lead silico chromate is equal to red lead in weatherability. However, red lead requires some alkyd in its best formulations, and could therefore be more susceptible to poor surface preparation. Zinc chromate prevents rust completely for shorter periods, but tends to leach out of the linseed oil vehicle if the primer is exposed by itself for many months before topcoating. Zinc dust/zinc oxide pigmentation is also excellent for hand-cleaned steel as well as galvanized steel.

SSPC-Paint 2, or Michigan Paint 2MP, or Federal Specification TT-P-615b, Type V, are examples of linseed oil formulations containing up to 20% alkyd, which have given excellent results. If surface preparation is adequate, the user gains a somewhat faster drying time and somewhat better moisture resistance, compared with straight linseed oil paints.

Most existing steel structures have been hand cleaned and painted with some type of oil-base paint system. Some of the states continue to use oil-base paints, even after they have adopted blast-cleaned steel, because of their excellent wetting, adhesion, flexibility, and weathering properties. Properly formulated and applied, the film tends to wear away rather than to undercut or to build up excessive thicknesses on repainting.

SEVERE ENVIRONMENTS AND LONG PAINT LIFE

There are many exposures for which hand-cleaned steel or oil-base systems are inadequate and for which synthetic systems should be seriously considered. Table 3 recommends several of these types of paint systems, each having its advantages for specific zones and special uses.

Zinc-Rich Paint Systems

The coatings classified as zinc-rich have grown greatly in use because of their proven effectiveness in high humidity and marine atmospheres, and because of their good abrasion resistance. When properly topcoated, they may be used in fresh- or sea-water exposure; without topcoats they have no resistance to acids or alkalies.

TABLE E-1

RELATIVE CORROSIVENESS OF VARIOUS ATMOSPHERES[a]

Number	Location	Type of Atmosphere	Relative Rating *
1	Norman Wells, N.W.T.	Rural	0.02
2	Saskatoon, Sask.	Rural	0.2
3	Fort Clayton, C.Z.	Tropical jungle	0.4
4	Rocky Point, B.C.	Marine	0.7
5	Potter County, Pa.	Rural	0.8
6	Detroit, Michigan (roof)	Urban	0.9
7	Ottawa, Ontario	Rural	0.9
8	Morenci, Michigan	Rural	1.0
9	State College, Pa.	Rural	1.0*
10	York Redoubt, N.S.	Marine	1.2
11	Montreal, Quebec (roof)	Industrial	1.3
12	Middletown, Ohio	Semi-industrial	1.4
13	New Hampshire Coast, N.H.	Marine	1.5
14	South Bend, Pa.	Semi-rural	1.6
15	Columbus, Ohio (roof)	Urban	1.7
16	New Cristobal, C.Z. (roof)	Tropical marine	1.7
17	Pittsburgh, Pa. (roof)	Industrial	1.8
18	London (Battersea), England (roof)	Industrial	2.0
19	Trail, B.C.	Industrial	2.1
20	Miraflores, C.Z.	Tropical urban	2.1
21	Research Center, Pittsburgh, Pa.	Semi-industrial	2.2
22	Daytona Beach, Florida	Marine	2.2
23	Bethlehem, Pa.	Industrial	2.4
24	Cleveland, Ohio	Industrial	2.4
25	Newark, New Jersey	Industrial	2.6
26	Brazos River, Texas	Marine	2.7
27	Bayonne, New Jersey	Industrial	3.4
28	Kure Beach (800-ft. site), N.C.	Marine	3.6
29	Pilsey Island, England	Marine	4.0
30	East Chicago, Indiana	Industrial	5.2
31	London (Stratford), England	Industrial	6.5
32	Halifax, N.S. (Federal Building)	Marine-industrial	7.3
33	Point Reyes, California	Marine	9.5
34	Dungeness, England	Marine	15
35	Galeta Point Beach, C.Z.	Tropical marine	18
36	Widnes, England	Industrial	19
37	Kure Beach (80-ft. site), N.C.	Marine	33

* Fortuitously, a corrosiveness of 1.0 represented about 1 mil loss the first year. State College, Pennsylvania—Taken As Unity.

[a]Adapted from report of ASTM Committee B-3, Sub VII, for 1-year exposure (1960-61); Materials Research & Standards, December 1961, pp. 977.

Descriptions and Specifications for Some Alternative Oil-Base Paints For Hand-Cleaned Weather-Exposed Highway Structural Steel *

For example of the use of these paints in a paint system specification, please see SSPC-Paint Systems 1.01 through 1.06.

GENERAL DESCRIPTION

Oil-base paint systems are effective and economical for painting weather-exposed structures where unusual factors, such as condensation, chemical fumes, brine drippings and other extremely corrosive conditions are not present.

The oil-base primers are slow in drying, but provide the wetting ability necessary for adhesion to non-descaled steel. A typical system consists of hand-tool or power-tool cleaning, one coat of oil-base primer, one or more intermediate coats, and one finish coat of alkyd or linseed oil paint.

Film thickness for a 3-coat system is usually 4.0 mils, for a 4-coat system, 5.0 mils.

OIL-BASE PRIMERS

Unlike most synthetics, oil-base primers can be applied over properly wire-brushed steel for use in ordinary mild atmospheric exposure. Blast cleaning may be used, however, to extend the life expectancy of paint, especially when the original steel is badly rusted or when the exposure is severe.

SSPC-Paint 14 , "Red Lead-Iron Oxide Linseed Oil Primer".	Because of its all raw linseed oil vehicle and pigmentation with 75% red lead and 25% iron oxide, this primer is considered an outstanding one for non-descaled steel surfaces with respect to surface wetting, rust inhibition, good uncoated primer life and reasonable cost. It requires a drying time of at least 36 hours.
AASHO Specification, "Red Lead Ready-Mixed Paint", Designation M-72-57, Type I" or SSPC-Paint 1 , "Red Lead & Raw Linseed Oil Primer".	This is a straight red lead primer with raw linseed oil vehicle. A heavy duty structural primer with very good wetting properties and excellent rust inhibition. It can be used effectively over surfaces imperfectly cleaned. This primer is very slow drying and is expensive because of the high red lead content.

* Although many states have equivalent specifications, this listing is confined to nationally available public specifications. This table is based upon SSPC-PS 1.00-64T.

Figure E-1. Paints for hand-cleaned highway steel.

AASHO Specification, "Red Lead Ready-Mixed Paint", Designation M-72-57, Type II; or Federal Specification TT-P-86c, "Paint; Red Lead Base, Ready Mixed", Type I, "Red Lead Linseed Oil Paint".	A straight red lead primer with raw and bodied linseed oil vehicle. A structural steel primer with good wetting ability and faster drying than all raw linseed oil; however, drying time is still long.
Federal Specification, TT-P-641c, "Primer, Paint; Zinc Dust-Zinc Oxide (for galvanized surfaces)", Type I, Zinc Dust-Zinc Oxide Linseed Oil Paint.	TT-P-641c, Type I, has proved to be excellent for structural steel as well as galvanized metal. For penetration and adhesion to suspension cables, etc., the first coat of these zinc-dust paints may be thinned as much as 50%. Where protected from severe weathering red lead in rust-proofing grease has been used (see preceding section).

LONG-OIL ALKYD PRIMERS

These primers contain some alkyd resin in addition to their linseed oil content, and may require slightly more thorough hand-tool cleaning or power-tool cleaning, as a minimum surface preparation, than straight oil-base primers.

