FINAL REPORT

STEEL BRIDGE PROTECTION POLICY

VOLUME V

WARRANTY CLAUSES FOR INDOT STEEL BRIDGE PAINT CONTRACTS

FHWA/IN/JTRP-98/21

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16. Abstract

The study identifies various painting systems that are successfully used in Indiana's surrounding states and other industries. The identified systems are further screened and evaluated. After prudently comparing INDOT's inorganic zinc / vinyl system with the waterborne acrylic system, the moisture cure urethane coating system, and the 3-coat system of zinc-epoxy-urethane, the results show that the new 3-coat system fulfills INDOT's needs with the most benefits. Therefore, the 3-coat system is recommended to replace INDOT present inorganic zinc / vinyl system.

To deal with the problems facing the lead-based paint, a comparison between full-removal and over-coating alternatives is made. Results show that over-coating might provide a good protection for less than half the cost of full-removal; however it delays the lead full-removal process and does not completely solve the environmental problem.

The metalization of steel bridges is seemingly a potential protection policy. After reviewing standards and specifications on metalization, it is shown that metalization jobs require a higher degree of control. It suits on-shop practices, however, the initial cost is considerably high.

This study also describes a life cycle cost analysis that was done to determine an optimal painting system for INDOT. Herein, a deterministic method of economic analysis and a stochastic method of Markov chains process are used. The analysis not only reconfirms that the 3-coat system is the comparatively better painting system, but also generates an optimal painting maintenance plan for INDOT.

To assure the quality of paint material and workmanship after substantial completion of the painting contract, the development of legally binding and dependable warranty clauses is initiated in this study. The developed painting warranty clauses were primarily derived from the painting warranty clauses used by IDOT, MDOT, and INDOT's pavement warranty clauses. A comparative study was conducted on eleven essential categories. Among them, it was found that the warranty period, the definition of "defect", and the amount of the warranty bond all need further evaluation.

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CHAPTER I

INTRODUCTION

The service life of a steel bridge is contingent upon several parameters. Those parameters, however, affect the service life of the bridge with varying degrees. Provided that the design and construction of the bridge suffice all the long lasting considerations, the level of surface corrosion rises as the utmost parameter governing a bridge service life span. In 1987, a survey was conducted by the Federal Highway Administration (FHWA) on approximately 112,000 steel bridges in the United States (SSPC, 1989.) The survey was initiated with the purpose of investigating the current condition of the various steel bridges in the US. Over 4000 of these bridges were found to be deficient. A large part of the deficiency arose from the inadequate maintenance which resulted in a deteriorated and severely corroded condition of those bridges.

1.1 PROBLEM STATEMENT

Painting is considered to be the primary approach of protecting a steel bridge's surface against corrosion. It functions as an inhibitor or barrier to prevent, as much as possible, the corrosive attack of the steel substrate by moisture, high salt content air and oxidizing chemicals. However, the local environment drastically differs from one place to another. It is not uncommon to find a wide variation in the environment within a very small geographic area due to local effects (SSPC, 1989.)

Since it is hard to change these environmental conditions or limit their effect on the bridge, it is crucial to: (1) choose a suitable and durable coating system that endures the severe attacks of the environment, (2) control the application of such coating system, and (3) warrant that the coating system will sustain until the following rehabilitation activities are thought of.

After specifying a suitable painting system to coat the bridge substrate, the responsibility falls mainly on the contractor for the successful application of the painting system. During the original contract period, the contractor is bound by the contract to comply with specifications and to carry out works in full accordance with the engineer's instructions. However, acceptance of the project is deemed to be an important benchmark in the relationship between the owner, i.e., the State Department of Transportation, and the contractor. Without an explicit contract wording to warrant the materials used and the workmanship after the substantial completion of the works, it is hard to place any further responsibility on the contractor.

If defects were discovered after the final acceptance of the project, no claim for remedies could be sought for because of the absence of any warranty in the contract wording. A decision is to be made of whether to load the repair expenses on the State Department of Transportation; or to leave the bridge without any recovery until the following rehabilitation activity. The former choice will substantially increase the actual cost of maintenance while the latter will cause the bridge to deteriorate faster than usual and consequently to reduce the service life of the structure.

Currently, Indiana Department of Transportation (INDOT) is not using warranty clauses in its bridge painting contracts. Several cases were encountered where the incompetent workmanship of the contractor's workers resulted in a fast deterioration of the painting system. Various painting systems failed in a few number of years that is considered minimal if compared to the life expectancy of the system under working conditions.

Previous work of Chang and Hsie (1992) on a sample of Indiana steel bridges revealed some interesting inferences. The study was conducted on 6 bridges painted on shop and 13 bridges painted on site. All data were collected during the actual application of the paint. The statistical analysis of the data collected showed that there existed a significant difference between the quality of painting between the abutment areas and the middle span areas. The thickness of the top coat around the middle areas has a strong tendency to be thinner than that around the abutment area. Also, The study showed a noticeable difference in the painting system thickness for the different structural components of the bridge.

The inconsistency in the application of the painting system is a major pitfall in the process as a whole. Any thin areas of the paint constitute the weak spots that have higher potential for corrosion. Although a part of the severely deviated results of the study is due to the non-stringent inspection process, the responsibility of the contractor is unquestionable. Added to that, this non-stringent inspection process constitutes a strong stimulus for the contractor to perform the work recklessly. The backstay of all contractors is to do as much work as possible to sustain the fiercely competitive environment. Therefore, it is of much benefit for the contractor to finish the project in hand in the least possible time and to survive all the inspection stages. Without any clause in the contract wording that binds the contractor to the quality of work he performs, no extra care could be sought of. The contractor will act in a manner of Hit & Run.

1.2 PURPOSE AND OBJECTIVES

The absence of an explicit warranty clause in the contract wording hypothetically eliminates the contractors' accountability of any future defects in their work. One- or two-year guarantees are not rare in bridge paint specifications today, although the guarantees are often vague and poorly written (Hare, 1990.) Few guarantees are properly written or legally binding. A proper guarantee not only offers the Department of Transportation advantage in the improved quality assurance but also allows methodologies other than low prices in evaluating bids. It may also assist in eliminating the less competent contractors from entering the bid.

This report represents a study conducted to investigate the practices of using warranty clauses in steel bridge painting contracts. The ultimate goal of the study is to draft a warranty clause that can be put into experimental use in INDOT's 1997 construction-season. The proposed warranty clause will act as an experimental form to be used on one pilot project. It will be subject to further analysis and modifications according to its performance in the pilot project.

Chapter II discusses the methodology that has been followed to develop the warranty clause. Both the total conversion and the pilot project conversion as an implementation strategy for the new warranty clause are briefly reviewed. The chapter also explains the background and the foundation elements incorporated in the development process.

Chapter III represents an overview of some basic concepts that constitute the core of the study. Two main topics are thoroughly reviewed. The first half of the chapter presents the basic structure of any warranty clause. All the general concepts such as the warranty scope, the warranty period, the different bonds used to guarantee the owner rights, and others are explained in detail. The second half is devoted to discuss the various defects associated with the steel bridges painting practices. In general, the scope of the warranty clause or in other words, the type of defects warranted by the clause constitutes its major element. Therefore, special attention was taken to clarify this issue.

Chapter IV provides the comparative studies conducted to develop INDOT's proposed warranty clause. The chapter starts by a quick review of the different forms available to be used in developing INDOT's warranty clause. To facilitate the analysis process, eleven categories are identified that need to be addressed in the resulted warranty clause. For each of those eleven categories, a thorough analysis takes place to reach a conclusion about the ideal representation of this category. Finally, the chapter ends up with a draft of the proposed form of INDOT's painting warranty clause.

Chapter V summarizes the different elements constituting the report. Special emphasis is given to the development process of INDOT's warranty clause and the final drafted form previously presented in chapter III. Besides, the chapter includes some of the weakness areas in the proposed form due to the lack of use of advanced technologies in governmental projects. Various recommendations for future work are included that can substantially improve the performance of the warranty clause in particular and the steel bridges painting practices in general.

CHAPTER II
METHODOLOGY

Warranties are commonly used in most industries. People realized long ago that without a written warranty in a terminated contract, the other party has no further responsibility for the quality of works he has performed during the contract period unless an explicit breach of the common law exists. In the past few years, INDOT has experienced an increasing number of the deteriorated painting systems of its steel bridges after the substantial completion of the painting job. Developing a warranty clause to guarantee the quality of painting works has become a mandatory requirement for all future contracts. The introduction of the warranty clause as a part of the contact wording will impose an additional obligation on the contractor for the quality of work performed.

Adopting a total conversion strategy in introducing the warranty clause has its high potential risk. If the developed form turns out to be faulty, the implications can be destructive. A pilot implementation strategy can better fit the development process of such warranty clause. This strategy comprises the development process to take place into successive phases. Initially, a draft of the warranty clause is to be prepared and put into experimental use in the following construction season. Through limiting the implementation of the experimental warranty clause to one pilot project, the consequences of any faulty or insufficient portion of the clause can be confined to that specific project. The performance of the warranty clause in the pilot project will help more identify the possible points of weakness. According to the analysis results, the warranty clause can be modified to better satisfy INDOT's requirements. Afterwards, the warranty clause can be used on a more general basis. However, it will always be subjected to further modifications whenever a certain insufficiency is found out.

2.1 THE GENERAL FRAMEWORK

Painting steel bridges constitutes one of a huge variety of practices in construction realm. Each of those practices has its own peculiarities. This raises an important question about the extent to which the various warranty clauses used for each of those practices may differ from each other. It is crucial at this point to realize that the basic structure of any warranty clause is independent upon the specific field of application. However, the basic structure is subjected to all the needed adaptations to fit the specific practice in hand. One of the most explicit differences between any two sample warranty clauses is the part that defines the defects for which the contractor will be held responsible. For instance, the types of defects arising from a poor workmanship in concrete construction are completely different from those associated with painting systems of steel bridges. Whether the warranty clause is designed for concrete construction, painting steel bridges or any other application, it must include a portion that defines: (1) the possible defects that may arise after the substantial completion of works and which relate to the poor workmanship of works, (2) the methodology used for measuring the predetermined defects, and (3) the range of values for which the contractor will be held responsible.

