Maintenance Repainting of Structural Steel: Chemistry and Criteria

BERNARD R. APPLEMAN

ABSTRACT

The conditions and requirements for maintenance painting of structural steel are considerably different from those for the initial painting. One of the most important differences is the nature of the surface encountered. The ability of an applied paint to adhere depends on the characteristics of the surface as well as on the wetting and spreading properties of the paint. The degradation of the paint film is both cause and effect of the corrosion of the steel. Empirical plots of rust versus time are typically exponential; however, the low reliability and precision of such data indicate the need for better techniques for characterizing and evaluating coatings. Maintenance engineers need practical criteria for evaluating the condition of a structure and for deciding when and how much to repaint. Existing standards from ASTM and the Steel Structures Painting Council are suitable for obtaining quantitative ratings for small uniform areas of steel. Commonly used methods for assessing total surface condition are qualitative. A modification of these two approaches can provide quantitative, detailed, and more meaningful evaluations of the condition of a complex structure. This approach also can provide estimates of the need for future painting.

The phrase "maintenance repainting" may appear redundant to some readers. It was chosen deliberately to emphasize that one maintains a structure by applying paint to a surface that already has had a coat of paint; this makes it quite different from steel that has never been painted.

Repainting of previously painted steel represents by far the majority of structural steel painting each year, yet the understanding of basic processes and the technology available to the practitioner are far less advanced than those for painting of new steel. Some of the special considerations needed in maintenance painting are highlighted with a focus on two of these items: chemical interactions at the surface and practical criteria for decisions on repainting.

The major features of maintenance and initial painting are compared first. One of the most important differences between previously painted structural steel and new steel is the nature of the surface encountered. The discussion covers the major types of surfaces and their characteristics and the requirements for adhesion and compatibility.

Then the techniques for characterizing and evaluating the performance of coated structural steel are discussed. This leads to an assessment of the types of criteria needed for maintenance painting. Two of these types are discussed in some detail: criteria for the existing condition of the coating and steel and criteria for when and how much to repaint. The discussion includes a review of existing industry and government criteria and a proposed modification of these standards. Finally, examples are given of predicting future degradation patterns.

INITIAL PAINTING VERSUS REPAINTING

The major differences between initial painting and repainting are listed in Table 1. For a new structure, the painting is usually included in the design plans and specifications. Funds are earmarked for the painting. All structural steel parts, except for faying surfaces and other noted areas, are painted; surface preparation (e.g., blast cleaning) and priming are done in the shop under relatively controlled and defined conditions. Moreover, there are numerous painting and inspection guides and extensive performance data available from professional organizations and manufacturers.

TABLE 1 Initial Painting Versus Repainting

Category	Initial Painting	Repainting
What to paint	Predetermined	Survey and analysis required
Funding	Capital funds	Maintenance funds
Schedule	Construction and erection deadlines	Not set, often deferred
Application conditions	Shop, controlled environment, easy access	Field site, weather factor, scaffolding, etc.
Metal surface	Uniform, clean metal	Variable, contaminated
Paint selection	Data, guides available	Few guides, no performance data

In contrast, for maintenance painting, in general, there is no clear definition of what structures or parts of structures are to be or need to be painted. The funds for repainting must come from already tight maintenance budgets. These funds are often sporadic, which makes advance planning difficult. Unfavorable field conditions (e.g., weather, scaffolding) for surface preparation and application are familiar to all.

One of the most significant features of maintenance painting is the variability of the surface, a subject to be examined subsequently. Finally, in spite of and perhaps because of these unfavorable factors, there is a great lack of standards, criteria, and guidelines for the maintenance painting of structural steel.

SURFACES, ADHESION, AND COMPATIBILITY

Common types of surfaces encountered on previously painted structural steel are as follows: blast-cleaned steel, tight rust and millscale, aged paint, and organic and inorganic contaminants. Materials such as loose rust, popped millscale, and nonadhering paint, which would normally be removed by the minimal surface preparation techniques, have been excluded.

Table 2 gives some characteristics of four surfaces. The surface energy (or wettability) is a measure of the ability of a droplet of liquid to spread out and make intimate contact with a surface (1,2). A high surface energy signifies good wettability, and vice versa. Of course, wetting depends on the liquid as well. The surface area is a measure of the number of bonding sites on the surface. A high surface area is desirable for good adhesion. One of the major beneficial effects of abrasive blasting is to increase the surface area of the steel.

TABLE 2 Surface Characteristics

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

The ultimate objective of painting is to produce a coating that will adhere to and protect the metal. Thus, it is important that the surface to which the paint is applied have a strong bond to the underlying metal. The thin oxide of a freshly blasted metal will be strongly bonded to the metal, as will tight rust. Less well adherent are aged alkyd paints, which tend to be brittle, and thin oil films, which may interact with the solvent or polymer of the applied paint. Table 2 also lists some other properties that may affect interactions between paint and surface.

In consideration of what is required for an applied paint to form a strong, durable bond to the metal surface, the first requirement is for the paint to form a continuous film on the surface. This entails good wetting and spreading. Wetting depends on the nature of the interactions (both chemical and physical) between paint and surface. It is a thermodynamic property.