SSPC-Paint 2-64, "Red Lead, Iron Oxide, Raw Linseed Oil and Alkyd Primer".	A red lead and iron oxide primer with 2 to 2.5 parts linseed oil to one of alkyd. An excellent general-purpose heavy-duty primer for structural steel with good wetting ability and with somewhat reduced drying time due to the alkyd content. The steel surface must be well-cleaned. The iron oxide content gives it good weathering ability.
Federal Specification TT-P-57b, "Paint, Zinc Yellow-Iron Oxide Base, Ready-Mixed", Type I. Zinc Yellow-Iron Oxide-Alkyd Varnish-Raw Linseed Oil Paint (50/50 Raw Linseed Oil-Alkyd Resin).	Yellow iron oxide and zinc chromate primer with 50/50 raw linseed oil-alkyd vehicle. Slow to semi-quick drying.
AASHO Specification, "Zinc Chromate-Iron Oxide Ready-Mixed Paint", Designation M-142-49, or SSPC-Paint 11-64T, "Red Iron Oxide, Zinc Chromate, Raw Linseed Oil and Alkyd Paint".	Red iron oxide chromate primer similar to above.
TT-P-615c, "Primer Coat, Basic Lead Silico Chromate, Ready-Mixed, Type V".	Primer with pigmentation and vehicle similar to this are now widely used by state highway departments, particularly in maintenance work, but also on new steel. Pigmentation is 94% basic lead silico chromate and 3 - 5.3% pure iron oxide. Ratio of linseed oil to alkyd is 2.25/1. Generally good results are reported.

Figure E-1 (Continued)

AASHO Specification, "Red Lead Ready-Mixed Paint, Type IV", Designation M72-57.

Similar to above, but a straight red lead primer.

U. S. Military Specification, TT-P-645C, "Primer, Paint, Zinc-Chromate, Alkyd Type"; or U. S. Maritime Administration Specification, 52-MA-202, "Primer; Zinc Chromate".

TT-P-645C, and U.S. M.A. 52-MA-202 are almost identical paints pigmented with titanium dioxide and zinc chromate; they are particularly useful for alternate immersion. Phthalic anhydride constitutes 23% of the non-volatile vehicle.

OIL-BASE INTERMEDIATE COATS

Often the intermediate coat of paint is the same as the first coat, or the finish coat, but tinted to give a contrasting color. The following intermediate coats are also in common use.

AASHO Specification, "Red Lead Ready-Mixed Paint", Designation M72-57, Type III; or Federal Specification TT-P-86c, "Paint; Red Lead-Base, Ready-Mixed, Type II, Red Lead Mixed Pigment --Alkyd Varnish Linseed Oil Paint".

This intermediate coat or primer has a red lead, iron oxide pigmentation with 50/50 raw linseed oil-alkyd vehicle; it has very good weathering, semi-quick drying, and is a suitable base for finish coats.

SSPC-Paint 101-64T, "Aluminum Alkyd Paint, Type II, Non-Leafing".

This non-leafing aluminum paint is suitable for use as an intermediate coat where the final paint coat is to be an aluminum paint and where longer weathering without the prime coat showing through the aluminum finish coat is essential.

AASHO Specification, "Red Lead Ready-Mixed Paint", Designation M72-57, Type IV.

Federal Specification, TT-P-86c, "Paint; Red-Lead-Base, Ready-Mixed", Type III, Red Lead Alkyd Varnish Paint.

SSPC-Paint 107-64T, "Red Lead, Iron Oxide, and Alkyd Intermediate Paint".

Among these alternate intermediate coats, some effect cost savings; their quicker drying rates are suitable since adhesion to the underlying paint is excellent; improved durability may be achieved by use of alkyd-containing paints. Primers listed (particularly semi-quick drying primers or contrasting colors) are suitable for intermediate coats over most of the other primer. These alternates may also be used as the second or third coat in a four-coat system.

Federal Specification, TT-P-57b, "Paint, Zinc Yellow-Iron Oxide-Base, Ready-Mixed", Type II, Zinc Yellow-Iron Oxide-Alkyd Varnish Paint.

An alkyd pigmented with yellow iron oxide and zinc chromate.

Figure E-1 (Continued)

FINISH COATS

The following are typical effective finish coats for use over the foregoing primers (or intermediates). When short-oil alkyd or phenolic finish coats or intermediate coats are used over oil-base paints, at least one week drying time should be allowed for oil-base paints.

Aluminum Finish Coats

SSPC-Paint 101-64T, "Aluminum Alkyd Paint, Type I, Leafing".	This aluminum alkyd paint has good stability, drying and application properties as well as excellent durability in atmospheric exposures. Its lapping properties are fairly good. It is generally mixed on the job by adding 2 pounds of aluminum paste to one gallon of alkyd varnish vehicle.
Ready-to-mix aluminum paint mixed on the job by adding 2 pounds of aluminum paste (TT-P-320a, Type II, Class B; or ASTM D962-49, Type II, Class B, "Aluminum Pigments, Powder and Paste, for Paints") to each gallon of Type II, Class B, Federal Specification TT-V-81d, "Varnish Mixing for Aluminum Paint".	This paint contains 2 pounds of aluminum paste to one gallon of mixing varnish. It has excellent mixing, application and appearance; it is considered to have somewhat less durability, but better lapping properties than SSPC-Paint 101-64T, Type I. This paint is also furnished in ready-mixed form, which is satisfactory as long as leafing and stability are not adversely affected.
Ready-to-mix aluminum phenolic paint containing 2 pounds of the above aluminum paste to one gallon of phenolic varnish conforming to Federal Specification, TT-V-119, "Varnish, Spar, Phenolic-Resin".	An aluminum phenolic paint mixed on the job by adding 2 pounds of aluminum paste to one gallon of phenolic varnish; highly resistant to water immersion, high humidity, condensation, general atmospheric exposure, and mild chemical environments, but should be used in strongly alkaline environments.
U.S. Coast Guard Specification, CGS-52P-2a, "Paint: Aluminum Ready-Mixed".	A ready-mixed aluminum tung-linseed oil phenolic.
AASHO Specification, "Aluminum Paint", Designation M69-54.	AASHO ready-to-mix aluminum finish coat for bridges, having an oleoresinous tung oil spar varnish vehicle.

Figure E-1 (Continued)

Black Finish Coats

AASHO Specification "Black Bridge Paint", Designation M68-52.	AASHO carbon black, metallic oxides, linseed oil finish paint for bridges; high durability in atmospheric exposure.
Federal Specification TT-P-27, "Paint, Graphite, Outside, Ready-Mixed". Type I or II may be used. (But if a natural crystalline flake Graphite is desired, Type I should be specified.)	A black graphite and linseed oil paint with very high durability in atmospheric exposure. Type I is a natural crystalline flake graphite while Type II contains amorphous graphite; particularly useful under very adverse conditions such as heavy industrial areas or railroad bridges where oil-base paint is desired.
Federal Specification TT-P-61d, "Paint, Ready-Mixed Black".	A carbon black metallic oxide and linseed oil paint that has high durability and provides excellent service in severe environment such as the preceding.
SSPC-Paint 102-64, "Black Alkyd Paint".	A very durable carbon black and long oil alkyd varnish paint which is recommended for severe exposures such as railroad bridges and industrial atmospheres.
SSPC-Paint 103-64T, "Black Phenolic Paint".	A carbon black and silica phenolic varnish paint which is suitable for water immersion, high humidity, condensation, or in industrial atmospheres, or in chemical environments.
SSPC-Paint 104-64, "White or Tinted Alkyd Paint", Types I, II, III or IV.	A long-oil alkyd paint that has good stability, drying, and application properties as well as excellent durability in atmospheric exposures. The type and shade shall be agreed upon between the parties concerned, using Federal Color Standard No. 595, or other stable color chips, or spectrophotometric requirements such as those in MIL-Standard No. 794, "Military Standard Colors" or other specified method of color designation. The paint may be tinted to shades ranging from white (Type I); to light to medium gray or tan (Type II); to light green or gray-green (Type III); to dark or forest green (Type IV). It has good resistance to atmospheric exposure, particularly industrial atmospheres, but the dark-green shades are pigmented with chrome green and may suffer some loss in color.
Federal Specification TT-P-71d, "Paint, Ready-Mixed, Exterior, Chrome Green".	A green linseed oil-varnish exterior paint that has good durability to atmospheric exposure; but due to the chrome green pigment, fading and loss of color may result. Not recommended for chemical environments.