The set of elements generally incorporated in any warranty clause constitutes the aforementioned basic structure or basic model. The similarity in the basic structure highlights the importance of acquiring sufficient knowledge and understanding of the general requirements of any warranty clause. During the development process of the steel bridges painting warranty clause, the predefined framework or structure of the warranty clause will minimize the possibility of any major insufficiency to take place. Added to that, it will help as a baseline for comparison purposes of any existing warranty clauses.

2.2 ALTERNATIVE APPROACHES

There is no single approach that can ideally be followed in developing a new warranty clause for a certain application. The choice itself depends to a great deal on the special circumstances of the development process and the type of data available. When the research was initiated to develop a new warranty clause for steel bridges painting contacts in Indiana, there existed no clear and sound route to follow. However, various approaches were to be examined. Those approaches can be summarized as follows;

(1) To conduct a thorough search for any warranty clause in practical use by another state. If one or more of those warranty clauses are found, they will be subjected to a complete review and analysis and, then, adapted in such a way to satisfy the special requirements of INDOT,
(2) To adopt one of the well-established warranty clauses in another painting practice like pipelines, or by the automotive industry. This base warranty clause will be subjected to all the necessary modifications to make it match with bridge painting practices, and
(3) To start from the basic structure of a warranty clause and build the applicable form for steel bridges painting practices.

It is obvious that the first alternative is the most efficient and economical regarding both time and effort. This directed the research to find any warranty clause in current use for steel bridges painting practices. A special attention was paid to the neighboring states. The States of the Midwest area have quite similar regional conditions. These regional conditions, however, can play a major role in defining the types of painting failures in the warranty clause wording. As will be discussed in greater detail in the succeeding chapter, the scope of the warranty clause constitutes its core element. This trend was appreciated by INDOT personnel as it can help in any future regional integration between the different Departments of Transportation of the Midwest.

2.2 THE FOUNDATION OF INDOT'S WARRANTY CLAUSE

The quest of the existing warranty clauses in the steel bridges painting practices was quite encouraging. Both IDOT (Illinois Department Of Transportation) and MDOT (Michigan Department Of Transportation) are currently using warranty clause in their steel bridges painting contracts. MDOT has two versions of the warranty clause that has been used in its contracts. The first version was established in 1989 while the second, which represents an adapted form of the first version, was established in 1994. Those two warranty clauses will constitute the foundation elements of INDOT's steel bridges painting warranty clause.

IDOT and MDOT warranty clauses represent the basic structure of a warranty clause adapted in such a way to match both the steel bridges painting practices and the special regulations of each of the two departments. The initial review showed that sometimes a certain bias exists in terms of the special regulations and permits required. To avoid any possible contradiction in the administrative practices of INDOT compared with those of IDOT and MDOT, INDOT's pavement warranty clause was provided as the third foundation element of the warranty clause. The pavement warranty clause is deemed by INDOT personnel to be among the most successful and well prepared in INDOT practices. The comparative analysis, conducted on the material of these three foundation elements, incorporated together in developing INDOT's painting warranty clause.

CHAPTER III

GENERAL CONCEPTS

If a quick comparison was conducted between two or more warranty clauses in different areas of practice, it can be easily noticed that they generally handle the same issues. Although each of these clauses may have a completely different wording, the structural elements are very close to each other. What actually determines the strength or weakness of a warranty clause is the compliance and full sufficiency of its basic structural elements. Realizing this fact, a thorough literature review took place to build the abstract model that can be adapted for the steel bridges painting practices.

3.1 THE BASIC MODEL OF WARRANTIES AND GUARANTEES

Warranties and guarantees are contractual commitments extended by the contractor to the contract owner. As a practical matter, the terms are synonymous in the context of construction contracting. The most basic warranty extended by contractors is the warranty of workmanlike methods applied during the contract period. Most contracts include a statement that the contractor extends such a warranty. The wording varies, of course, but typically the contractor warrants that he will use construction methods and techniques that are recognized as acceptable within the trade or industry and that his work will sustain acceptable for a fairly long period of time after the end of the contractual works (Jervis and Levin, 1988.)

Express and Implied Warranties

Two types of warranties are recognized under the law; express warranties and implied warranties. The term implied warranties mean that the construction products must be capable of passing in trade under the contract description and are fit for the purposes intended. Express warranties are those that specifically set forth in the contract itself (Fisk, 1997). If a construction contract does not contain an express warranty, courts will be quick to read an implied warranty into the contract. However, when reading an implied warranty into a contract, courts are somewhat restrained in determining the scope of the warranty. An express warranty will be broader than the implied warranty a court will find. Therefore, express warranties are more useful for owners and may enable the owner to hold the contractor to higher standards and commitments (Jervis and Levin, 1988).

Scope of the Warranty

The final construction product is subjected to all kind of factors that affect its life time. Among those factors, the workmanship of the contractor during the construction activity plays the major role. Nevertheless, a variety of external factors may affect the performance of the final product. The list includes the different environmental conditions, the abuse from the owner side or the end users, and the deficiencies associated with the material used. Contractors rely on those external factors to reason for all the apparent defects after the end of the construction-related works. This can cause a hassle for the owner to prove that the contractor workmanship has led to the existing defects.

The disturbance usually arises from the vague and puzzled wording of the warranty clause. As a matter of practice, a clear definition of what is considered a defective work owing to the poor workmanship of the contractor and the presence of standardized measurement procedures of those defects saves the owner a lot of effort. To reach a clear and well-defined scope of the warranty, three items must be included: (1) a clear definition of the defects that the poor workmanship may incorporate in its occurrence, (2) the typical method of measurement of the degree of severity for all the predefined defects, and finally (3) the limit that identifies the contractor involvement in the occurrence of the defect.

Warranty Period

Express warranties generally run for a stated period of time called the "Warranty Period." This means that if during the warranty period, the owner notifies the contractor of a defect in his work, the contractor must return to the job site and correct the problem at no charge to the owner. If there is a dispute as to whether the item falls under the warranty, the owner has the burden of establishing that the problem does in fact result from defective workmanship by the contractor during the execution of the works (Jervis and Levin, 1988.)

A common question that arises regarding warranties is the expiration date. As the express warranty typically runs for a certain period of time defined in the warranty clause wording, the determinative factor is the date the warranty starts to run. This factor, however, differs in accordance with the scope of the contract works. For most cases, contracts state that the warranty runs from the date of substantial completion. This is the date when the project becomes suitable for its intended purpose and the owner is able take occupancy and make use of the structure. When the purpose of the contract works requires the execution of such works into stages, the date can be set relative to the completion date of each stage. Consequently, each stage will have its own expiration date.

Performance and Payment Bonds

The existence of a written commitment in the contract wording does not fully guarantee the execution of the required corrective works. This is primarily due to the changing environment of the construction industry which may cause the contractor to become financially unable to do the job or continue what he has already started. Such possible risks highlight the need for warrant bonds. A warranty bond introduces a third party, i.e., a surety company, that guarantees the payment of a satisfactorily compensating amount of money in case of the contractor's failure to do the job. Bonds are regarded as a relatively quick and easy way to protect the various interests of the owner, contractor, and suppliers of labor and materials.

Two basic kinds of bonds are utilized after the establishment of a contractual agreement: performance and payment bonds (Stokes and Finuf, 1992.) Although this is not mandatory in private works, it is usually required in all public works (Fisk, 1997.) Those bonds are typically required by the owner after the award of the contract. A new set of bonds must be submitted by the contractor before the end of the contract works to guarantee the execution of repair works that may take place during the warranty period.

Under the terms of a performance bond, the surety company guarantees that the contractor will complete the required works to the satisfaction of the engineer and pay for any costs due to the contractor's failure to comply with its contract requirement. The benefit of the performance bond even exceeds that. Sureties usually review the financial position of the contractor as well as other qualifications before the issuance of the performance bond. This study helps in preventing the stoppage of works owing to the sudden insolvency of the contractor.

A payment bond is an additional remedy for suppliers of labor and materials in the event the contractor fails to pay whatever they have furnished for the project. The surety has an obligation for the owner to pay for the additional costs arising from such failure by the contractor.

Fisk (1997) mentioned that the customary amount of public works bonds are 100 percent on performance bonds and 50 percent on payment bonds. It is crucial that the reader realizes the previous figures are for the original contract works for which the first set of bonds will be typically issued. The Construction Industry Affairs Committee of Chicago, with membership spanning both the design profession and the contractor associations recommends that both the performance and payment bonds written in the amount of 100 percent of the contract price.

It is rational that the original set of bonds to be around the contract price or more. Basically, the bond is supposed to guarantee the works as specified in the contract drawings and specifications. However, the issue is different in case of the warranty bonds since the expected defects cannot be in the amount of the contract price. The value of the new set of bonds issued by the end of the contract are usually determined according to the owner's discretion. The basic drawback associated with the issuance of the performance and payment bonds is the increase in the incurred costs. Overstating the amount of the two bonds will increase the costs beyond the justified amount for the project works. Although the performance and payment bonds give the owner a satisfactory guarantee for the completion of the repair works during the warranty period, he may encounter a situation of no defects encountered while the contract price was increased by the contractor to cover the bonds fee. The owner has to trade-off between the value of the payment and performance bonds and that of the expected increase in the contract price according to the expected performance by the contractor.

Special Permits

For the special practice of public works, the owner -- which is typically a public authority -- may have its own regulations and rules that govern the flow of works in its contracts. Each owner has to tailor the warranty according to the special needs and requirements he may desire. Complete attention must be taken not to add any wording that seems to be unreasonable by the contractor and results in a noticeable augmentation in the contract price.

3.2 STEEL BRIDGES PAINTING DETERIORATION

While building the basic model of a warranty clause, it can be easily realized that the different elements composing this model have different degrees of importance. Although some of those elements incorporate into the development of the model, others can determine its success or failure. The most obvious example is the definition of defects that may arise from the poor performance of the contractor. The inability to clearly define both the various painting defects and the extent to which the contractor will be held responsible for them may result in excessive future disputes.