Spreading depends on the kinetics of film formation. Of importance is the liquid paint's viscosity, both as applied and during the spreading. Processes such as solvent evaporation and chemical reaction will increase the viscosity and reduce the spreading rate.

Once the paint has spread out and formed a film, it must be capable of establishing permanent bonds to the surface. The strength of adhesion depends on several factors: the chemical interaction between paint film and surface moiety, the total number of bonds, and the bond distance. The bond strength falls off rapidly with distance. Any contaminant on the surface can preclude any direct bond between paint and surface molecules.

Several commonly used maintenance paints will be examined in light of the requirements for film adhesion. Paints are composites whose properties depend on the various components. The surface energies given in Table 3 are based primarily on the solvents; reliable data on the paints themselves (3,pp.F33-F36;4) were not available.

TABLE 3 Properties of Paints Affecting Film Adhesion

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

[a]These data are based on solvent properties.

Non-oil-containing, so-called "high-performance" paints (vinyl, epoxy, and zinc-rich) all have volatile solvents, so that very rapid increases in viscosity follow application. They all can form direct valence (primary) bonds to blast-cleaned steel, the substrate for which they were primary developed. The oil-containing paints form only polar bonds with metal. The epoxy and oil-alkyd paints have a higher proportion of polar groups capable of bonding to organic surfaces.

The overall strength of adhesion for the different surfaces considered is shown in Table 4. The numbers in parentheses are the solid and liquid surface energies. The general rule is that a liquid will wet a surface whose critical surface energy of wetting is greater than the liquid's surface energy (1). Note that vinyls and epoxies tend to form good bonds to existing vinyls and epoxies, but these are not nearly so common on older structures as oils and alkyd paints.

TABLE 4 Overall Strength of Adhesion

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

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

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

PERFORMANCE OF COATINGS AND STEEL

The application and adhesion of a paint are necessary but not sufficient conditions for substrate protection. Also required of a paint is long-term ability to maintain its integrity and prevent corrosion of the metal. These constitute the performance of a coating system. A few aspects of paint performance will be examined briefly. Major factors responsible for coating degradation and steel corrosion will be identified. Also to be discussed and illustrated are observed patterns of coating degradation with time and the deficiencies of empirical plots of rust versus time.

It is important to emphasize that performance depends on the condition of both the coating and the steel and that the two influence each other. Coatings degrade from the outside (moisture, abrasion, ultraviolet radiation), the interior (internal stress, film embrittlement, leaching of additives), and from the inside (undercutting, rust, blisters). The process of corrosion causes the coating to degrade more rapidly than it otherwise would.

Metallic corrosion requires a source of water and oxygen along with areas of differences in steel potential. While intact, a good barrier coating can limit the access of water and oxygen. As the coating degrades (i.e., film breaks and disbonding), it provides less and less of a barrier. Thus, the degradation of the coating leads to increased rate of corrosion in the metal.

The combined effects of the coating and steel performance are an example of negative synergism. The corrosion of the metal accelerates the degradation of the coating, and the breakdown of the coating accelerates corrosion. This phenomenon is important because it helps explain the observed rates and patterns of deterioration in coated steel.

Figure 1 shows some examples of generalized performance behavior with time. The top curve (A) represents a property in which the rate of degradation decreases with time and the bottom curve (B) a property in which the rate of degradation increases with time. The corrosion of bare steel in the atmosphere

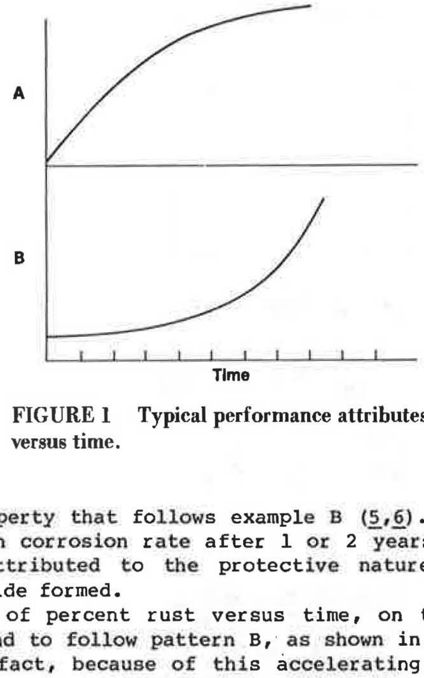

FIGURE 1 Typical performance attributes versus time.

is a property that follows example B (5,6). The decrease in corrosion rate after 1 or 2 years (Figure 2) is attributed to the protective nature of the loose oxide formed.

Plots of percent rust versus time, on the other hand, tend to follow pattern B, as shown in Figure 3 (7). In fact, because of this accelerating degradation pattern, a linear scale is not well suited for characterizing rust versus time for coated steel. ASTM, the Steel Structures Painting Council (SSPC), and others have adopted a logarithmic scale. This will be discussed later.