Figure E-1 (Continued)

AASHO Specification "Foilage Green Bridge Paint" Designation M67-60, Type I shall be specified for white lead base, Type II for white lead and zinc oxide base.	Green chrome oxide-linseed oil paint; white lead, or white lead and zinc oxide bases available. Very good durability in atmospheric expsure, although some slight loss in color may occur.
Federal Specification TT-P-20, "Blue Lead Paint". If a darker color is desired, it shall be tinted to a shade agreed upon between the parties concerned.	A blue lead and linseed oil paint, gray in color and used as a chalking gray finish coat for atmospheric exposure. The color may be tinted to a darker shade if desired.
Federal Specification TT-P-31c, "Paint, Iron Oxide, Ready-Mixed, Red and Brown". The color shall be agreed upon between the parties concerned.	Iron oxide paint with an oil base; may be obtained in shades ranging from red to brown; extremely durable in atmospheric exposure although the colors are dark. It is widely used on tin roofs and is frequently referred to as "roof and barn"paint.
AASHO Specification "White and Tinted Ready-Mixed Paint", Designation M70-52. One of the following shall be specified; Type I-Class A, White, general purposes; Type I-Class B, Tint-Base; Type I-Class C, White, special fumeproof (lead free); Type II, White (lead base).	The AASHO white or tint base paints for highway bridges; may be tinted to light shades if desired. The color should be specified, as well as the type.
Federal Specification, TT-P-102a, "Paint (Titanium-Lead-Zinc and Oil, Exterior, Ready-Mixed, White and Light Tints)". If a chalking white is desired, Class A shall be specified; if a non-chalking white or light tint is desired, Class B shall be specified and the color shall be agreed upon between the parties concerned.	White oil paint containing a mixture of titanium, lead and zinc pigments. Two types are available, chalking and non-chalking. If the paint is to be tinted, the non-chalking type should be specified.
Federal Specification TT-P-103, "Paint (Titanium-Zinc and Oil, Exterior, Fume Resistant, Ready-Mixed, White)".	White oil paint which is recommended for industrial areas where lead base paints may turn black.
Federal Specification TT-P-104, Paint, (White Lead and Oil, Exterior, Ready-Mixed, White and Light Tints)." If a color other than white is desired the color shall be agreed upon between the parties concerned.	White lead oil-base paints for exterior use; may be tinted as desired.

Figure E-1 (Continued)

Federal Specification TT-E-489c, Class A, "Enamel, Gloss, Synthetic". The color shall be specified.	A series of medium oil, alkyd colored enamels, suitable for interior or exterior use; high gloss but low build per coat; particularly suited for machinery and similar equipment where appearance is important.
Federal Specification TT-E-529a, Class A, "Enamel, Synthetic, Semi-Gloss". The color desired shall be specified.	Similar to preceding, but semi-gloss.
Federal Specification TT-E-527a, "Enamel, Synthetic, Lustreless".	Similar to preceding two paints, but flat finish.

Figure E-1 (Continued)

There are two principal types—organic and inorganic; the latter may be of the self-cured or post-cured type. In general, the organics require better surface cleanliness and profile, but a few inorganics are equally tolerant. Organics tend to be less resistant to solvent and chemicals. Unfortunately, along with the outstanding zinc-rich paints, a number of poorer ones are now available.

Most of the known public specifications for zinc-rich paints appear in Table E-3, and are also described in SSPC-PS 12.00, "Guide to Zinc-Rich Coatings Systems." This guide lists the characteristics and typical uses of these coatings and provides criteria for their selection. These criteria include coating history, minimum zinc content, a scratch test, and a V-notch test. The V-notch test requires that no rusting be evident in the coated areas, and at least 10% of the uncoated area be free of rust after 96 hr in the salt-spray cabinet. In addition, however, over-reactivity is avoided by requiring that at least 10% of the uncoated V-notch show red rust.

TABLE E-2

CHARACTERISTICS OF SOME OIL AND ALKYD BASE PRIMERS[a]

	PRIMER						
CHARACTERISTIC	SSPC-PAINT 14	AASHO M-72-57, TYPE II (OR TT-P-86C, TYPE I)	AASHO M-72-57, TYPE I (OR SSPC-PAINT 1)	SSPC-PAINT 2	TT-P-57b	AASHO M-72-57, TYPE III (OR TT-P-86C, TYPE II)	TT-P-645
Lb/gal	22	24	25	22	13	16.7	11.5
Weight (%):							
Pigment:	*(73)*	*(77.5)*	*(77.2)*	*(75)*	*(59)*	*(66)*	*(47)*
Red lead	75	100	99.7	75	—	65	—
Zn chromate	—	—	—	—	39	—	50
Zn oxide	—	—	—	—	14	—	—
Iron oxide	25	—	—	25	18	15	30
Extenders	—	—	—	—	29	20	—
Other	—	—	>0.3	—	—	—	20
Vehicle:	*(27)*	*(22.5)*	*(22.8)*	*(25)*	*(41)*	*(34)*	*(53)*
Raw LSO	95	35-50	21.1	56	32.5	28	15
Bodied LSO	—	15-30	—	—	—	—	—
Alkyd solids	—	—	—	21-28	32.5	28	25
Thinner, drier, other	>5	[b]	[b]	[b]	[b]	[b]	[b]
Drying (hr)	72	36	72	24	24	16	6
Wetting	Exc.	V. good	Exc.	F. good	Good	F. good	Fair
Weathering	Exc.	V. good	V. good	Exc.	V. good	V. good	Good
Color	Red oxide	Orange	Orange	Red oxide	Yellow oxide	Brown	Light yellow

[a] For use over wire-brushed (or blast-cleaned) steel to be exposed to the weather. See Fig. E-1 for alternate primers and finish coats.
[b] Remainder.

Steel Structures Painting Council Specifications

Oil Base Paint System *
With Linseed Oil Primer and Alkyd Topcoat

(For Weather-Exposed Wire-Brushed Steel)

1. Scope

1.1 This specification outlines a complete oil base paint system for steel bridges and other structural steel surfaces that will be wire brushed, painted and exposed to the weather in moderately corrosive atmospheres. It consists of hand tool or power tool cleaning, one coat of red lead—iron oxide linseed oil primer, one intermediate coat of medium oil alkyd, and one finish coat of alkyd linseed oil aluminum paint. The alternate finish coat offers a choice of white, grays, tans, or greens.

2. Description

2.1 This paint system is effective and economical where unusual factors, such as condensation, chemical fumes, brine drippings and other extremely corrosive conditions are **not** present.

The oil base primer is slow in drying, but the intermediate paint and topcoat dry more rapidly.

3. Requirements

The surfaces of the steel shall be cleaned and painted as follows:

3.1 SURFACE PREPARATION: The surface shall be cleaned as specified in either SSPC-SP 2-63, "Hand Tool Cleaning" or SSPC-SP 3-63, "Power Tool Cleaning" as elected by the contractor.

3.2 PRETREATMENT: Pretreatment of the steel shall not be required.

3.3 PAINT APPLICATION: All paint shall be applied in accordance with SSPC-PA 1-64, "Shop, Field and Maintenance Painting."

3.4 NUMBER OF COATS: A minimum of three coats of paint shall be applied.

*Based upon SSPC Paint System 1.01.

Figure E-2. Typical oil-base paint system.