The Environmental and Workmanship Effects

Starting from the first day the painting system is applied on the bridge, it is subjected to continuous attacks from the environment. The severity of the environment determines to a great deal the expected life of such painting system. The SSPC environment-zone approach is helpful in the semi-quantification of the type of environment (Hare, 1990.) However, within these general classifications, there are inevitably degrees of exposure not only from one part of the country to another but from bridge to bridge and even from section to section of a particular bridge, depending upon location, type of crossing, bridge design, and traffic volume. The three major classifications are:

- 1B-Dry Exterior.
- 2A-Fresh Water Wet.
- 2B-Salt Water Wet.

Most snow-belt structures undoubtedly should be classified as 2B, and that classification should worsen in the expansion bay areas or where deck leaks occur. Sheltered underdeck areas of bridges in good condition over non-water crossings might easily be classified as a rather mild 1B environment. Over inland waterways, a 2A rating might be more appropriate for the same underdeck steel and over a busy well-salted highway, splash back from the highway below will intensify the immediate environment beneath the bridge to class 2B (especially on the bottom flanges).

The environment is only one face of the coin. Poor surface preparation and inadequate film thickness have been widely held as being the predominant causes of the premature failure of the coating system (Hare, 1990). The poor workmanship from the side of the contractor which results in those occurrences can substantially reduce the service life of the painting system. An NACE report estimates that some 70% of premature coating system failures may result solely from poor surface preparation.

While there is probably some truth in this, such generalities are dangerous because they foster a preconceived bias against the contractor. Unfortunately, it is not rare that coating failures are found to be outcomes of several apparently unrelated phenomena. This requires being more cautious in handling this issue. For any bridge, there must be a realistic evaluation of the environmental conditions surrounding it, and therefore better judgment about the life expectancy of the coating system. When there is a fast deterioration of the coating system beyond the expected rate, the failure can be claimed to be a result of the poor workmanship of the contractor.

Painting Failure Types and Causes

Steel bridges' painting is the principal protection strategy of the steel substrate against deterioration. With all of the variables involved in the formation and use of paints, there exists a wide variety of painting failure types. The types of these different failures can be classified into seven categories (SSPC, 1989.) The list includes : (1) failures due to the selection of the coating system, (2) failures which are inherent within the coating itself, (3) adhesion-related failures, (4) application related failures, (5) failures due to the substrate, (6) design-related failures, and (7) failure by exterior forces. Table (3.1) enumerates the different failure types that fall within each of the aforementioned categories. A group of failure types that are most frequent are described below (SSPC, 1989) and (Tam and Stiemer, 1996.)

Chalking

With chalking, the organic binder in the coating tends gradually to disintegrate on the surface releasing the pigments and allowing them to remain on the surface as powder or chalk. This is strictly a surface phenomenon. While in some cases it can result in rapid reduction in coating thickness, it is generally a relatively slow process and one which does not result in catastrophic failure or severe corrosion to the substrate.

Checking

Checking is an age-related failure of a coating. It is characterized by uneven and generally non-linear, non-continuous breaks in the coating. These breaks are primarily a surface phenomenon and do not penetrate the full depth of the coating. Checking can be characterized as "visible" if the checks can be seen with the naked eye, or "microscopic" if they can be seen only under low magnification. It is basically a formulation problem that results in surface stresses in the coating layer which causes the small checks to appear.

Cracking

Cracking is also an age-related failure. It contrasts with checking in that it is not a surface phenomenon but one where breaks in the coating penetrate to the underlying surface. This makes it a more damaging type of failure than checking, since corrosion can rapidly take place at the breaks in the coating.

Table 3.1. The various types of paintings failures (SSPC, 1989)

	Failures Due to Selection of the Coating System	Failures Inherent Within the Coating Itself		Adhesion-Related Failures
		Organic	Inorganic	
TYPES of FAILURES	Contingent upon the characteristical resistance of the coating system to the surrounding environment.	Chalking	Checking	Blistering
		Erosion	Mud-Cracking	Peeling
		Checking	Chemical Reactions	Flaking or Scaling
		Cracking	Pinpoint Rusting	Intercoat Delamination
		Alligatoring	Pitting in Seawater	Undercutting
		Mud-Cracking		
		Wrinckling		
		Micro-Organizm		
		Discoloration		

Table 3.1. The various types of paintings failures (Continued)

	Application-Related Failures	Failures Due to the Substrate	Design-Related Failure	Failure by Exterior Forces
TYPES of FAILURES	Improper Mixing Improper Thining Improper Thickness Oversray Pinholes Spatter Coat Holidays Cratering Bleeding Blushing Lifting Orange Peel Runs & Sags	Contingent upon the substrate material type and quality	Can arise from the difficulty of appltying paint due to complicated design of: Edges Interior Corners Discontinuous areas Welds Skip Welding Back to Back Angles	Chemical Erosion and Abrasion Faying Surfaces

Discoloration

Because appearance may be as much a function of a coating as its corrosion resistance, coatings that change color after application and become unsightly can be considered to have failed.

Pinpoint Rusting

Pinpoint rusting occurs primarily in areas that are thinner than the remainder of the coating, starting with an isolated pinpoint of rust showing here and there in these thin points. As time goes by, the pinpoints become closer together, and finally, at the time of full failure, the spots of pinpoint rust cover the entire surface.

Blistering

Blistering is one of the most common forms of adhesion related coating failure, particularly when the coating is immersed in water or sea-water. It can also occur in areas of high humidity where there is continuing or intermittent condensation on the surface. Poor application of the coating results in gases and liquids to develop within or under the coating that exert pressure stronger than both the adhesion and the internal cohesion of the coating. This allows the coating to stretch and to form the hemispherical blister. If the pressure is greater than the tensile strength, the blister will break. Afterwards, the substrate will be readily attacked, causing rust.

Peeling

Peeling is a coating failure usually caused by a coating having a tensile strength greater than its bond strength to the surface. Any coating will peel or pull from the surface if is has less adhesion to the substrate than it has tensile strength, or if it reacts adversely with the substrate over a period of time, thus substantially reducing the adhesion.

Flaking and scaling

These two types of failure are adhesion-related. Flaking is a term describing a condition where small pieces of coating detach themselves from the surface of the substrate. Its edges are generally raised up from the surface and the small pieces can rather be easily removed, leaving the bare substrate. Scaling is similar to flaking, except that the pieces that break away from the surface are much larger. Pieces of coating several inches in diameter may break due to aging stresses, curl and come off in large flakes. The two phenomena arise primarily from the poor surface preparation that reduces the required adhesion forces and leads to that problem.

Undercutting

Undercutting is another type of adhesion failure that involves the gradual penetration of corrosion underneath the coating from a break or pinhole in the film or from unprotected edges. It often occurs when a coating has been applied over mill scale. Moisture and oxygen penetrate the coating and react with the scale causing it to lose adhesion and thus form progressive corrosion beneath the coating. Most of these undercutting failures can be substantially reduced by proper surface preparation prior to the application of the coating and the use of a coating with strong adhesion characteristics.

Runs and Sags

Runs are downward movements of a paint film resulting when excess material continues to flow after the surrounding surface has set. Sags are also downward movements of a pint film but between the time of application and setting resulting in a curtain appearance. Both of the two problems may be caused by the use of too much wet paint. Coating failures usually occur because of a thin coating above the sag or run.

Responsibility of the Contractor

Whenever a certain form of failure appears on the bridge, the inspector encounters a problem of determining whether such failure is due to the environment attacks, the poor workmanship of the contractor, or both. The decision is not always easy to make. The reason is that there is no clear cut between the two and will never be. However, some failures are more vulnerable to the poor workmanship than others. If a certain failure of such group appears within a short period of time after the substantial completion of works, it is more evident that the contractor is responsible for it while the environment attacks worsen the situation.

This sentence is true for those failures emerging for the improper surface preparation. For most cases, the improper preparation of the steel surface results in severe adhesion- and rusting-related problems. This includes blistering, peeling, flaking and scaling, and undercutting rust. Any remaining debris from the surface preparation process extensively accelerates the occurrence of those failures.

Another category of failure types associates with the application process itself. This category includes all failures that emerge from the improper paint mixing procedures, incompetence in applying the paint layers, and others. Some examples are the insufficient coating thickness, cracking, checking, discoloration, and above all the pinpoint rusting. Unfortunately, the environment affects the failure types just mentioned in this category in varying degrees which makes the judgment process more difficult. While the contractor is responsible for any over-thinned areas of the coating system, unless an abrasion from the environment is apparent on the surface, it is difficult to impose such responsibility on him in case of rusted areas in leaking areas or where dicing ice is used extensively. On the same time, the inspector should keep in mind that even with the severe environment, a coating system resulting from a good job can last for some reasonable period of time without apparent deficiencies.

CHAPTER IV

WARRANTY CLAUSE DEVELOPMENT

One- or two- year guarantees are not rare in bridge painting specifications today, although the guarantees are often vague and poorly written. These guarantees properly offer little real protection to the bridge authority. The current practices in the United States are still in their infancy. Guarantees are more common in Europe and Japan. In Germany, for instance, large painting contracts have been underwritten by insurance companies as part of a protocol methodology (Hare, 1990.) In spite of the apparent proficiency of some of the guarantees used outside the United States, the full dependency on the foreign practices has its inconveniences. First, the European and Japanese environment in terms of the technical and administrative practices are quite different from those of the United States. Second, lack of communication arising from the language may have its effect on the progress of research work especially with the limited time frame available.

The aforementioned reasons made the other alternative of considering the currently used warranties in the United States, more favorable. To facilitate the development process, a special attention was taken to Indiana's neighboring states. The Midwest area has its unique geographical and environmental conditions. After the substantial completion of the contract works, the deterioration of the painting system can be heavily affected by those conditions. As discussed earlier in Chapter III, the existing environmental conditions play a major role in identifying the painting defects which in term constitute the primary part of the warranty clause.