The particular example given is a smoothed curve based on large amounts of empirical data. Most of the time it is not practical to produce plots such as these. Even when it is, there are problems re-

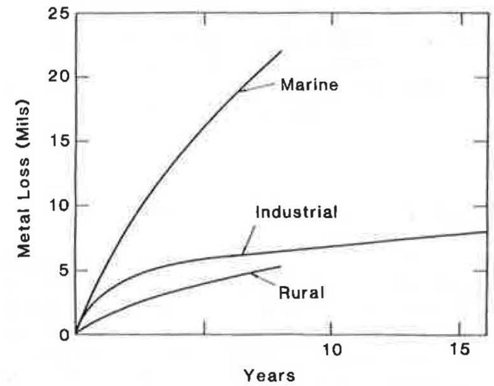

FIGURE 2 Corrosion of bare carbon steel.

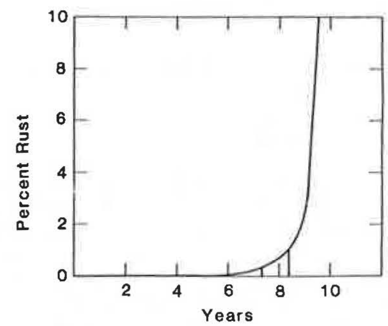

FIGURE 3 Deterioration of coated steel.

garding their interpretation. Frequently the conditions under which data were obtained (e.g., salt fog test) are not representative of actual environments for which information is needed. Even where data are from outdoor panel tests or structures themselves, there are large variations in the coating system used, the type of surface, or the exposure environment. These items, particularly the first, have been widely discussed in the literature.

A related factor is the lack of statistical reliability of most reported performance data. Because of the large amount of scatter, it is frequently necessary to prepare and evaluate several replicate test specimens. In evaluating performance of field data, even larger numbers of surfaces must be examined. Most tests do not provide enough replicate data to establish error limits (degree of reliability).

Finally, in monitoring the performance of coated steel, the inspector or researcher evaluates and records visual properties such as percent of surface rusted, number and type of blisters, and degree of chalking. It is unfortunately not practical to detect more fundamental quantities such as underfilm rust, electrical potential of steel, changes in polymer tensile strength, or internal stress.

It is hoped that eventually techniques will be available to monitor these properties in situ. This would provide earlier indications of deterioration of performance and facilitate coating system testing and timely maintenance painting. There is a considerable amount of effort directed toward understanding and monitoring basic processes. For example, Lehigh University and National Bureau of Standards researchers and others are investigating how corrosion initiates and spreads under a film and are developing more quantitative methods for evaluating coating performance. These studies should provide the coatings scientists with better knowledge of the fundamental processes of coatings and steel degradation and eventually lead to more efficient and accurate methods for monitoring and evaluating field performance.

CRITERIA NEEDED FOR MAINTENANCE REPAINTING

However, the current crisis in structural maintenance cannot wait for these techniques. What can be done about the immediate needs for corrosion protection? How can better advantage be taken of existing technology? In particular, how can the maintenance engineer or inspector be assisted in carrying out more effective corrosion protection?

The start is to identify the major decision points or criteria for maintenance painting. A criterion is defined as a standard of judgment. The criteria are as follows:

- Condition of existing paint and steel,
- When to repaint,
- How much to prepare and paint, and
- What paint system to use.

Fist, a standard is needed for the condition of the existing paint and steel. The second and third of the foregoing criteria depend on the condition of the structure as well as on the philosophy or objective of the maintenance painting program. The final criterion listed depends partially on these factors and also on individual preferences and experience. It will not be addressed in this paper.

CRITERIA FOR COATING AND STEEL CONDITION

As discussed earlier, the performance of coatings on steel is normally evaluated by visual properties. Coatings specialists are all familiar with ASTM standards for quantitative evaluation of defects. The most widely used standard is ASTM D-610 (Degree of Rusting). A numerical value from 1 to 10 is assigned on the basis of the percentage of surface rusted (Figure 4). The correspondence between D-610 rust rating and percent rust is as follows:

Percent Rust	Rust Rating (R)
≤0.01	10
0.03	9
0.1	8
0.3	7
1.0	6
3.0	5
10.0	4

As noted, there is a mathematical logarithmic relationship between the two:

$$R = -2X \langle \log (\% \text{ Rust}) \rangle + 6 \quad (1)$$

where R is the rusting rating.

The ASTM standards evaluate a single specific defect each (e.g., rusting for D-610 or blistering for D-714). SSPC specification SSPC PA-4 (8) provides a rating scheme that recognizes the need to account for both coating defects and steel corrosion when decisions are made on repainting (see Table 5). SSPC PA-4 rates the total surface area affected by paint