Summary of Paint System 1.01

Sec.	Item	Specification
3.1	Surf. Prep.	SSPC-SP 2-63 (or better)
3.2	Pretreat.	None Required
3.3	Paint Appl.	SSPC-PA 1-64
3.4	No. Coats	Three minimum
3.5	Primer	SSPC-Paint 14-64T
3.6	Touch-up	SSPC-PA 1-64, Sec. 3.5.3
3.7	2nd Coat	TT-P-86c, Type II
3.8.1	Finish Coat	SSPC-Paint 101-64T, Type I
3.8.2	(Alt. Fin. Ct)	(SSPC-Paint 104-64)
3.9	Dry Film Thickness	First Coat 1.7 mils, etc. Total System 4.0 mils.

3.5 PRIMER: After cleaning, the steel shall be primed with one coat of paint conforming with specification SSPC-Paint 14-64T, "Red Lead-Iron Oxide Linseed Oil Primer."

3.6 TOUCH-UP PAINTING: Touch-up field painting shall be performed in accordance with specification SSPC-PA 1-64, "Shop, Field and Maintenance Painting" and in particular with Section 3.5.3 thereof entitled "Field Painting."

3.7 INTERMEDIATE COAT: The intermediate paint coat shall conform with Federal Specification TT-P-86c, "Paint, Red Lead Base, Ready-Mixed," Type II, Red Lead, Mixed Pigment-Alkyd Varnish Linseed Oil Paint; or AASHO Designation M72-57, Type II, "Red Lead, Ready-Mixed Paint."

3.8.1 FINISH COAT: The finish coat of paint shall conform with specification SSPC-Paint 101-64T, "Aluminum Alkyd Paint," Type I, Leafing.

3.8.2 ALTERNATE FINISH COAT: If

specified in the contract, a finish coat complying with specification SSPC-Paint 104-64, "White or Tinted Alkyd Paint," Type I, II, III or IV shall be substituted for the standard finish coat. The type and shade shall be agreed upon in advance.

3.9 PAINT FILM THICKNESS: The dry film thickness of the paint at any point shall not be less than the following: for the primer 1.7 mils (0.0017 inches); for the second coat 1.3 mils; for the finish coat 1.0 mils; for the three-coat paint system 4.0 mils. If the required paint film thickness is not achieved, additional coats shall be applied until the required thickness is obtained.

4. *Inspection*

4.1 All work and materials supplied under this specification shall be subject to inspection by the owner or his representative. The contractor shall correct such work or replace such material as is found defective under this specification. If the contractor does not agree with the inspector the arbitration or settlement procedure established in the contract, if any, shall be followed. If no arbitration or settlement procedure is established, the procedure specified by the American Arbitration Association shall be used.

4.2 Samples of ingredients or paints used under this paint system should be supplied upon request along with the supplier's name and identification for the materials.

4.3 Unless otherwise specified, the methods of sampling and testing should be in accordance with Federal Test Method Standard No. 141, or applicable methods of the American Society for Testing and Materials.

4.4 The contract covering work or purchase should establish the responsibility for testing and for any required affidavit certifying full compliance with the specification.

5. *Notes On Requirements*

5.1 SURFACE PREPARATION: Under the terms of the surface preparation specifications, oil, grease or salts must first be removed by the methods outlined in SSPC-SP 1-63, "Solvent Cleaning."

With the mutual agreement of both owner and contractor, any of the SSPC surface preparation specifications requiring more complete cleaning or scale removal may be substituted for the surface cleaning specified. (SSPC Surface Preparation Specifications No. 5, 6, 7, 8 or 10.)

5.2 PAINT APPLICATION: SSPC-PA 1-64, "Shop, Field and Maintenance Painting" specifies methods of application (brush, spray, airless, hot spray and sometimes roller), storage, mixing, temperature, humidity, contact surfaces, tinting of intermediates, treatment of weld areas etc. If any exceptions or further limitations to these requirements are desired, they should be stipulated.

5.3 INTERMEDIATE COAT: When specifically stipulated in the contract, the intermediate coat may instead be the same as the prime coat (tinted for contrast) or the same as the finish coat (tinted or non-leafing for contrast).

5.4 FINISH COAT: If the alternate finish coat, SSPC-Paint 104-64, "White or Tinted Alkyd Paint" is specified, the type and shade should be agreed upon between the parties concerned, using a suitable method of color designation such as Federal Color Standard No. 595, or other stable color chips, or spectrophotometric requirements such as those in MIL-Std. 794, "Military Standard Colors" or other specified method. The paint may be tinted to shades ranging from white (Type I); to light or medium gray or tan (Type II); to light green or gray-green (Type III); to dark green or forest green (Type IV).

5.5 GENERAL NOTES: All of the requirements and safety precautions of the specifications included by reference are considered a part of this specification and should be fully complied with.

In case of a conflict between a specific provision herein and any requirement of a specification included by reference, the former should govern.

This specification applies to maintenance painting, its specific instructions are included regarding the degree and amount of solvent cleaning, spot cleaning, spot priming, priming and finish painting. (See SSPC Paint Application Guide.)

The latest applicable issue, revision, or amendment of the specifications listed herein in effect on the date of invitation for bids should be used.

All safety requirements shall be considered to supplement any local or state safety codes applying to any particular project.

Figure E-2 (Continued)

TABLE E-3

SOME ZINC-RICH SPECIFICATIONS

CODE	SOURCE	TYPE
SSPC-PS 12.00	SSPC	Guide.
MIL-P-23236	U.S. Bureau of Ships (fuel and ballast tanks)	Performance in lab and field (4 types).
MIL-P-26915	U.S. Air Force	70-80% zinc. Any vehicle. Accelerated and electric test.
MIL-P-21035	U.S. Bureau of Ships	Any vehicle. (95% pigment × 97.5% zinc.) Salt spray.
MIL-P-46105	U.S. Army Materials	Weld-through zinc-rich.
1-GP-171	Canadian Government Specifications Board	Coatings—inorganic zinc.
1-GP-181	Canadian Government Specifications Board	Coatings—zinc-rich, organic, ready-mix.
TT-P-001046	General Services Administration	Chlorinated rubber. 88% zinc. One package.
MIL-P-38336	U.S. Air Force	Self-curing inorganic.
66-G-55	California Highway Department	Lithium silicate or ethyl silicate.
Special Provision No. 1 to D-9-1	Texas Highway Department	Urethane.

Table E-4 summarizes some of the special characteristics of zinc-rich paints, some of which depend on the types of vehicles used and the topcoating (if any) that was employed. Most of the inorganic types will have an important advantage in air pollution control zones because of their aqueous vehicles. In highly industrial chemical areas the zinc-rich coatings provide considerably longer protection than unpainted galvanized steel because the zinc particles are surrounded by a matrix of inert vehicle.

Table E-4 compares some of the properties of inorganic and organic zinc-rich paints. Typical organic vehicles include chlorinated rubber, polystyrene, epoxy esters, catalyzed (polyamide, amine), esters, polyesters, urethanes, acrylics, vinyls, silicones, and many variations within each class. The earliest inorganics were zinc silicates and lead zinc silicates, but other modern formulations include silicate esters, phosphates, and modifications thereof.

Often the key to successful use of zinc-rich paints lies in the selection of the topcoat. Many manufacturers insist that the investment in surface preparation and zinc primer be protected by one, two, or more finish coats which are both compatible with zinc-rich paint and resistant to the environment. In topcoating, the recommendations of the manufacturer should be carefully followed. Sometimes tie-coats are used to achieve adhesion and avoid blistering. Some tie-coats consist of wash primers or topcoats to which a solvent diluent has been added. It has been said that if a topcoat can be applied to galvanized steel, it will adhere to a zinc-rich primer. In addition, because of its high pigment volume, the zinc-rich coating tends to be a rough, open coating that will tolerate a variety of topcoats. Often the topcoat selected has the same generic composition as that of the zinc-rich primer, especially for the organic types. The inorganics have been overcoated with vinyls, epoxies, chlorinated rubber, acrylic, inorganic silicates, silicates, silicones, and coal tar epoxies.