The search revealed that both Illinois and Michigan are currently using warranties in their painting contracts. The two warranties are noticeably close to each other in content and wording. At least, one of the two warranties was dependent on the other in its development. Michigan DOT was active in the review and modification process of its warranty form. Two different versions of those warranties were available. The first version was established in 1989 while the second was used starting from 1994. It must be borne in mind that such clauses are regarded as the starting point in establishing Indiana's warranty clause. By the end of the data collection stage, the following set of material was available, refer to Appendix B for a review of the exact forms;

- Illinois DOT provisions for cleaning and painting steel structures with a special provision for performance warranty after the substantial completion of works,
- Michigan DOT special provision for warranting bridge paintings (established in November 1989), and
- Michigan DOT revised provision for warranting bridge paintings (established in July 1994).

Although IDOT and MDOT practice span for more than 5 years, the degree of success of either of them cannot be guaranteed without a continuous review of the warranties performance. Michigan was fast to realize this fact. Two periodical reports were prepared to address this issue since the date the warranty clause was first introduced in a steel bridge painting contract. A copy of the second interim report for the performance of the warranty clause used by Michigan DOT - issued on November 1, 1996 - is included in Appendix C. This report updates the status of structures completed or inspected since the February 4, 1994 first interim report. At the second report date, all the structures included in the warranty clause performance study have been coated. Because two bridges were coated just before the issuance of the second report, the final report is expected to be written in 1998. This report will close out the research conducted for the performance of the existing warranty clause in MDOT steel bridges painting contracts.

4.1 PRELIMINARY REVIEWS

Referring to Appendix A, the three forms that present Illinois and Michigan practices resemble each other in different aspects. It is obvious that at least one of the two states has depended upon the other's experience in developing its own warranty clause. The major components of the available set of warranties can be summarized as follows;

- All three warranty clauses set the warranty period to be two years. The wording was clear such that no possible confusion may occur. However, the warranty clauses do not show any distinction in the warranty period for alternate weathering and environmental conditions.
- The defects covered by the warranty clause were defined in four categories. The first two categories handle most of the painting defects' causes that were discussed earlier in chapter III. Not all the possible causes were included but the important ones. The third category addresses the coating thickness less than the minimums specified in the specifications. Finally, the fourth category addresses the damages caused by the scaffold removal or other works by the contractor.
- The recognition of defects is the duty of the Engineer. This will be done through the visual inspection and dry film thickness measurement. All three warranty clauses fail to define a measurement procedure for the visible defects especially the rusted areas. Only the decision about the film thickness is unambiguous.
- The warranty clauses successfully avoid the possible disputes arising from the previous approval of any parts of the painting works during the contract period. A clear wording is included to clarify the issue.
- Illinois was more conservative in defining the period at which the contractor will complete and submit the repair procedures and progress schedule. No similar restriction is experienced in MDOT's two versions.
- The contractor is required in all three forms to submit a proof of a valid liability insurance covering the period of corrective works.
- Realizing that the original contract bonds do not cover the period of corrective works, both IDOT and MDOT require the furnishing of supplemental performance and lien bonds. Generally, the definition of the performance bond is quite clear and complete. It raises no possible conflicts regarding its interpretation. Nevertheless, the portion in all three forms handling the lien bonds is defective. This culminates in Illinois practices where neither a

description of the submittal procedure nor a defined value of the bond is expressed in explicit terms. MDOT's warranty clause describes the submittal procedure in more detail while lacking any defined value for the lien bond.

- Only the second version of MDOT's warranty clause adopts an additional paragraph that addresses the required permits during the corrective works period.

4.2 THE COMPREHENSIVE ANALYSIS

The initial review highlights two important aspects. It can be noticed that none of the existing warranty clauses satisfy all the requirements of the basic model of a warranty clause. Among the three forms, the second version of MDOT's warranty clause is the closest in satisfying those requirements. However, the currently available forms need further adaptations in order to be put into practical use by INDOT. Secondly, permits and administrative practices differ from one Department of Transportation to the other. MDOT has added a supplementary paragraph to its revised form that showed up in 1994 to handle the permits required during the corrective works period.

Therefore, and after discussing the issue with the Advisory Committee members of the research project, a recommendation of including the pavement warranty clause used by INDOT was taken into consideration. INDOT's pavement warranty clause has been extensively used in the last few years. The successful performance of such warranty clause encouraged the committee members to recommend its use in the development process of INDOT's steel bridges painting warranty. On the same time, it will give more insight about the existing practices in Indiana such as the traffic control and right-of-way.

The comparative study is planned to be conducted on the four available sources of information. To facilitate the analysis, eleven categories were identified. The list includes the warranty period, the defects definition, inspection schedule, submittal of repair procedure and progress schedule, season of work, liability insurance, traffic control, supplementary performance bond, supplementary lien bond, surety company, and required work permits. The comparative study results are summarized in table 4.1.

Table 4.1 Comparative Study Summary

	Area of Comparison	IDOT	MDOT (November, 1989)
1	*Warranty Period*	Two years from the date of final inspection by the Engineer.	Same as IDOT Plus: Two years from the acceptance date of each portion in case of projects that extend over more than two years and work is done in portions.
2	*Defects Definition*	a) Four main categories for defining failure types. b) Depends on thickness measurements and visual inspection. c) There is no reference specifications for comparison purposes.	Same as IDOT
3	*Inspection Schedule*	No later than the month before the end of the warranty period. No schedule of inspection is specified.	During the month before the end of the two year warranty period, OR, earlier. No schedule of inspection is specified.
4	*Submittal of Repair Procedure and Progress Schedule*	To be submitted in writing within 10 working days of notice of defective areas.	No specific time period from the issuance of notice of defective areas is identified. Only: Submittal is required prior to the start of any work by the contractor.
5	*Season of Work*	Limited to the same season of inspection.	Same as IDOT Unless the seasonal limitations stated in the painting specifications prevents the completion this season.
6	*Liability Insurance*	To be submitted to the Engineer prior to any works	To be submitted to the Financial Services Division prior to any works.
7	*Traffic Control*	No special provision	The Contractor is obliged to maintain the traffic as described in the original contract documents.
8	*Supplementary Performance Bond*	The bond accounts for 15% of the total contract amount. To be submitted upon completion of the work and final inspection of the project. The Engineer withholds in reserve an amount of 15% until the bond is received.	Same as IDOT
9	*Supplementary Lien Bond*	Not required.	Required for the period on which the corrective work is undertaken. BUT: no value is specified.
10	*Surety Company*	No special provision	The company must be authorized to do business in the State of Michigan.
11	*Work Permit*	No special provision.	No special provision

Table 4.1 Comparative Study Summary (Continued)

MDOT (July, 1994)	INDOT "Pavement Warranty"	INDOT Proposal
Same as MDOT (November, 1989)	Five years after the date all warranted asphalt is complete. The pavement shall be designed for 15-year lifetime.	Ratio from the paint expected lifetime under the existing environmental conditions of the area. PS Two years for experimental purposes.
Same as MDOT (November, 1989)	Not applicable to painting practices	a) Six main categories for defining failure types. b) Depends on thickness measurements and visual inspection. c) It contains reference specifications from ASTM and SSPC for comparison purposes.
Same as MDOT (November, 1989)	Initial survey within 45 calendar days after the substantial completion of works. Plus: Annual survey on specific times of the year.	Annual inspection on specific time of the year. OR, at any time the bridge coating system requires immediate remedies.
Same as MDOT (November, 1989)	No matching provision.	To be submitted in writing within 10 working days of notice of defective areas to the contractor. AND prior to any work.
Same as MDOT (November, 1989)	No matching provision.	Same as MDOT (July, 1994)
Same as MDOT (November, 1989)	No matching provision.	To be submitted to INDOT prior to any works.
Same as MDOT (November, 1989)	No matching provision.	The Contractor shall comply with all regulations described in the original contract documents such as, but not limited to, the maintenance of the traffic.
The bond accounts for 20% of the total contract amount. To be submitted upon completion of the work and final inspection of the project. The Engineer withholds in reserve an amount of 20% until the bond is received.	No matching provision. Upon completion of work, the warranty Bond becomes effective for a total of 5 years. The bond warrants the proper performance in conducting the repair works in addition to the various payments for the labor, material, and equipment. The bond value is a fixed amount of money.	Same as INDOT pavement warranty clause. Except: warranty value = 20% of the total contract amount. The value is subject to increasing if needed in the future.
Same as MDOT (November, 1989)		
Same as MDOT (November, 1989)	The company must be satisfactory to the Department.	Same as INDOT pavement warranty
Permit is required with a waiver from any additional fees.	A Miscellaneous Permitshould be obtained from the Department	Same as INDOT pavement warranty

Warranty Period

The warranty clause is introduced to warrant the quality of works done by the contractor for a certain period of time following the substantial completion of works. In the previous chapter, the different factors affecting the paint life expectancy were discussed. The two major factors are the environment and the contractor's workmanship. The warranty of the painting system is offered by the contractor to cover his own work. The Department of Transportation should realize that the contractor will not be willing to warrant the painting system for long periods where the environment will definitely affect the system even with an excellent painting job. The most obvious drawback will be the increase in the original contract sum by which the contractor will try to cover those contingencies. The trade-off between the increase in the contract sum due to extending the warranty period and the costs incurred due to the failure of the unwarranted painting system is one of the toughest decisions to be taken by the Department of Transportation.

Both IDOT and MDOT have set a fixed warranty period of two years for the coverage of their steel bridges painting jobs. Although the fixed period cannot be described as simplistic, the expected accuracy and sufficiency are not guaranteed. Correspondence with MDOT revealed that there exists no statistically scientific background for establishing the warranty period. The choice was totally dependent on the previous experience with the currently used painting system in Michigan.

Currently, INDOT is planning to switch to a new painting specification other than the one in use for the last decade or more. The new painting system may consist of organic/inorganic zinc primer, epoxy middle coat, and urethane top coat. According to Hare (1990), the new painting system has an excellent performance in resisting water, UV, alkalies, acidic pollutants, and abrasion. The expected service lives of such system in 1B, 2A, and 2B environments (refer to chapter III for full explanation of the different environment classes) are 35, 13 and 10 years respectively. The service life estimates are based on numerous interviews with highway departments, paint manufactures, contractors, engineers, and other specifying authorities across the country, together with data from a few available published sources. It must be noted that many such sources reflect the use of the same coating in industries other than bridge painting and considerable divergence is very apparent.