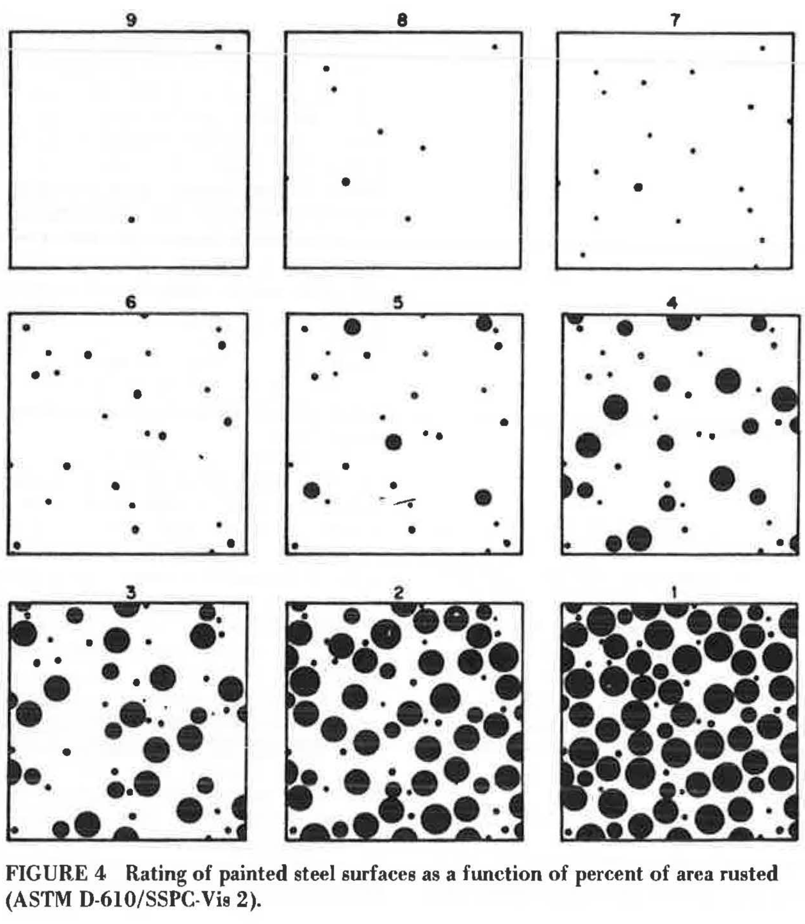

FIGURE 4 Rating of painted steel surfaces as a function of percent of area rusted (ASTM D-610/SSPC-Vis 2).

TABLE 5 SSPC PA-4: Maintenance Painting of Oil-Alkyd Paint

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

system defects (e.g., loose paint, blistering, rust) by using the ASTM equivalency scale. This rating scheme also reduces the total number of conditions from 10 to 5.

ASTM-type standards were developed and intended for evaluating small test specimens. They are difficult to use on real structures because of the nonuniformity of rusting and coating degradation. Because of this, several users have developed rating schemes that take into account the entire surface area. An example is that of the British Standards Institute (9), which has established five conditions for a painted structure:

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

However, there appears to be a need for some intermediate rating between Conditions 3 and 4.

An example of an industrial-user rating scheme is the following (10):

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

The conditions are based on a visual estimation of the percent of surface requiring preparation. A secondary consideration is the percent of the surface area showing loss of topcoat. Both of these schemes are based on qualitative, broad-brush evaluations of general surface condition. There is no definition for what type of surface requires preparation or how to determine this. Unless one has an experienced inspector, these schemes could result in highly erratic recommendations.

PROPOSED SCHEME FOR RATING TOTAL SURFACE AREA

It is possible to apply more quantitative assessment techniques for rating large surface areas. One such proposed scheme consists of four steps:

1. Identify the major structural elements (e.g., plates, girders, braces);
2. Subdivide each of these parts into ratable areas, defined as ones with a relatively uniform coating or steel condition; then visually or otherwise estimate the percentage of the total surface covered by the rating area;
3. Assign a numerical or semiquantitative rating to each rating area; these can be limited to ASTM rust ratings or can include multiple defects such as those described earlier; and
4. Compile the data.

Clearly, the final rating will not consist of a single percentage rating or general condition statement, but rather will reflect the complex patterns of coating and steel degradation. Of course, the user could always establish an overall condition rating of the structure that is a distillation of the ratings of the individual parts.

This technique is most suitable for relatively large surface areas. For small equipment and structures with intricate configurations, it is often more feasible to assign a single rating to an entire unit or subunit. An experienced inspector can assign a single rating for a larger structure if the total amount of deterioration and the degree of nonuniformity are not too great.

An example illustrated is a bridge with about 40 fascia plates (Figure 5). Approximately 12 plates showed some evidence of deterioration. For some there were only a few spots (5 percent of the surface with a rating of 9). On Plate 3, 10 percent of the surface had a rating of 4 (Figure 6), and on Plate 4, 40 percent had a rating of 6 (Figure 7). A rust rating of 8 is shown in Figure 8. The second example is a storage tank. Most of the structure (90 percent of the painted surface) showed no visible signs of rust or paint breakdown (Figure 9). By using the method outlined previously, it was determined that about 3 percent of the entire surface had a degradation rating of 9 according to ASTM D-610 (Figure 10). Another 3 percent received a rating of 8 (Figure 11), and 4 percent of the surface received a rating of 7 (Figure 12). These ratings were based on total defects, including rust breakthrough and topcoat cracking.