Manufacturer's directions should also be followed in regard to film thickness. Some who originally recommended a dry film thickness of 2 to 3 mils are now advocating 4 to 7 mils.

Vinyl Paint Systems

SSPC tests have shown the vinyls, when properly formulated and used, to be superior to any others tested in water-immersion tests, as well as one of the best performers in salt brine exposures. Vinyls are recommended for floor systems of bridges exposed to de-icing salts. The general characteristics of this system and its many variations are discussed in Figure E-3, which is based on SSPC-PS 4.00. Figure E-3 gives a guide to the choice of vinyl paint systems, and includes references to existing specifications whereby they may be procured.

An independent consultant has completed a survey in which he found that vinyl paint systems had far more case histories of long paint life than any other system. In a few areas, it is still difficult to find contractors who are thoroughly experienced in the use of various synthetics including vinyl paints, which have low solids and require at least four multiple-pass coats for best protection. Higher solids vinyl paints are also available, usually combined with alkyds or other resins, resulting in a greater film thickness per coat than is obtained with these SSPC systems. Such paints may also have the advantage of lower cost due to less expensive resins, higher amounts of extender, and lower amounts of solvent. Nevertheless, the higher solids (and consequently greater film thickness) are obtained by using lower-molecular-weight resins which sacrifice some resistance and durability.

Care and skill must be exercised in the application of vinyls, especially when open to wind. However, the SSPC generally has found them unequaled in water immersion and in the other recommended applications.

TABLE E-4

SOME CHARACTERISTICS AND PROPERTIES OF ZINC-RICH PAINTS

	EVALUATION	
ITEM	ORGANIC	INORGANIC
Hardness, toughness	Good	Excellent
Abrasion resistance	Good	Excellent
Flexibility	Fair-good	Fair-poor
Rust inhibition	Galvanic and barrier	Galvanic and barrier
Resistance to:		
Humidity	Yes	Yes
Marine	Yes	Yes
Weather	Yes	Yes
Oil and solvents	Varies	Yes
Fresh water	Fair-excellent	Fair-excellent
Salt water	Okay topcoated	Okay topcoated
Acid and alkali	Okay topcoated	Okay topcoated
Fungi, etc.	Varies	Unaffected
Fire	Varies	Resistant
Temperature (dry)	400 F or less	700 F +
Temperature (wet)	To 212 F or less	140 F
Air pollution	Varies	Mostly exempt
Surface preparation	Commercial or near-white	Usually near-white
Application	Latitude	Varies
Topcoating	Tolerant	Varies
Zinc (wt. % on solids)	80 to 95	75 +
Thickness (mils)	2 to 7	2 to 7
Packages	1, 2, or 3	2 or 3
Cure	Self or catalyzed	Self or post
Miscellaneous	Drying, welding, pot life vary widely	
Type	Chlorinated rubber, styrene, vinyls, epoxies, phenoxy, polyesters, acrylics, urethanes, silicones	Silicates, silicate esters, zinc-lead silicates, phosphates, modifications

Alternate solvent formulations are being investigated so that vinyls, epoxies, chlorinated rubbers, and other paint systems can be used where air pollution control legislation prohibits the use of aromatic solvents.

Wash primers are usually recommended, especially for use in salt-water exposure. The wash primer may also serve as temporary protection in cases where blast cleaning is carried out before fabrication.

Epoxy Paint Systems

Epoxy paint systems are recommended as alternates for use on steel which is frequently wet, steel immersed in water, floor systems of bridges exposed to de-icing salts, and for many chemical exposures. Advantages and limitations of this system are given in SSPC-PS 13.00.

Surface preparation for epoxy paint systems is less critical than for inorganic zinc-rich systems (commercial or near-white). Because the solids content is much higher than for vinyls and a higher film thickness per coat can be obtained, applied cost is usually lower. Adhesion to steel is excellent, but neither the epoxy primer nor topcoat is compatible with other base coats such as alkyd, chlorinated rubber, oil base, or vinyl. With some formulations, the second coat must be applied fairly soon to achieve proper intercoat adhesion. Chalking is the most widely recognized limitation of epoxies; this effect can be minimized by use of white or light tints.

Excellent results have been obtained with epoxies in chemical plants, refineries, aircraft, and weapons. Successful field trials have been obtained by several of the states. However, only a limited number of open specifications are available which will insure obtaining best products on open bid. These include MIL-P-23377, MIL-C-22750, MIL-P-52192, MIL-P-27316, and MIL-P-23236, all of which were developed for other special purposes.

Coal Tar Epoxies

Where a dark color is acceptable, a two-coat coal tar epoxy system provides a thick film which is highly resistant to immersion in fresh or salt water, tidal zone, splash zone, weather zone, marine environments, or most chemical environments. Like other two-compartment materials, they require some experience in handling. The reduced number of coats (usually two) and high-build (16 mils minimum) have been an advantage on bridges, pipes, dams, and tanks in severe exposure where intercoat contamination presents problems with multi-coat vinyl.

This type of coating consists essentially of coal tar pitch and epoxy resin. A coal tar epoxy paint will also include

Descriptions and Specifications for Some Alternate Vinyl Paints for Use on Blast-Cleaned (or Pickled) Highway Structural Steel

GENERAL DESCRIPTION

Vinyl paint systems are used for structural steel surfaces that will be exposed to very severely corrosive conditions. The standard system consists of commercial blast cleaning, near-white blast cleaning or pickling, one coat of vinyl primer, one (or two) intermediate coat(s) of paint, and one finish coat of vinyl paint. For salt-water immersion and some other applications, a wash primer pretreatment is used under the primer.

Vinyl paint systems are excellent for very severe exposures, including most chemical atmospheres, water immersion and corrosive environments. They are highly recommended for complete or alternate immersion in fresh or salt water, high humidity and condensation, and exposure to the weather. They are recommended for floor systems of bridges exposed to brine drippings or de-icing salts, or for bridges in marine exposures. Some vinyl systems are excellent for use over zinc-rich paints on metallized zinc or aluminum, but manufacturer's recommendations should be obtained. With the wash primer, vinyls are effective on unrusted galvanized steel.

Full instructions for application of vinyls are given in SSPC-PA 1, especially in Section 3.5.5.2.

The paints listed in this specification are compatible with one another; however, several precautions shall be taken when using vinyl paints. The vinyl paint should be vinyl chloride-acetate copolymer, modified by carboxyl or hydroxyl groups if required. Some vinyl primers are satisfactory over wash primer only, some over bare steel only, while some may be used over either. Some vinyl paints will not adhere to wash primers, but must be used over a suitable intermediate coat (many proprietary vinyl paints are of this type).

SURFACE PREPARATION

Because of the great increase in paint life, blast cleaning or pickling of the steel is the minimum recommended surface preparation for new work. In maintenance painting when only small areas need to be cleaned, hand or power tool cleaning may suffice. Mill scale is particularly detrimental on immersed or wet steel.

If blast cleaning or pickling is not feasible, vinyl paint systems may be used over hand-cleaned or power-tool-cleaned steel, but with considerably poorer results.

Profile depth of the blast-cleaned surface should be several mils less than the system film thickness.

Figure E-3. Vinyl paints for severe exposures.

NOTES ON APPLICATION

To obtain the required thickness per coat, without pinholing or sagging, airless spray or hot spray with multiple passes are helpful. Single coats more than 3 - 5 mils thick, on the other hand, can lead to solvent release problems.

Air-dry of as much as 24 hours between coats is desirable, if feasible, to assure essentially complete solvent removal.

If vinyl paints must be applied in very hot weather, cyclohexanone may be used as a thinner to prevent drying too rapidly.

A minimum of 3 coats of vinyl paint are recommended for the less severe exposure. For very severe exposure, 4 coats are recommended; and for extremely severe exposure 5 or 6 coats may be required.