Knowing the life time expectancy of the painting system under the different environmental conditions, how can we identify the corresponding warranty period? Answering this question may be tougher than it seems to be. Since the deterioration of the painting system is non-linear, the determination of the appropriate warranty period depends on the profile of the deterioration curve. Unfortunately, the deterioration curves for many painting systems are not available especially as a function of the various environmental conditions. This needs the ratio of the warranty period to the paint life expectancy to be approximated for practical purposes.

Although pavement practices are quite different from those of painting, the theoretical deterioration curves of each are very similar. INDOT's pavement warranty clause establishes a five-year warranty period for its highway practices. The pavement is commonly designed for periods around 15 years of life time. The ratio is roughly one third. Because of the unavailability of the painting deterioration curves, a ratio of 25% - 35% can be used until more statistics about the painting system performance becomes available.

During the 1997 construction season, there was a decision to apply an experimental warranty clause as part of the contract wording of one pilot project. INDOT Advisory Committee members preferred to limit the warranty period to only two years and not to extend it beyond that. On the second interim report prepared by MDOT on the performance of their warranty clause (Appendix C), it is stated that with a two-year warranty period, the warranty provisions do not seem to change the final costs of the contract. However, there is no estimate of the possible drawbacks associated with extending the warranty period beyond that on the contract sum.

For future purposes, the warranty period should correspond to the existing environmental conditions in the area on which the bridge is located. Referring those conditions to one of the predefined environmental classes will help keep the consistency in warranty periods for similar bridges. Warranty periods up to 5 years are expected in those future practices.

The warranty period must start from a fixed point in time. In IDOT warranty clause, the date of final inspection by the Engineer is chosen to represent this reference point. MDOT practice is not much different except for a supplementary sentence to handle the projects that extend over more than one year in contract duration. In such case, the Engineer may accept portions of the painting at the end of each annual work period and the warranty period will start from the acceptance date for each portion respectively. Without full control of the Engineer, such distinction in contract works may lead to unexpected conflicts. MDOT became aware of that, and therefore, changed the corresponding provision in the revised version of its warranty clause to let the warranty period start from the date of final acceptance of the project regardless of the acceptance date of each portion. This alteration is more conservative than the one of the first version. INDOT Advisory Committee members were convinced that the provision in the second version of MDOT's warranty clause is the most appropriate in real practices.

Defects Definition

The core element of the warranty clause is to define the various defects that arise from the poor workmanship of the contractor and against which the warranty clause warrants the Department of Transportation. Without a clear definition, as much as possible, conflicts may occur between the two parties. On the same time, and as explained before, any explicit bias from the Department of Transportation will result in an increase in the contract sum by which the contractor tries to cover those apparent contingencies.

IDOT and MDOT use almost an identical form to identify the painting defects. Four different categories are included:

1. The occurrence of visible rust or rust breakthrough, paint blistering, peeling or scaling.
2. Paint applied over dirt, debris, blasting debris, or rust products not removed during blast cleaning.
3. Incomplete coating or coating thickness less than the minimums specified in the painting specifications.

4. Damage to the coating system caused by the contractor while removing scaffolding or performing other work.

It is evident that both IDOT and MDOT raise an important cause of painting failure that is rarely mentioned in literature which is the damage of the coating system emerging from the reckless removal of scaffolding after the final inspection by the Engineer.

Comparing the composition of this part of the warranty clause with the basic model previously represented in chapter III, it can be easily noticed that it lacks several requirements. The basic model requires - in addition to a clear identification of defects - both a well-defined method of measurement for those defects and the range for which the contractor will be held responsible. Unfortunately, the second and third portions are not included.

Correspondence with MDOT revealed that the generalized definition of defects is established to warrant the work regardless of the actual cause of deterioration. If a certain defect emerges during the warranty period, the contractor has to return to site and fix such defect. Considering the limited warranty period of two years, it is admitted that such generalization is reasonable. It is rare that unexpected and fast deterioration can happen in the first two years even with a severe weathering and/or environmental conditions. The only side effect of this generalization is the increase of the contract sum used by the contractor to cover any future contingencies. However, this possible increase is expected to be minimal due to the fact of the limited warranty period. The second interim report prepared by MDOT (Appendix C) states that there was no correlation between cost and the warranty provision use in that particular form. It also adds that a warranty is just one of many factors that determine the final project cost, such as time of year, how busy the contractor is, etc.

INDOT policy is to use the two year warranty period for the experimental pilot project. Afterwards, the warranty period will be extended depending on the performance of the warranty clause in the pilot project and the data available on the new painting system. Although the previous definition of defects may seem reasonable for a two-year warranty period, it will become totally insufficient for extended periods. This part must be redeveloped to contain all three portions required for an ideal warranty clause.

Because of the severe rainfall, hail and/or wind, the surface of the paint may be aggravated such that its thickness becomes less than the value in specification. The degree of erosion of exterior paint can be evaluated using ASTM-D 662 standards. Without the existence of such case, the over-thinned or -thick dry film thickness can be unquestionably referred to the poor workmanship of the contractor. The readings of the dry film thickness are usually taken using magnetic gages. To identify the status of the paint thickness, SSPC-PA 2 was developed. The specifications state that five separate spot measurements should be made over every 100 square foot. Each spot measurement consists of an average of three gage readings next to one another. The contractor's work will be considered satisfactory *if and only if* the average of the five spot measurements are within the specified thickness, while single spot measurements are permitted to be 80% of the specified thickness.

Referring to chapter III, a certain category was identified where the corresponding defects of this category arise from the deficient surface preparation. Those defects are mostly the contractor's responsibility. The list includes blistering, peeling, scaling, and undercutting rust. This gives INDOT more freedom to generalize the definition of the aforementioned defects.

In case of no apparent adhesion problem exists, the degree of adhesion of the coating to the substrate can still be evaluated using ASTM-D 2197 (Adhesion by scratching or scraping) and/or ASTM-D 3359 (Adhesion by tape test). The specifications support the idea of the expected life time of the existing paint system depending on the results of the test. The acceptability of results is based upon 95% confidence level. Refer to Appendix (E) for a copy of the test methods and procedures. If any of the various adhesion problems resulting from the poor surface preparation occurs, the responsibility of the contractor is more obvious. The list includes peeling, blistering, scaling and undercutting rust. Unfortunately, the only standard available for measuring the degree of severity in this category is the one associated with blistering. Appendix (E) contains a copy of the standard procedure ASTM-D 714 for measuring the degree of blistering of paints. The test method employs photographic references to evaluate the degree of blistering deterioration.

The aforementioned forms of deterioration are easier to judge by the inspector since the effect of the poor workmanship far exceeds the effect of the environment in developing them. Unfortunately, this does not include one of the most widespread and detrimental form of paint deterioration, or in other words, rusting. The second interim report on the performance of warranty clauses in painting practices prepared by MDOT (Appendix C) shows pinpoint rusting as the major deterioration form noticed during the two-year warranty period. The danger of rusting associates with the fact that it attacks the substrate and causes the steel to corrode and then a reduction in the steel sections occurs.

The difficulty in determining what stimulated the rust to occur is that both the poor workmanship and the severe environmental effects incorporate together in its development. This even happens with different degrees from one section to another on the same bridge. Sometimes the deficient design on special sections of the bridge subjected to settled water or continuous leakage leads to excessive rusting on those specific areas. The emergence of the set of problems related to the location, design, or use of the bridge should attract the attention of the Department of Transportation to their long-run effects on the life expectancy of the bridge itself.

Whenever no apparent cause of rusting beyond the contractor's control exists, the poor workmanship rises as the major cause. The improper mixing and application of the paint can easily cause the water to penetrate the painting system to the underneath steel substrate and start the rust. ASTM-D 610 standard covers the evaluation of the degree of rust on a painted surface using visual standards (Appendix E). The visual standards were developed in cooperation with the Steel Structures Painting Council (SSPC) for the further standardization of the procedure. The rusting measurement depends on the comparison between the inspected bridge and a set of photographic reference standards to determine the percentage of the area rusted.

Eleven different ratings are identified in the evaluation procedure. The no rust case is graded by 10 and the 100% rusted area is graded by 0. The corrosion performance rating system is based on visual inspection; therefore, variations can occur between different inspectors. In addition, visually quantifying the amount of corroded area can be very difficult even for a well-trained inspector. To reduce the amount of discrepancy in the data collection, Tam and Stiemer (1996) recommended the use of a set of photographs showing different corrosion ratings on actual bridge components with schematic representation of the ASTM-D 610 standard. Furthermore, in their development of a bridge corrosion cost model, they approximated the area to be repainted as a function of the rating given by ASTM-D 610. Table 4.2 represents the values used in developing the cost model;

Table 4.2. Estimated area to be repainted (Tim and Stiemer, 1996)

Corrosion rating	Description	Area to be painted (%)
10	No rust or less than 0.01% rust	0
9	Minute rust, less than 0.03% rust	0
8	Few isolated rust spots, less than 0.1% rust	0
7	Less than 0.3% rust	0
6	Extensive rust spots, less than 1% rust	8
5	Less than 3% rust	18
4	Less than 10% rust	40
3	Approximately 1/6 of surface rusted	60
2	Approximately 1/3 of surface rusted	100
1	Approximately 1/2 of surface rusted	100
0	Approximately 100% of surface rusted	100

Identifying both the type of defect and its method of measurement leaves us with the range for which the contractor will be held responsible for the rusting of the bridge surface. Comparing the different values of the areas to be repainted corresponding to the corrosion ratings, it can be noticed that no repair work is required in case of rust less than 1% of the area. Although no explanation is given, it is believed that conducted repair for rusted area less than 1% is unrealistic. If the rust is spread over large areas with this minimal ratio, it will become almost impossible to identify a certain area to be repainted. Added to that, the unreasonable interruption to the traffic and the possible damage to the existing paint resulting from erection and removal of scaffolds may become more costly and time consuming to the Department of Transportation.