In some instances it might be appropriate to determine the percentage of the surface area showing a rating of 8 (Figure 8) or worse. For the tank example a total of 7 percent of the surface was rated as 8 or worse. For this tank, a walk-around inspection would yield an overall rating of 9. Alternatively the inspector could identify the number

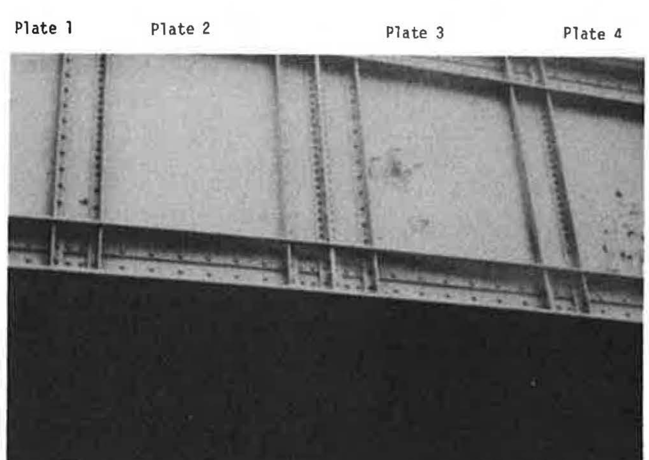

FIGURE 5 Rating of plates on highway bridge.

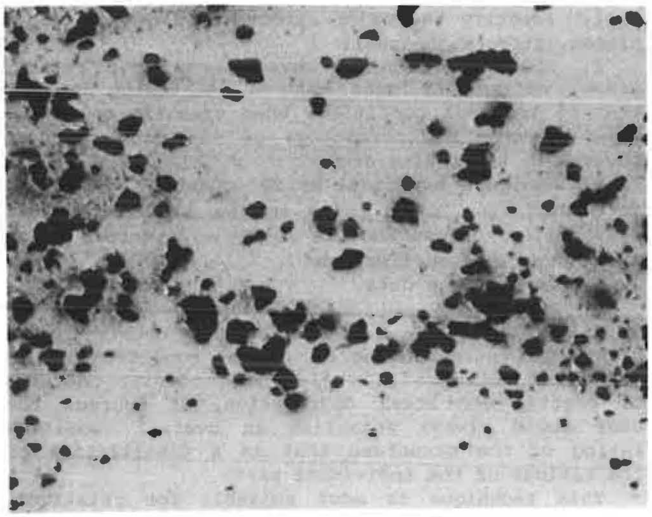

FIGURE 6 ASTM D-610 rust rating of 4.

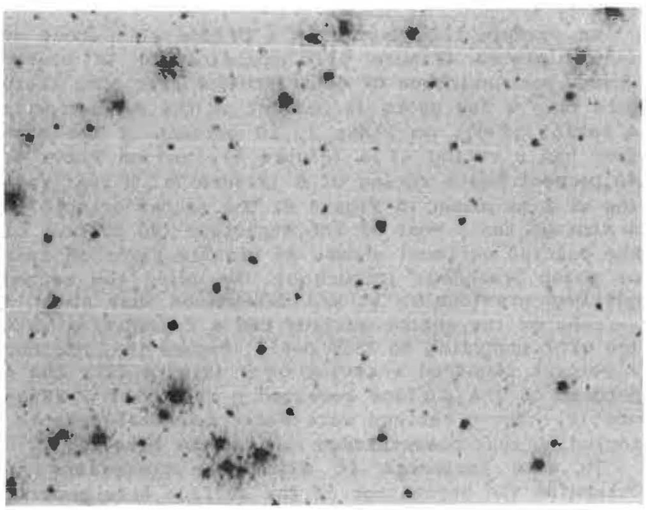

FIGURE 7 ASTM D-610 rust rating of 6.

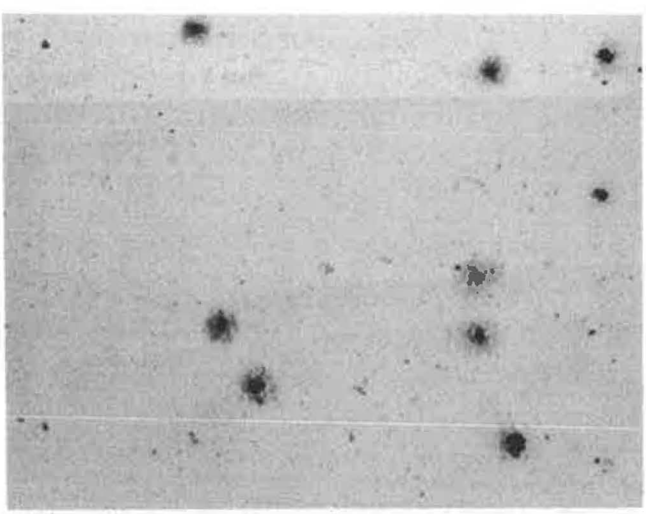

FIGURE 8 ASTM D-610 rust rating of 8.

of plates requiring 0 to 10 percent, 10 to 50 percent, or 100 percent repainting. For the bridge example Plates 1 and 2 required 0 to 10 percent repainting, whereas Plates 3 and 4 required 10 to 50 percent repainting. It is important to establish a systematic, consistent procedure that takes into account the number of components and structures to

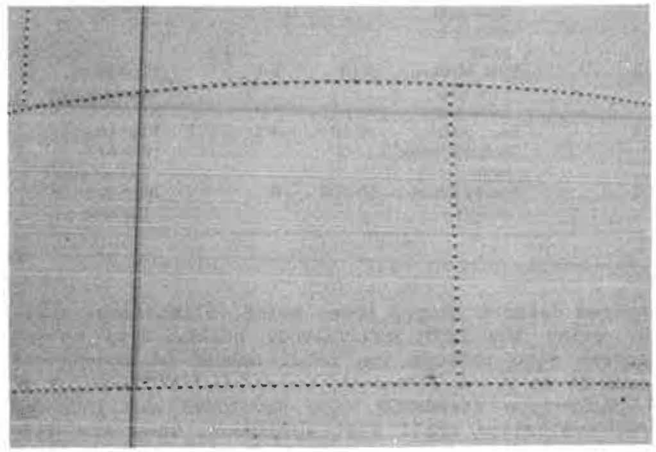

FIGURE 9 Portion of tank with ASTM rust rating of 10.