The dry film thickness of the paint for a 3-coat system is usually 3.5 - 4.0 mils; for a four-coat system 4.0 - 4.5 mils; for a five-coat system 5.5 - 6.0 mils.

WASH PRIMER

A wash primer is recommended for salt-water immersion (SSPC-Paint Systems 4.01, 4.03, and 4.05). It also aids adhesion to less-than-adequately prepared surfaces. Some users have even obtained good results by brushing the wash primer thoroughly onto hand-cleaned steel before applying a vinyl system. For fresh-water immersion, however, the wash primer is no longer recommended by most manufacturers. The vinyl butyral wash coat (wash primer) should be applied to bare metal only and in spot-pretreating care should be taken to minimize over-lapping old paint.

For fresh-water immersion, wash primer is not ordinarily required. For salt-water immersion, the surfaces, after cleaning are pretreated in accordance with:

SSPC-PT 3-64, "Basic Zinc Chromate Vinyl Butyral Washcoat"

VINYL PRIMERS

U.S. Military Specification, "MIL-P-15929B, "Primer, Vinyl Red Lead Type (Formula 119)".	This red lead vinyl paint is the most widely used of the vinyl priming paints; it may be used for intermediate coats also; it is used over wash primer pretreatment or other vinyl paints.
U.S. Military Specification, "MIL-P-15930B, "Primer, Vinyl Zinc Chromate Type (Formula 120)".	The zinc chromate vinyl paint is similar to the above, but it is not used as widely on steel. It is not recommended for fresh-water use.
SSPC-Paint 9-64T, "White (or Gray) Vinyl Paint".	SSPC-Paint 9-64T is a white vinyl paint that may also be procured in gray, or tints; used as a primer over wash primer or over bare steel; as intermediate or finish paint over any vinyl paint; highly recommended as an extremely inert pigmented vinyl paint for extremely severe chemical exposure that would attack wash primer pigments or other vinyl paint pigments.

U.S. Bureau of Reclamation VR-3, "Vinyl Resin Paint".	This high solids vinyl paint is available in white, medium gray, and aluminum colors. (The aluminum is recommended as a topcoat only.) Developed for tank service, these coatings are also suitable for highway use. The white and gray are pigmented with titanium dioxide, extenders and black tint. They are formulated with vinyl tripolymer and copolymer to meet requirements for: overall composition, density, application, dry (3-hour recoat), stability, adhesion and cohesion, flexibility, permeability; resistance to solvent, salt spray and abrasion.
Proprietary primers based on vinyl chloride-acetate copolymer solutions.	Several proprietary primers are available for use over slightly rusty or hand-cleaned steel and may be topcoated with vinyl paints. These are not usually recommended for water immersion, but can provide heavier film build than the above low-solids specification products.

INTERMEDIATE VINYL COATS

Any of the primers listed may be used for intermediate coats. If two or more coats of the same paint are applied, alternate coats should be tinted to contrasting colors, preferably by the paint manufacturer. Any of the finish coats listed below (except aluminum paints) may be used for intermediate paints also.

VINYL FINISH COATS

SSPC-Paint 8 , "Aluminum Vinyl Paint".	This is an aluminum vinyl paint that may be used over any vinyl paint as a finish coat. Aluminum topcoats are preferred for water immersion, but not for use in alkaline or strongly acid exposures; not to be used under other vinyl paints or applied in overly thick films (e.g. 3 mils per coat) because of the possibility of solvent entrapment by the aluminum flake.
SSPC-Paint System 9 , "White (or Gray) Vinyl Paint". The color shall be agreed upon between the parties concerned.	An inert pigmented straight vinyl paint suitable for chemical exposures; may be used as a primer or as an intermediate or finish coat. May be used alternately with preceding or suceeding vinyl paints for color contrast. It may be procured in colors by specifying the color desired and substituting suitable colored pigment for the titanium dioxide.

Figure E-3 (Continued)

U.S. Bureau of Reclamation, VR-3, "Vinyl Resin Paint, Aluminum, White or Gray".	This high-build vinyl paint system is described under primers. Either the white, gray or aluminum types may be used as finish coats, although the aluminum paint is not recommended for use as primer or intermediate coat; nor is it recommended for use in alkali or strong acid. Because of its superior permeability, however, it is the preferred topcoat for other services such as water immersion or exterior sunlight.
U.S. Military Specifications:	
MIL-P-15932B, "Paint, Outside, Gloss Black (Vinyl Alkyd) (Formula 122-1)". MIL-P-15933B, "Paint, Outside, Dull Black (Vinyl Alkyd) (Formula 122-3)". MIL-P-15934B, "Paint, Outside, Gray No. 7 (Vinyl Alkyd) (Formula 122-7)". MIL-P-15935B, "Paint, Outside, Gray No. 11 (Vinyl Alkyd) (Formula 122-11)".	The formula 122 series provides a range of color-coded vinyl alkyd intermediates and topcoats. Although not as chemically resistant as straight vinyls, they have brushability and good durability in severe exposure. Particularly useful for weather-exposed steel. The first two are black paints and gloss or dull black are available. The remainder of the formula 122 series are grays, ranging from dark to light. The number in the title refers to the reflectivity of the paint. 1 is a black and 100 a perfect reflecting white.
MIL-P-16188B, "Paint, Outside, Gray No. 17 (Vinyl Alkyd) (Formula 122-17)". MIL-P-15936B, "Paint, Outside, Gray No. 27 (Vinyl Alkyd) (Formula 122-27)". MIL-P-16501B, "Paint, Outside, Gray No. 37 (Vinyl Alkyd) (Formula 122-37)". MIL-P-16502B, "Paint, Outside, Gray No. 46 (Vinyl Alkyd) (Formula 122-46)".	This series is generally low in gloss, but MIL-P-16738B is a glossy white paint.
MIL-P-16738B, "Paint, Outside, White, Vinyl Alkyd Type (Formula 122-82)".	A white alkyd paint with inert pigments, high reflectivity, and good gloss.
U.S. Maritime Administration, MAP-55, "Paints; Boottopping, Vinyl Alkyd, Bright Red Undercoat and Indian Red Finish Coat".	Two inert pigmented vinyl alkyd paints of contrasting shades developed for boottopping or other severe exposure. The first is bright red, the second is an iron oxide red--specify which is desired.

Figure E-3 (*Continued*)

U. S. Maritime Administration, MAP-47a, "Paint; Boottopping, Vinyl Alkyd, Green Finish Coat".	A relatively inert pigmented, green vinyl alkyd similar to above.
U. S. Coast Guard Specification, CGS-52P-5b, "Paint, Exterior, Vinyl Alkyd Type". "White", "Black", "Red", "Yellow", and "International Orange".	A series of colored vinyl alkyd paints of good gloss and good color retention. Specify color desired. Where conditions are less severe than indicated herein, oil paints, alkyds, or phenolics may be used as field paints. If conditions are even more severe, inert pigmented vinyl finish paints such as described above should be selected, instead of vinyl alkyds. For maximum chemical resistance use straight vinyl intermediate or finish paints; for maximum brushability and gloss use vinyl alkyd intermediate or finish paints. If desired, the oil-base, alkyd, or phenolic paints listed in Paint System 1, 2, or 3 may be used over the vinyl or vinyl alkyd paints listed herein, but poor adhesion will result if the vinyl under-paint does not include considerable hydroxyl-containing vinyl resins.

Figure E-3 (*Continued*)

mineral filler (extender pigment), a gelling agent to introduce thixotropic properties, and volatile thinners. Lastly, the paint will contain a curing agent—in this case a coreacting polyamide resin. Coal tar epoxy paints are necessarily two-compartment materials, with the curing agent isolated from the epoxy resin until just prior to use. A two-coat system may be specified as SSPC-PS 11.01. MIL-P-23236, Clause 2, has a qualified products list of coal tar epoxies, administered by the U.S. Navy.