Discussions with INDOT Advisory Committee members attracted the attention to the AASHTO requirements for the inorganic zinc primer where a maximum ratio of 1% rusting is allowed in a three-year period after the substantial completion of all contract works. It worth mentioning that the AASHTO specification M300 (Section 4.7) allows the 1% rusting in coastal and marine environments which are the most harsh in all possible environments. This environment is equivalent to 2B as defined by Hare (1990). The system composed of organic/inorganic zinc as primer coat, epoxy as mid coat, and urethane as top coat is regarded as one the possible candidates to be put into broader use in the future by INDOT. This stimulates increasing the warranty period for values up to 5 years in mild environments with a maximum of 1% rusting in case of adopting such system. However, the various coating systems under study characterize long lifetime expectancy which in term encourage using a low allowed rusting of 1%. The ratio can be accustomed to varying possible warranty periods; each corresponds to a class of environment as defined in an earlier chapter.

Inspection Schedule

The schedule of inspection determines when the painting works will be inspected for defects. The inspection schedule, in general, is dependent upon the inspection policy of the Department of Transportation and the warranty period. IDOT does not specify a certain inspection schedule as the corresponding provision states that "*The Engineer will inspect the bridge thoroughly for the paint system defects no later than the month before the end of the warranty period.*" The decision is left for the Engineer to choose the most appropriate time to conduct the inspection process. His decision will basically depend on his judgment on the performance of the painting system.

MDOT is more specific in identifying the inspection schedule. The painting system is to be inspected during the month before the end of the warranty period, i.e., the last month of the warranty period. Although this schedule is more specific, it can have a detrimental effect on the bridge in case of a fast deteriorated painting system. Realizing this fact, MDOT adds a supplementary part to allow for earlier inspections to take place whenever the Engineer feels there is a need for such inspection of the painting system. For a complete control of the inspection process, MDOT notifies the contractor that the inspection process will be done using Department maintenance personnel and equipment.

There is no ideal arrangement for the inspection process since it depends to a great deal on the administrative practices of the Department of Transportation, as aforementioned. Discussions with the members of INDOT Advisory Committee and the thorough review of the pavement warranty clause revealed that INDOT follows a different policy in conducting its inspection after the substantial completion of works.

INDOT's pavement warranty clause requires an initial pavement condition survey to be conducted 45 calendar days after the substantial completion of the project. Afterwards, an annual inspection takes place at predefined times of the year with no cost to the contractor. In addition, a final inspection occurs just before the end of the warranty period. It can be noticed that the pavement warranty provides an extensive inspection policy. One of the obvious reasons is that the warranty period for INDOT's pavement warranty extends for 5 years while the corresponding warranties for painting practices in Michigan and Illinois span for only 2 years. On the same time, the defects in the pavement works can cause serious safety problems to the users of the highway which is not the case for painting practices.

For painting practices, INDOT has a continuous inspection policy for its steel bridges. Every bridge in Indiana is inspected for the quality of paint every other year. After the thorough examination of the bridge, it is rated for the paint quality on a 0-9 scale where "0" represents the highest quality and "9" the worst. The existing data is very helpful in developing the deterioration curves for the existing painting systems. Because of the possible change to the organic/inorganic, epoxy, urethane system, there exists no data to verify the previous figures given by Hare (1990). However, the crucial point is that the annual inspection policy during the warranty period will not add up excessive effort on INDOT. On the contrary, it matches the general current policy of inspection.

The only difference will be that the bridge will be inspected annually during the warranty period instead of every two years.

INDOT Advisory Committee members recommended that the inspection process to be conducted during the month of October each year. This timing complies with the general administrative arrangements for INDOT. Although the same policy of annual inspections can be followed, the two-year experimental warranty period is quite short such that this provision may seem unrealistic. Thus, the inspection is arranged such that it occurs in October of the last year of the warranty period in the pilot project. However, the annual inspection policy needs to be reconsidered in future practices especially with the recommended extension in warranty period.

Submittal of Repair Procedure and Progress Schedule

During the usual course of the original contract works, the contractor is required to submit to the Engineer a progress schedule with a detailed procedure description. The progress schedule identifies the different jobs he is going to perform with the logical sequence of those jobs. The Engineer must approve all of those plans in writing before the start of works. When the Engineer finds that some of those jobs are not properly planned, he notifies the contractor with all the corrections that should take place.

The repair works are by no means different. The contractor is bind to perform the works under the same conditions of the original contract. Therefore, he is required to submit a detailed repair procedure and progress schedule to the Engineer for review and approval. The submitted plans form a guarantee of the contractor's willingness to perform the repair works properly. However, the correspondence of plans and formal letters has been always a major delay cause in the construction industry. Sometimes the process is abused to postpone the date of the start of works.

The provision handling the submittal of the repair procedure and progress schedule has double benefit. First, it guarantees the proper execution of repair works since all repair plans will become available to the engineer before the start of repair works. Consequently, he will be able to make all the needed corrections and clarify the possible conflicts that may occur. Secondly, setting a strict period for the preparation of the progress schedule could save the Department of Transportation a lot of wasted time. Under this provision, the contractor will be prohibited from extending the period for long periods without an apparent reason.

MDOT provision states that "*The repair procedures and progress schedule shall be submitted in writing to the Engineer for review and approval prior to any work.*" However, there is no restriction on the period on which the contractor is supposed to get it done. IDOT extends its provision to enforce the repair procedure and progress schedule to be submitted within 10 working days of notice of defective areas. This achieves the double benefit discussed in the previous paragraph.

A question may arise about the validity of establishing a certain period to prepare the repair procedure and progress schedule while the size of work can substantially vary from one project to another. This is true to some extent. If the size of the project is huge such that it takes more than a year in contract period, it will be unrealistic to crunch the period allowed for preparing the repair schedule to only ten days. The period needed for revising and approving the schedule may drastically increase because of all the conflicts need to be cleared. The Department of Transportation should handle the issue more flexibly depending on the size of the project itself. The period given for preparing the progress schedule is recommended to vary according to the size of the project from one to three weeks. The value used for the attached draft at the end of the chapter is left as ten days for explanation purposes but it must be kept in mind that this value should vary according to the size of the project.

Season of Work

When a certain defect is identified by the Engineer that requires an immediate repair action, the contractor is entitled to perform the corrective works as soon as possible. Any delay in conducting the corrective works will have a negative effect on the existing paint in the defected area and consequently the underlying substrate. To ensure the quick action, both IDOT and MDOT enforce the corrective works to take place within the same season on which the bridge was inspected by the Engineer. This is identified by the sentence: "*All paint repair work will be done by the same season as the inspection.*"

The Engineer has the complete freedom to choose when to conduct his inspection. Sometimes, he takes such an action far before the end of the warranty period whenever a severe deterioration of the painting system has been noticed. However, in reality, the corrective works cannot be conducted all over the year. Generally, most painting systems are sensitive to temperature and humidity. The specifications usually determine the ideal range of temperature and humidity at which the painting system can be applied. The same range, of course, is valid for the repair works. Under the severe weathering conditions, the painting material cannot be prepared or applied properly. Taking into consideration the occasional conflicting weathering conditions in the Midwest area, MDOT added a supplementary sentence to the previously quoted one to cover such an occasion. Thus the Contractor is obliged to take an immediate action such that the corrective works to be done the same season, "*Unless the seasonal limitations stated in the painting specifications prevents the completion that season. In this case, the corrective work will be completed the following season.*"

Reviewing INDOT's pavement warranty clause showed no matching sentence that has the same meaning. However, this is not an issue since the pavement warranty clause obligates the contractor to take an immediate action within 24 hours if a safety problem is discovered in the pavement works. Assuming that the Engineer responsible for the inspection process is aware of the effects associated with a badly deteriorated painting system, it is of low possibility that the deterioration of the painting system may cause such a safety problem. Regarding the effect of weather on continuity of works in the same season, the pavement materials are less vulnerable to the weather conditions as paints. Therefore, delaying the works for long periods as those required for painting systems is impractical.

Discussions with INDOT's Advisory Committee members pinpointed that on many occasions, the works were delayed because of the inconvenient weathering conditions. It was obvious that the supplementary part added by MDOT can save any conflicts arising from such an issue. Therefore, MDOT's interpretation of the season of work is adopted entirely without any further modifications.

Liability Insurance

This type of insurance protects against legal liability to the public (Fisk, 1997.) All owners require their contractors to submit such an issuance before the start of the original or repair works. The purpose of the liability insurance is to avoid any legal problem with a third party that may arise from the construction works. This insurance was not introduced as a part of the basic model of a warranty clause because it is always submitted to the owner in case of any construction activity.

Fisk (1997) explains that the contract documents should require that evidence of specified insurance be submitted. There are many forms of liability insurance, but the one usually recommended for construction is the Broad Form Comprehensive Liability Policy. Under this type, all forms of liability insurance are combined in one contract.

Both IDOT and MDOT include the liability insurance provision using almost the same wording. The liability insurance is in effect during the period the corrective work is being done. However, there is a difference in identifying the person or entity to whom the contractor is to supply the verification of the liability insurance. IDOT requires the verification to be submitted to the Engineer while MDOT requires it to be submitted to its Financial Services Division. The distinction by no means changes anything in the validity of the submittal process since it depends on the inherent regulations of each department. The existing practice of INDOT in its current painting contracts is to represent INDOT by itself, i.e., all verifications are to be submitted to the name of INDOT regardless the person or entity that officially represents INDOT at that time.

Other than the aforementioned modification, the rest of the liability insurance will remain the same.

Traffic Control

During the execution of repair works, the traffic may become obstructed because of the contractor's equipment and/or labor. In such occasion, the flow of traffic on the bridge and sometimes the reach of the highway on which the bridge is located might be affected. It is important for the Department of Transportation to guarantee that such interruptions for the traffic are limited to the lowest possible levels. Otherwise, further considerations are to be taken which sometimes require detouring this portion of the highway. These circumstances are not common in painting practices as much as highways' construction and rehabilitation. However, the Department of Transportation must be cautious to these possible occasions.

When the second version of MDOT's warranty clause was introduced, a supplementary provision was added to handle this issue. There is no matching provision in Illinois practice. MDOT's provision states that "*When completing any identified corrective work, the contractor shall maintain traffic as described in the original contract documents*."