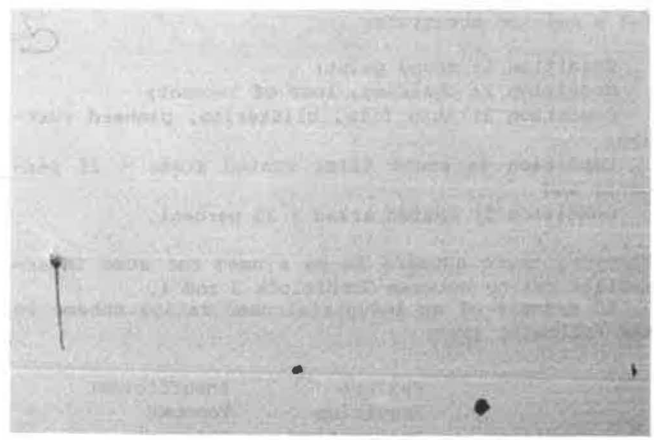

FIGURE 10 Portion of tank with ASTM rust rating of 9.

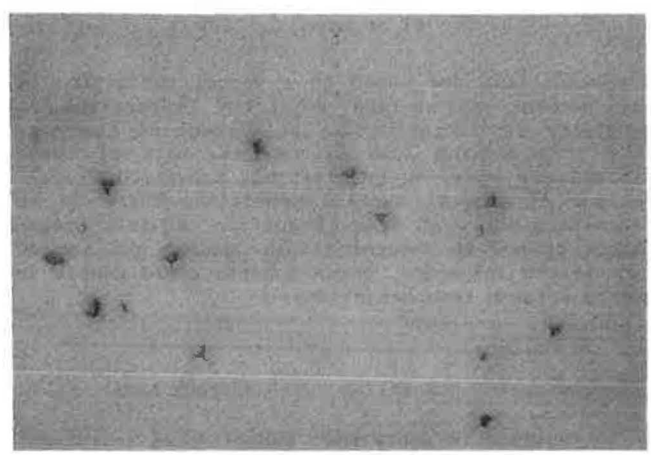

FIGURE 11 Portion of tank with ASTM rust rating of 8.

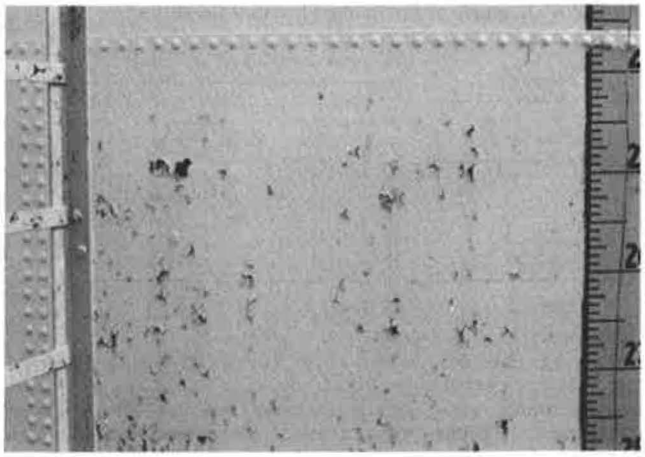

FIGURE 12 Portion of tank with ASTM rust rating of 7.

be rated, the uniformity of the surface condition, and the eventual use of the results. Use of numerical ratings for the individual areas can prove advantageous in estimating future degradation, as will be discussed later.

CRITERIA FOR WHEN AND HOW MUCH TO REPAINT

The preceding has been concerned with criteria for evaluating the structure's condition. Also of interest are criteria for when and how much to repaint. These depend to a great extent on the painting philosophy or objective. Painting to maintain appearance at the least cost will likely require repainting at an earlier stage than if preventing metal loss were the primary objective. A structure will be painted still less frequently, and even then only in critical areas, if maintaining structural capacity is the only requirement.

It is also important to distinguish between situations in which repainting is already mandated and the only questions are "how much" (and "how") and situations in which one also must decide whether to paint now or to wait ("when"). Several examples will be given of published criteria for when and how much to paint.

SSPC PA-4 is an example of a "how much" criterion (8). It prescribes what to do on the basis of existing conditions (Table 5). It does not specify, for example, whether it is preferable to paint at Condition 1 or 2. Other authorities, however, do include such recommendations. Repainting is frequently specified when a structure reaches an ASTM D-610 rating of between 7 and 8 (11). The industrial-user rating scheme cited earlier recommends painting when coating passes from Condition 2 to 3. However, if appearance is of little import, the author suggests waiting until the surface reaches Condition 5, at which point 100 percent abrasive blast cleaning is recommended. This example highlights the need for a maintenance painting philosophy in formulating repainting criteria.