Chlorinated Rubber Paints

Chlorinated rubber paints in SSPC tests have protected a railroad bridge for more than 8 yr of salt brine exposure, and have had a long record of successful use in protecting damp or chemically corrosive interiors. Case histories are also being obtained on many exterior metal surfaces, including bridges and guardrails. To achieve better elasticity and adhesion, linseed oil, alkyd or plasticizers may be added to the priming coat. The alkyd-modified types provide a considerable measure of chemical resistance without requiring meticulous surface preparation and without difficulty in application. Chief limitations are some chalking and a relatively poor resistance to solvents (particularly aromatics, esters, and ketones). Five common types of chlorinated rubber paint formulations are named in the *Steel Structures Painting Manual* (Vol. 2, 2nd ed., pp. 130-131).

Other Coatings

Other coatings that have shown great promise for highway use are discussed in this report, particularly the urethanes, silicones, silicone-alkyds, water-base paints, high-build thixotropic coatings (two-coat systems instead of the usual three or four), and the various alternatives such as metallizing, galvanizing, or greases, which are used in place of paint.

OTHER FACTORS IN CHOICE OF PAINT SYSTEMS

Topcoats

Because topcoats need not wet bare steel, they often contain larger amounts of synthetic resin than the primer. Finish coats now include a wide range of colors and compositions. Aluminum-pigmented finish coats are probably still used more often than any other; work is under way with them to develop colors, to develop better one-package paints, and to add corrosion-inhibitive constituents. The practice of tinting the intermediate aluminum coat with prussian blue is discouraged; as an alternative, the use of non-leafing aluminum is advocated in the second-last coat (for example, SSPC-Paint 101, Type II).

Titanium dioxide is the next most commonly used topcoat pigment, followed by zinc oxide and white lead. Extenders (including talc, barytes, silica, silicates, cement, and

glass) may be used in small quantities or in mild environments. Special topcoat pigmentations which have shown considerable promise in field tests also include stainless steel particles and glass flakes. Their effectiveness often depends on the type of vehicle used; the heavy film thickness that they are able to present; and leafing effects similar to those obained with micaceous iron oxide, graphite, or aluminum. New means of achieving high-film build in stable paints are very promising, especially through the use of thixotropic vehicles, and glass flake pigmentation.

The use of silicone-alkyds of the type tested in Connecticut has shown great promise in improving gloss retention and in achieving better paint life. Experimentally, many bridge authorities have succeeded in topcoating conventional paint systems with highly resistant finish coats to combat increasingly corrosive environments. These topcoats have included vinyl alkyds, chlorinated rubber, and phenolics as barrier coats or topcoats. In the present state-of-the-art, however, spot-checks should be made for lifting, to assure that the previous oil-base paint or alkyd paint has dried sufficiently hard so that it is not lifted by the strong solvents.

Surface Preparation and Paint Application

Methods of surface preparation are an integral part of each paint system specification. The common surface-preparation methods are listed in Table E-5, including visual (photographic) references SSPC-Vis 1 (in *Pictorial Surface Preparation Standards for Painting Steel Surfaces*). Table E-6 gives the surface preparation recommended for various types of paint systems. Photographs such as SSPC-Vis 1 are exceedingly helpful in arriving at a common understanding of the requirements of surface preparation specifications. The specifications, however, should be detailed and explicit, leaving little or no opportunity for misunderstanding.

Paint application methods are discussed in SSPC-PA 1, including requirements on storage, mixing, drying, and handling; in addition to the general provisions required for the various application methods in shop, field, and maintenance paint. Specifications should cover the permissible application method (brush, spray, airless, roller, etc.), temperature, humidity, cover, touch-up, striping, thickness, and painting of contact surfaces.

Air-Pollution Considerations

Legislation in Los Angeles County and San Francisco Bay areas limits the types of solvents (particularly aromatics) that can be used in paints. Because similar regulations are in process of adoption in many other parts of the country, the materials engineer may be called on to work with suppliers to make certain that (1) approved types of mineral

TABLE E-5

TYPICAL SURFACE PREPARATION SPECIFICATIONS

Specification	*Subject*	*Purpose*
SSPC-Vis 1-63T	Description of Visual Standard	Photographic standards used as optional supplement to SSPC Surface Preparation Numbers 2, 3, 5, 6 and 7.
SSPC-SP 1-63	Solvent Cleaning	Removal of oil, grease, dirt, soil, salts, and contaminants by cleaning with solvent, vapor, alkali, emulsion, or steam.
SSPC-SP 2-63	Hand Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by hand chipping, scraping, sanding and wire brushing.
SSPC-SP 3-63	Power Tool Cleaning	Removal of loose rust, loose mill scale, and loose paint to degree specified, by power tool chipping, descaling, sanding, wire brushing, and grinding.
SSPC-SP 4-63	Flame Cleaning of New Steel	Dehydrating and removal of rust, loose mill scale, and some tight mill scale by use of flame, followed by wire brushing.
SSPC-SP 5-63	White Metal Blast Cleaning	Removal of all visible rust, mill scale, paint and foreign matter by blast cleaning by wheel or nozzle (dry or wet) using sand, grit or shot. (For very corrosive atmosphere where high cost of cleaning is warranted.)
SSPC-SP 10-63T	Near-White Blast Cleaning	Blast cleaning nearly to White Metal cleanliness, until at least 95% of each element of surface area is free of all visible residues. (For high humidity, chemical atmosphere, marine or other corrosive environment.)
SSPC-SP 6-63	Commercial Blast Cleaning	Blast cleaning until at least two-thirds of each element of surface area is free of all visible residues. (For rather severe conditions of exposure.)
SSPC-SP 7-63	Brush-Off Blast Cleaning	Blast cleaning of all except tightly adhering residues of mill scale, rust and coatings, exposing numerous evenly distributed flecks of underlying metal.
SSPC-SP 8-63	Pickling	Complete removal of rust and mill scale by acid pickling, duplex pickling or electrolytic pickling. May passify surface.
SSPC-SP 9-63T	Weathering Followed By Blast Cleaning	Weathering to remove all or part of mill scale followed by blast cleaning to one of the above standards.

spirits, low in aromatics, are used; (2) synthetic paint formulations are adjusted to reduce aromatics and other non-exempt solvents to the proper levels; and (3) the substitution of solvents has not adversely affected film properties. As an interim measure, until durability tests have been completed, measurement of film tensile strength, flexibility, and adhesion, or other short-term tests, may be regarded as indications of satisfactory film properties.

TABLE E-6

MINIMUM SURFACE PREPARATION REQUIRED BY SSPC PAINT SYSTEMS

PAINT SYSTEMS	MINIMUM SURFACE PREPARATION
1.00-1.06 Oil-base paint systems	Hand-tool cleaning (SSPC-SP 2)
2.00-2.05 Alkyd paint systems for weather exposure	Blast cleaning (SSPC-SP 6) or pickling (SSPC-SP 8)
3.00 Phenolic paint systems for fresh-water immersion	Blast cleaning (SSPC-SP 6) or pickling (SSPC-SP 8)
4.00-4.05 Vinyl paint systems for chemical exposure	Blast cleaning (SSPC-SP 6 or 10) or pickling (SSPC-SP 8)
6.00-6.03 Paint systems for vessels	Blast cleaning (SSPC-SP 6 or 10) or pickling (SSPC-SP 8) (most areas)
7.00-7.01 One-coat shop paint for structural steel	Nominal cleaning
8.00-8.01 Rust preventive compounds	Solvent cleaning (SSPC-SP 1) and/or nominal cleaning
9.01 Asphalt mastic	Blast cleaning (SSPC-SP 6)
10.00-10.02 Coal tar coatings	Blast cleaning (SSPC-SP 6)
11.01 Coal tar epoxy	Blast cleaning (SSPC-SP 6 or 10)
12.00 Zinc-rich systems	Blast cleaning (SSPC-SP 6 or 10)
13.00 Epoxy systems	Blast cleaning (SSPC-SP 6) or pickling (SSPC-SP 8)