The provision of traffic control perfectly addresses the problem such that the contractor is obliged to perform work in full accordance with the original contract documents. However, the wording itself can cause legal conflicts. It is not uncommon that specifying a certain requirement out of a whole set of requirements may be interpreted such that it is the only one valid under the new circumstances. In reality, the Department of Transportation needs the contractor to comply with all the original contract provisions and rules with special emphasis on the importance of traffic control. The original contract documents that are used by INDOT usually include various requirements other than the traffic control. For example, a special provision is commonly included in the original contract documents to provide the contractor agreement to comply with all federal, state and local laws, rules, regulations, or ordinances, that are applicable at the time of his services.

This necessitates altering the provision to represent the whole picture. In other words, the provision must provide the traffic control requirement as one of the various responsibilities the contractor is obliged to comply with under the original contract. The new form of the provision can take the form: "*When completing any identified corrective work the contractor shall comply with all regulations as set in the original contract documents such as, but not limited to, the maintenance of traffic.*"

Supplementary Performance and Lien Bonds

Issuance of bonds, that ensure the owner against all possible contingencies associated with the execution of the contract or warranty works, is a common practice in almost all construction-related projects. Conflicts that arise from this issue emerge from the ambiguous issuance procedure, improper bonds value, and rejection of the surety company or the form used. All matters related to the surety company will be discussed in more detail in a succeeding section.

As explained earlier in chapter III, there exist two types of bonds required for the warranty of painting works; i.e., supplementary performance bond, and supplementary payment bond. IDOT requires only a supplementary performance bond to be furnished to the Department. The bond is in the sum of 15 percent of the of the original total contract amount. The bond will be in force for the period covering the two-year warranty period and the time required to perform any corrective work covered by the warranty. To ensure the proper issuance of the supplementary bond before the final inspection by the engineer, an amount of 15 percent of the total contract sum will be withheld until the supplemental bond has been received by the engineer.

Although IDOT does not require a supplementary payment bond, which can be considered a major defect in its warranty clause, the construction of the part associated with the supplementary performance bond is quite integrated. It satisfies all the basic requirements including the issuance procedure, the bond value, and the items covered by the bond. Moreover, IDOT realized the possible future conflicts arising from the elusive wording of the bond itself. This stimulated adding a provision that limits the supplementary performance bond to the form prepared by the Department.

MDOT has almost the same form for requiring the supplementary performance bond. The only difference is that the value of the bond was raised from 15% to 20% in the second version of the warranty clause. No reason was apparent for this augmentation of the bond value. Also, all correspondence with MDOT did not reveal the reason behind the change. Regarding the supplementary lien bond, a special provision associated with this bond is added in MDOT warranty clause. If, after the inspection process during the warranty period, a specific corrective work is required, the contractor should submit a supplementary lien bond to MDOT that is in effect for the duration of the corrective work. Again, the special form of this lien bond is limited to the one prepared by the Department. Although MDOT does not have the same defect of ignoring the supplementary lien bond in its clause, the form is unclear and ambiguous. MDOT warranty clause fails to identify a specific value of the supplementary lien bond. The special provision stating the two bonds to be satisfactory and acceptable by MDOT can not compensate the elimination of the lien bond value. If it does, therefore, there is no need to define a value for the performance bond too. The truth it does not compensate ignoring the value of any of them.

INDOT pavement warranty clause has different practice in terms of the definition of performance and lien bonds. INDOT eliminates the differentiation between the two common bonds. In other words, the pavement warranty clause requires the contractor to submit to the Department of Transportation a warranty bond for a defined amount of money. This warranty bond warrants both the performance and payments to whoever cooperated in executing the repair works. This change from the traditional representation of contract bonds, however, requires a clear definition of the items covered by the bond. An explicit provision states that "*The bond is intended to ensure completion of required warranty work, including payments for all labor, equipment, and material.*" This inclusion simply extends the coverage of the warranty bond to include, in addition to the ordinary performance requirements, the payments for labor, equipment and material which constitute the core of the lien bond.

There is no standard form that can ideally be used to express the procedure and quantity of the warranty bond. Whether the warranty bond is identified as a single entity or two entities where the first covers the performance and the second covers the payments, the clear cut is that the warranty bond definition should be unambiguous in terms of coverage, issuance procedure, and amount. INDOT's pavement warranty clause offers a clear and condensed provision that is more appealing to be used in painting practices. However, the use of a pre-defined ratio seems more realistic for this practice since painting projects can differ substantially in contract value. INDOT's Advisory Committee members reached a consensus on the ratio of 20% to represent the warranty bond value. At this point, it is hard to predict whether this amount is satisfactory or not. The final decision will depend on the feedback from the various projects composing the first phase of practically implementing this warranty clause.

Surety Company

The surety company constitutes the entity that guarantees the proper execution of works to the satisfaction of the Department of Transportation. The contractor may become unable to perform the repair works or pay his material, equipment, or labor suppliers because of any financial difficulties. Under those circumstances, the Department of Transportation can benefit of the existing bonds to get the work done or to relieve them from any external obligations to a third party who shares in the execution of repair works.

Without the support of a reputable surety company, the Department of Transportation may encounter unexpected losses. Therefore, the Department must be cautious in accepting the bonds and the surety company issuing them. The acceptance of the surety company by the Department of Transportation is implicitly interpreted by any reader of the warranty clause if the clause does not state it explicitly. However, the explicit wording prevents from any possible future conflicts.

IDOT's warranty clause does not enforce the acceptance of the surety company in explicit terms while both MDOT's painting warranty and INDOT's pavement warranty explicitly stipulates that. INDOT's pavement warranty states that "*The warranty bond must be properly executed by the a surety company satisfactory to the Department*". This gives the Department of Transportation more flexibility in rejecting the submitted bonds and the surety company issuing them when needed. Moreover, MDOT enforces that the company must be authorized to do business in the state of Michigan. It is believed that this addition by Michigan is not essential since the final decision about accepting or rejecting the surety company will remain in the hands of the Department of Transportation. Although this limitation may help in reducing the possible risks from out-of-state contractors, it may prevent many competent contractors who are willing to open a new market to bid the project.

Work Permit

Each Department of Transportation sets its own local regulations. This item, therefore, is not comparable between the different Departments. Generally, highway-related projects such as pavement and steel bridges painting cause certain interruption to the traffic flow. So as to be allowed to do so, the contractor is required to get certain permit(s) from the Department.

There is no explicit provision for such requirement in IDOT and the first version of MDOT warranty clauses. However, the second version of MDOT's warranty clause adds a provision that requires the contractor to apply for a permit to work within MDOT right-of-way. Again, this provision corresponds to Michigan policy. INDOT's pavement warranty clause requires that "*Prior to proceeding with any warranty work or monitoring, a Miscellaneous Permit shall be obtained from the department.*" Discussions with INDOT Advisory Committee members end up with a consensus on adopting the same policy for painting practices.

4.3 THE WARRANTY CLAUSE DRAFT

The comparative study presented in the previous section sets the grounds for establishing the first version of INDOT's steel bridges painting warranty clause. The following pages represent the proposed form to be put into experimental use by Indiana Department of Transportation.

CHAPTER V
CONCLUSIONS

In the past few years, Indiana Department of Transportation (INDOT) has adopted a continuous improvement strategy for its current practices. One the major areas that seemed in need for such improvement is the quality of workmanship. In the field of steel bridges painting, INDOT has encountered an increasing number of the fast deteriorated painting systems after the substantial completion of the contract works in various jobs. The reckless performance of the contractor's workers and the willingness of the contractor himself to close-up the project as soon as possible resulted in apparent high deterioration rates for the existing coating systems. The risk that INDOT is facing right now is the severe ramifications of these deterioration rates on the life expectancy of the steel bridges in Indiana.

One of the major causes for this irresponsibility from the contractor is the lack of any legal binding agreement; or in other words, a warranty for the quality of works he has performed during the contract period. Realizing this fact, an active movement towards developing a well-prepared and dependable warranty clause was initiated. The report in hand represents the study conducted to develop the first version of INDOT's steel bridges painting warranty clause. The word "*first version*" is used intentionally to indicate that the experimental warranty clause is only the first step that will be followed by others. In the coming few years and after the warranty clause is put into actual practical use, the feedback about its performance will justify the current arguments or help modifying any portions of the experimental warranty clause in need for such change.

5.1 SUMMARY AND CONCLUSIONS

The literature review indicated that some painting warranty forms are in practical use in the United States although most of them are vague and poorly written (Hare, 1990). A survey was conducted to investigate the current practices of the neighboring states hoping that some warranty form is used in the steel bridges painting area. The survey reveled that both IDOT and MDOT have established an agreed upon warranty form to be put in their painting contracts. The quick review of the available forms indicated an apparent difference in the administrative practices compared with those of Indiana. This fact stimulated the use of INDOT's pavement warranty clause as a reference document in addition to taking advantage of its successful performance over the last few years.

The four available sources of information, i.e., IDOT, MDOT (1,2), and INDOT warranty clauses constituted the foundation elements used in the development process. The drafted warranty clause was dependent mainly on the results of the comparative study conducted on eleven pre-identified categories presumably existing on all the available forms. These categories include the warranty period, the defects definition, inspection schedule, submittal of repair procedure and progress schedule, season of work, liability insurance, traffic control, supplementary performance bond, supplementary lien bond, surety company, and required work permits.

Recently, INDOT is studying various alternative coating systems that are characterized by their long lasting lifetime. The warranty period of two years used by both IDOT and MDOT seemed unrealistic in warranting the painting job for this system. However, the experimental warranty form is preferred to cover a warranty period of only two years. The two main reasons are to allow for a gradual change in the Department policy and to alleviate the reaction expected with the introduction of this new approach. Generally speaking, the most appropriate warranty period is a function of the deterioration curve of the identified painting system under the environmental conditions characterizing the area on which the bridge is located. Currently, no accurate set of deterioration curves is available to be used for the determination of the warranty periods. It is believed that this issue in particular has a high potential in the future research that seeks more solid grounds for establishing the painting warranty periods.