DETERMINING FUTURE CONDITION OF PAINTED STEEL

Another important factor in estimating the condition and time for repainting is the interval between the survey and the actual inspection. Frequently budgets and schedules must be prepared 1 or 2 years in advance. Thus, the inspector may have to estimate what the condition of the paint and steel will be in the future.

The California Department of Transportation rating system for bridges includes tips for estimating how long it takes to go from Code 4 (rust starting along edges) to Code 5 (requires repainting within 5 years) (12). For a red lead alkyd paint system, the telltale signs are enlarging rust "freckles," and peeling of the topcoat and exposure of the primer. Rapid deterioration has been observed within 1 year for some systems in marine atmospheres.

Windler (13) suggests assigning coating priorities based on the condition of the metal and the coating. He recommends immediate recoating of areas showing an ASTM D-610 rust rating of 4 or less and of areas where coating exhibits marginal adhesion. Recoating is recommended within 12 to 24 months in areas showing ASTM ratings of 6 to 8 and topcoat delamination. Repainting of other areas, including those with minor localized spot rusting, can be delayed more than 2 years.

RUST RATINGS LINEAR WITH TIME

In order to estimate or predict what the condition of a structure will be in 2 or 3 years, information is needed on the rate of degradation as well as on the current coating and steel condition. A rearrangement of some data shown earlier (Figure 3) is given in Figure 13. Figures 13 and 14 (7) show ASTM D-610 rust ratings (instead of percent of rust) versus time. The data suggest that the rate of deterioration in the ASTM rust rating is approximately linear with time. This is equivalent to the statement that the percentage of surface rusting is approximately exponential with time, because the ASTM rating system is essentially an exponential scale.

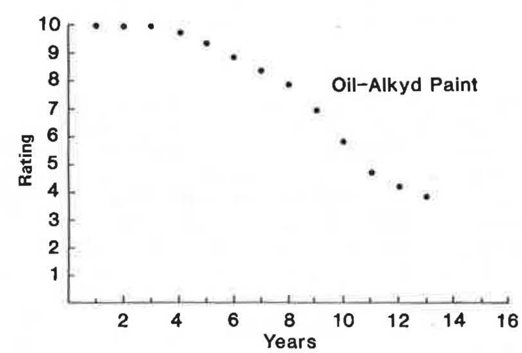

FIGURE 13 ASTM rust rating in industrial environment.

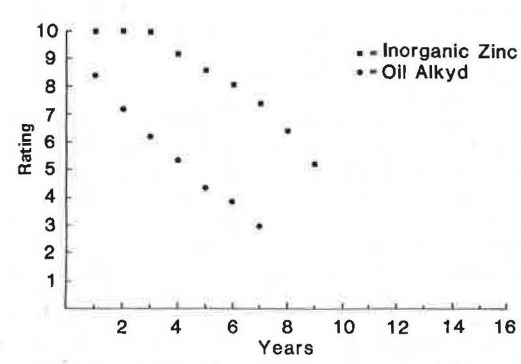

FIGURE 14 ASTM rust rating in marine environment.

There are also in some instances apparent threshold or induction periods lasting up to several years, during which no rust is observed. This time period depends on the type and thickness of coating and the exposure environment and is one of the most frequently used criteria for comparing coatings. This threshold period varies enormously, ranging from as little as 1 to 2 years for an alkyd in a marine environment to 15 to 20 years for an inorganic zinc in a mild or rural environment (Figures 13 and 14).

However, the slopes of these curves have considerably less variability than the thresholds. For most systems studied, the slope ranges between 0.5 and 1.0 ASTM units per year. These observed rates can be used to construct high and low ranges for predicted corrosion rates for an oil-alkyd paint in an industrial environment (Figure 15). The high-rate curve has a threshold of 2 years and a deterioration rate of 1.0 ASTM unit per year. The low-rate curve has a threshold of 4 years and deteriorates at 0.5 ASTM unit per year.

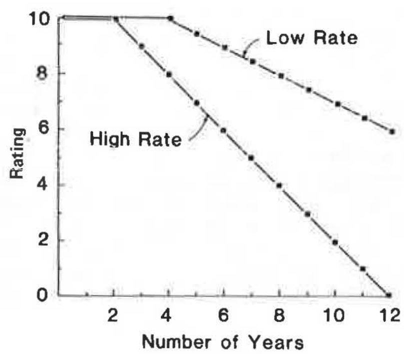

FIGURE 15 Estimating ASTM rust rating from high and low corrosion rates.

These curves can be used to estimate future corrosion effects and from those to determine future maintenance painting needs. This evaluation requires the ratings of the current condition of the structure. The example used is the tank shown in Figures 8-12. Future condition can be estimated on the basis of the graphs of high and low degradation rates (Figure 15). For example, under the high-degradation-rate assumption (1.0 ASTM unit per year), in 2 years the 10-rated areas would drop to 8, the 9-rated areas would drop to 7, the 8-rated areas to 6, and so on. Under the low-degradation-rate assumption (0.5 ASTM unit per year), the 9-rated areas would drop to 8, the 8-rated areas to 7, and so on, after 2 years. (Because of the threshold effect, it is assumed that for the first year the 10-rated areas do not degrade in the low-rate analysis.)