Maintenance Painting

In maintenance painting, it is not ordinarily intended that sound, adherent old paint be removed, unless it is excessively thick or brittle, or is incompatible with the new paint system. A guide to maintenance painting practices is given in Table E-7. Figure E-4 is a visual aid for the inspector in determining when maintenance is necessary. This diagram, or preferably the corresponding color photography in SSPC-Vis 2 (in *Pictorial Surface Preparation Standards for Painting Steel Surfaces*) is also a useful reference in establishing an approximate rating for paint on exposed structures. Here, the recommended paint practice depends upon the degree of deterioration. It is almost always economic to repaint before a rating of 7 is reached (or about 0.3% rusting). If more than 10% to 25% rust is present, the surface should be spot-cleaned, feathered, spot-primed, and given one overall coat of priming paint before topcoating. Table E-7 is based on repainting of a paint system that is compatible with the previous one. Where an entirely new paint system is being applied to an old surface and incompatibility is expected, complete removal of all old paint is necessary.

BASIS FOR RECOMMENDATIONS

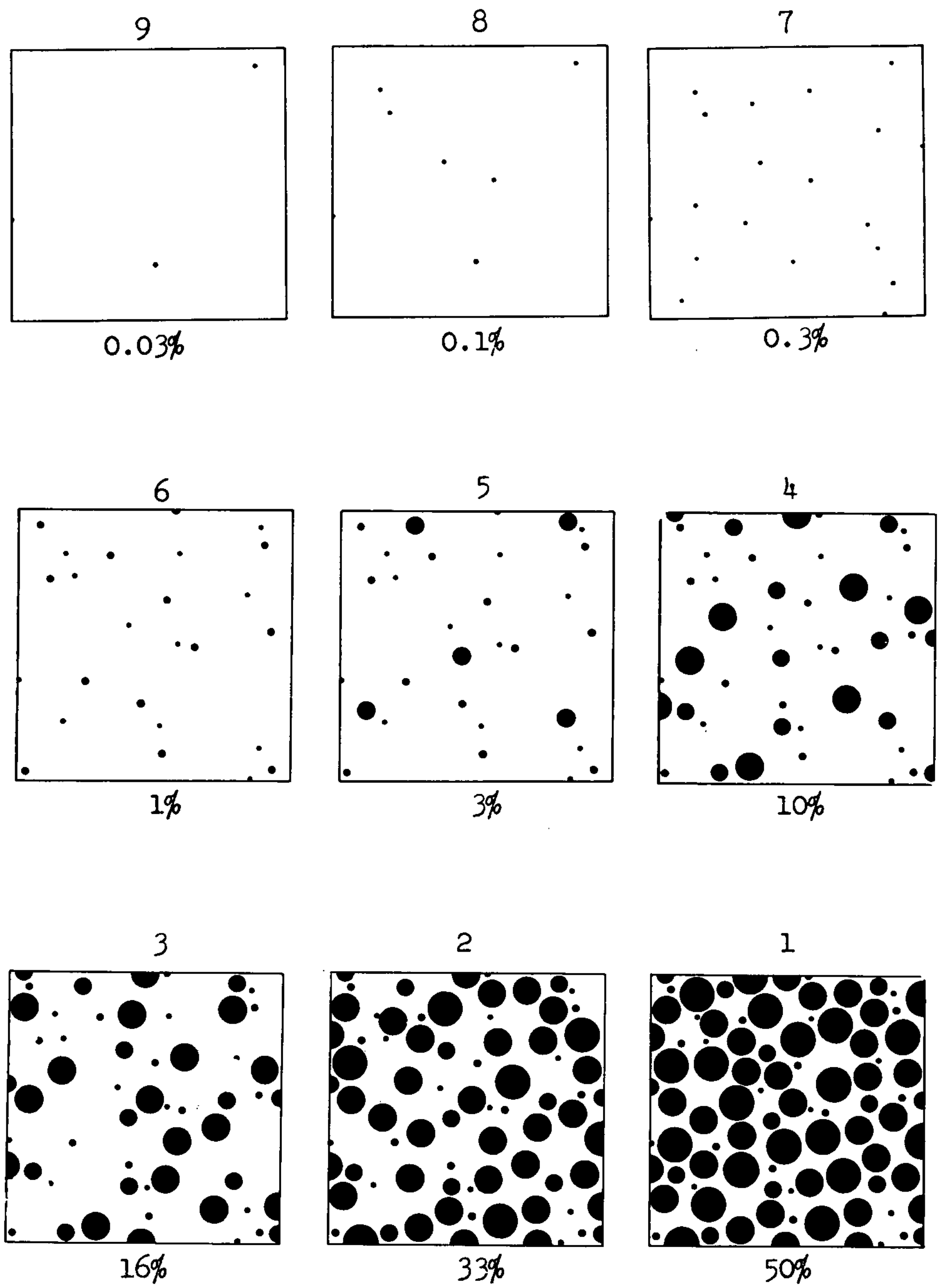
Recommendations in this report are based on a combination of SSPC tests, highway experience, documented literature, and accumulated experience of SSPC members, most of which are cited herein.

TABLE E-7

TYPICAL MAINTENANCE PAINTING PRACTICE

DEGREE OF RUSTING (OR BLISTERING OR FILM EMBRITTLEMENT)	SSPC-VIS 2 [a]	CLEANING AND PAINTING RECOMMENDED
Paint almost intact; some primer may show; rust covers about 0.1% or less of the surface.	9-10	Solvent-clean and spot-clean if necessary. Apply 1 or 2 coats of finish paint if required to maintain film thickness and continuity.
Finish coat somewhat weathered; primer may show; slight staining or blistering; after stains are wiped off, less than 1% of area shows rust, blistering, loose mill scale, or loose paint film.	7-8	Spot-clean and spot-prime. Apply 1 or 2 overall coats of finish paint as necessary. It is almost always economic to repaint at this stage.
Paint thoroughly weathered, blistered, or stained; up to 10% of surface is covered with rust, rust blisters, hard scale, or loose paint film; very little pitting visible to the naked eye.	5-6	Spot-clean back to adherent paint film; feather edges, spot-prime (2 coats) and apply 1 or 2 overall coats of finish paint as necessary. Remove all loose paint; avoid removing good paint and avoid building up overly thick paint film.
Large portion of surface is covered with rust, pits, rust nodules, and non-adherent paint. Pitting is visible to the naked eye.	3-5	Spot-clean and spot prime. Apply 1 overall coat of priming paint and 1 or 2 coats of finish paint as necessary. Observe precautions listed above.
—	0-2	Remove as much rust and old paint as is practical (preferably all). Apply 2 priming coats and 1 finish coat, or 1 priming coat and 2 finish coats, as necessary.

[a] 10 = no rust; 0 = completely rusted. (Same as ASTM-D610.) See Figure E-4 for illustration. If new paint is incompatible with the old, all paint must be removed.



Taken from SSPC-Vis 2, "Standard Methods of Evaluating Degree of Rusting on Painted Steel Surfaces." May be used in conjunction with Table E-4 to determine degree of maintenance painting.

Figure E-4. Visual aid for determining percentage of rust.

Published reports of the

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are available from:

Highway Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

* Highway Research Board Special Report 80.

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Under the terms of its Congressional charter, the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE HIGHWAY RESEARCH BOARD, organized November 11, 1920, as an agency of the Division of Engineering, is a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of transportation. The purpose of the Board is to advance knowledge concerning the nature and performance of transportation systems, through the stimulation of research and dissemination of information derived therefrom.

HIGHWAY RESEARCH BOARD
NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL
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