The ultimate objective of such an analysis would be to determine when the structure will require repainting. In this case (oil-alkyd paint over hand-cleaned steel in an industrial atmosphere), repainting is often stipulated when a large portion of the surface reaches a condition rating of 8. The ratings showed that currently 7 percent of the surface has a rating of 8 or worse (3 percent at 8, 4 percent at 7). This is the proportion of the surface that would require surface preparation by wire brushing if the structure were to be repainted. After 1 year, that would increase to between 8 and 10 percent (Table 6). After 2 years, this proportion is 10 to 100 percent and after 3 years 33 to 100 percent. These figures indicate that repainting cannot be deferred for 3 years. Even 2 years may be too long to wait, because if the corrosion rate is in the high range, the entire structure will have a rating of 8 or worse. Thus, some action is required for the following year, either repainting or reinspection. The latter would determine whether painting could be deferred for one more year.

TABLE 6 Example of Predicting Structure Condition

Current Condition		Projected Condition (% of surface)					
		1 Year		2 Years		3 Years	
ASTM Rating	Percent of Surface	High	Low	High	Low	High	Low
10	90	0	90	0	45	0	0
9	3	90	2	0	45	0	67
8	3	3	3	90	3	0	24
7	4	3	5	3	3	90	3
8 or worse	7	10	8	100	10	100	33

This example illustrates the value of conducting regular systematic surveys and documenting and applying the observed trends. The model predictions are approximations. They are dependent on the reliability and accuracy of the data used to derive the degradation curves. In applying the results, the user must be aware of the limitations of predicting coating behavior. In many cases, the input data can be modified to approach more closely existing conditions of a specific structure. Although far from being precise or proven tools, the methods proposed are expected to be an improvement over crude "guesstimating" or "eyeballing" techniques commonly used for making maintenance painting decisions.

SUMMARY AND CONCLUSIONS

The differences between maintenance painting and initial painting have been highlighted. One of the most important differences is the nature of the surface encountered. The wetting and spreading properties of paints and the characteristics of various surfaces determine the adhesion of the paint to the steel. Once paint is bonded to steel, its ability to protect steel from corrosion and retain its integrity is the problem to be addressed. The performance characteristics of coated steel versus time have been described and the negative synergism, deficiencies in current evaluation techniques, and possible improvements were noted.

A more immediate problem is to assist maintenance engineers in evaluating structural condition and deciding when and how much to repaint. Existing ASTM, SSPC, and other published criteria were reviewed and a technique was described for obtaining quantitative ratings for an entire structure. This approach may require some modification for different structures and conditions. It also may be used to estimate the need for future painting. These as well as more conventional standards and techniques, though far from perfect, can be effective tools in the effort to maintain, preserve, and protect the nation's public structures in the least costly and most efficient manner.

REFERENCES

1. W.A. Zisman. Surface Energetics of Wetting, Spreading, and Adhesion. Journal of Paint Technology, Vol. 44, Jan. 1972, pp. 42-57.
2. T.C. Patton. Surface Tension. In Paint Flow and Pigment Dispersion (Ch. 9), 2nd ed., John Wiley and Sons, New York, 1979.

3. C.R.C. Handbook of Chemistry and Physics, 64th ed. C.R.C. Press, Inc., Boca Raton, Fla., March 1983.
4. M. Tellor. Corrosion Resistant Zinc Paints. In Proceedings of Zinc Protective Coatings Conference, Zinc Institute, Inc., New York, 1981.
5. C.P. Larrabee. Mechanisms of Atmospheric Corrosion of Ferrous Metals. Corrosion, Vol. 15, 1959, p. 526.
6. F.W. Fink and W.K. Boyd. The Corrosion of Metals in Marine Environments. Battelle DMIC Report 245, Bayer and Company, Inc., Columbus, Ohio, 1970.
7. S. Frondistou-Yannas. Coating and Corrosion Costs of Highway Structural Steel. Report FHWA-RD-79-121. FHWA, U.S. Department of Transportation, March 1980.
8. Guide to Maintenance Painting with Oil-Alkyd Paint. SSPC PA-4. Steel Structures Painting Council, Pittsburgh, Pa., Nov. 1982.
9. Code of Practice for Protective Coating of Iron and Steel Structures Against Corrosion, Section 5: Maintenance. BS 5493. British Standards Institute, London, 1977.
10. S.P. Thompson. Managing a Maintenance Painting Program to Reduce Costs. Materials Performance, Vol. 21, No. 10, 1982, pp. 48-51.
11. A.H. Roebuck and G.H. Brevoort. Coating Work Costs and Estimating. Paper 145. Presented at CORROSION/82, National Association of Corrosion Engineers, Houston, Tex., 1982.
12. B.F. Deason. Methods of Evaluating Paint Conditions on Existing Steel Structures. California Department of Transportation, Sacramento, Dec. 1980.
13. F.J. Windler. The Corrosion Survey: An Engineer's Guide to Maintenance Painting Specifications. Paper 35. Presented at CORROSION/83, National Association of Corrosion Engineers, Houston, Tex., 1983.

Publication of this paper sponsored by Committee on Structures Maintenance.