The proposed draft of INDOT's warranty clause has undergone substantial changes in terms of the defects definition. IDOT and MDOT forms are written in a generalized form that can arise various conflicts around the scope of the warranty offered by the contractor. The defects definition in Illinois and Michigan practices are limited to the visual identification of defects without any accurate methods of measurement of those defects or the ranges for which the contractor will be held responsible. Because this issue constitutes one of the most sensitive elements of any warranty clause, further studies were done to establish more scientific grounds for the judgment procedure by the engineer. The readings of the dry film thickness are based on the SSPC standards while most of the other apparent deterioration-related failures are based on the ASTM corresponding standards. Several arguments are offered to reason for the different decisions taken regarding those standards. However, some of the established limits were decided about after the extended discussions with INDOT's Advisory Committee members.

The inspection-related topics had less argument compared to the aforementioned ones. The main reason is that they are highly dependent on the private practice of the Department of Transportation. Indiana is quite active in inspecting its steel bridges where each bridge is inspected every other year. This policy strengthened the idea of an annual inspection to occur for the whole warranty period. However, the two-year warranty period of the pilot project is too short if the previous policy is thought of. This stimulated the bridge of the pilot project to be inspected only once before the end of the warranty period unless an apparent deterioration form emerges. To guarantee the quick reaction of the contractor, he is bind to the contract to submit a copy of the repair procedure and progress schedule within a short period of time of the notice of defective areas. The determination of the appropriate period is decided by the engineer before the contract is signed and according to the size of the project.

The Surety company that issues the warranty bonds is the actual entity guaranteeing the proper execution of repair works to the satisfaction of the engineer and making all the payments to the labor, equipment, and material suppliers. This requires the full attention to the importance of the surety company and the clear wording and timeliness of the various bonds offered by the contractor. IDOT warranty clause requires the submittal of only a supplementary performance bond which does not cover all payments required from the contractor. Although MDOT was more cautious to that weakness, the part of the warranty clause requiring the issuance of a supplementary lien bond is ambiguous. There is no value of the bond explicitly stated in the warranty clause wording. INDOT proposed form adopts a different approach to define the required warranty bonds where the two are combined in one bond covering the execution of works and the payments to all labor, equipment, and material, etc. The coverage of the warranty bond is defined in explicit words in the warranty clause. In addition, the contractor is obliged to use the warranty bond form prepared by the Department to avoid any misleading words.

Finally, the administrative practices defined by the warranty clause are quite systematic although they may be different from those adopted by Illinois and Michigan. The existence of INDOT's pavement warranty clause helped much as the reference point for comparison purposes. Regarding the traffic control during the repair works period, the form used by both IDOT and MDOT was substantially modified because it may be misinterpreted to free the contractor from some of his obligation under the original contract. Thus, a more generalized form is used where the traffic control constitutes one of the basic obligations binding the contractor during the execution of all repair works.

All of the constituents of the drafted warranty clause and the arguments around them are based on the currently available information. The form is understood to be experimental where the different elements of this form will be subjected to further evaluations in the future. The most obvious elements need to be reevaluated are the warranty period, sufficiency of the defects definition, and the value of the warranty bond. The available set of information when the report was prepared is admitted to be incomplete to give a clear cut decision. Moreover, the reevaluation itself will depend to a great deal on the performance of the warranty clause for a relatively long period of time before a final decision can be made on them.

5.2 RECOMMENDATIONS FOR FUTURE WORK

The preparation of this report has unveiled various deficiencies regarding both the insufficiency of information in literature or practice and the inconvenient technological advancements in some areas. Although those deficiencies restricted any further improvements to take place on the proposed warranty form, they stimulated the thinking of some possible research activities that may take place in the future. The thought of research activities will not only have a positive effect on the warranty clause but also many relevant practices. For instance, such knowledge can improve the quality control program, inspectors' capabilities, accuracy of decisions, and others. The following represents some of the proposed areas that could be investigated and would contribute to the success of the entire system;

As mentioned in an earlier section, the deterioration curve of the used painting system(s) is/are the key element in determining the most appropriate warranty period. This is unquestionable. The determination of the deterioration curves as a function of the various environmental conditions can broadly support the decision making of the maintenance program. Indiana or any other state is facing a dilemma of which bridges are expected to undergo repainting or overcoating within the coming strategic plan and when exactly each bridge will need such maintenance procedure.

The process can become even more complicated in case of several painting systems in use by a certain state. In Indiana, three basic painting systems have been used in the last 30 years where extensive pool of information is available. This can help develop the deterioration curves for those systems. However, the possibly adopted coating systems in the future are still ambiguous regarding their performance although literature supports their use under most environmental conditions. For practical purposes, the deterioration curves could be approximated until further information becomes available. Without a complete and dependable set of deterioration curves, the establishment of sound maintenance plans may be difficult to reach. Further statistical studies are recommended in this area.

Another area of possible future research is the measurement procedure used for identifying the deterioration-related failures of the painting system. The standards are based on the visual inspection and through the comparison with a group of pictorial references. This means that the decision can vary from one inspector to another and even the same inspector will give different ratings for the same area on different occasions. Tam and Stiemer (1996) proposed the use of actual photographs showing different deterioration ratings on actual bridge components to provide some sense of reality and reduce the amount of discrepancy in the data collection. Although this can improve the judgment procedure, it will remain far from being described as accurate.

The previous argument reveals the necessity of automating the whole procedure. The introduction of an advanced computerized technology will reduce the possibility of discrepancies to nil providing that the system can successfully recognize the target deterioration form. In the last few years, an active effort was initiated in BIRL, Northwestern University, to provide a computerized system for the processing of images taken for any deteriorated painting surface. The system is composed mainly of a digital camera that captures the image and transforms it to the portable computer it is analyzed to provide more accurate judgment about the degree of deterioration. Although there are sound grounds now for the developed system, a lot of advancements are still underway and the area is very fruitful for future research.

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Appendix A: INDOT Proposed Warranty Clause.

INDIANA

DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION

FOR

PERFORMANCE WARRANTY ON BRIDGE PAINTING

Performance Warranty

The Contractor shall unconditionally warrant to the Indiana Department of Transportation (INDOT) the paint system applied to the bridge to be free of defects, as hereinafter defined and determined by visual inspection and paint thickness measurements, for a period of two years from the date of the final inspection by the Engineer. On projects that extend over more than one year in contract duration, the warranty period shall be for two years from the project acceptance date.

The paint system will be considered defective if any of the following conditions are discovered within the two year warranty period:

1. The occurrence of application-related failures including pinholes, holidays (incomplete coating), bleeding, blushing, or runs and sags.
2. Coating thickness less than the minimums specified in the painting specifications. The thickness will be considered satisfactory if and only if the average of the five spot measurements as specified by SSPC-PA 2 are within the specified thickness range, while single spot measurements are permitted to be 80% of the specified thickness.
3. Paint applied over dirt, debris, blasting debris, or rust products not removed during blast cleaning.
4. The occurrence of adhesion-related failures including undercutting, paint blistering, peeling, flaking, or scaling.
5. The occurrence of visible pinpoint rust or rust breakthrough in excess of 1% of the surface area of any painted structural element as specified by ASTM-D 610.

6. Damage to the coating system caused by the Contractor while removing scaffolding or performing other work.

Warranty Evaluation

During the month of October before the end of the two year warranty period(s), or earlier if the Engineer finds a need to do so, the Engineer will inspect the bridge thoroughly for the paint system defects listed above. This inspection will be done by INDOT personnel using INDOT equipment. The Contractor will be notified in writing with the date of inspection. The Contractor may accompany the Engineer during the inspection process. The Engineer will determine if there are defective areas present as defined above or not.

Acceptance by the Engineer of any portions of the work during the original contract cleaning and painting will not relieve the Contractor of the requirements of this warranty.

Corrective Work

All defective areas identified by the Engineer shall be repaired by the Contractor in accordance with the painting specifications. The repair procedures and progress schedule shall be submitted in writing within 10 working days of notice of defective areas to the Engineer for review and approval prior to any work. All paint repair work will be done the same season as the inspection, unless the seasonal limitations stated in the painting specifications prevents the completion that season. In this case, the corrective work will be completed the following season. The Engineer shall be given at least two weeks notification before the contractor begins the corrective work and shall be allowed full inspection of all operations and provided safe access to the area being repaired.

The Contractor shall supply verification to INDOT prior to any work that the required liability insurance is in effect during the period the corrective work is being done.

When completing any identified corrective work, the Contractor shall comply with all regulations described in the original contract documents such as, but not limited to, the proper maintenance of traffic.

Warranty Bond

The Contractor shall furnish, upon completion of the original contract works, a Warranty Bond to INDOT. The bond shall be in the sum of 20 percent of the original total contract amount. The bond is to secure the performance by the Contractor of correction work of any paint system defects that he is directed by INDOT to perform and all associated costs including payments for all labor, equipment, material, etc. The Warranty Bond shall be in force for the period covering the two year warranty and the time required to perform any corrective work covered by the warranty. The Contractor shall use the form provided by INDOT, a copy of which is attached, and executed in accordance with the requirements of this special provision. The Warranty Bond must be properly executed by a surety company satisfactory and accepted to INDOT and be payable to the State of Indiana.

Upon completion of the work and final inspection of the project, Warranty Bond shall become effective and shall continue in full force and effect until such time as INDOT advises the Contractor that there are either no paint system defects, or, if the Contractor has been notified that there are paint system defects, and said paint system defects have been repaired by the Contractor to the satisfaction of the Engineer. The Engineer shall withhold in reserve an amount equal to 20 percent of the total contract amount until the Warranty Bond has been received.

Measurement and Payment

All costs associated with performance of the work, the required maintenance of traffic, and the required Warranty Bonds will not be paid for separately but will be considered to be included in the contractor's overhead and administrative costs.

INDIANA
DEPARTMENT OF TRANSPORTATION

1 of 2
WARRANTY
PAINT QUALITY

THIS WARRANTY, made by ______________________________
(Contractor)

of ____

hereinafter called "Warrantor", in favor of the Indiana Department of Transportation, hereinafter called "Department";

WITNESSETH:

RECITALS:

1. The Department has contracted for the cleaning and painting structural steel on the ______________________________ bridge on the ____________________ Highway in ____________________ County, Indiana.
2. Under the provision of Contract No. ____________________ pertaining in part to painting of structural steel, entered into by ______________________________ (Contractor), and the Department in which ______________________________ (Contractor) is required to furnish the Department a written warranty for the paint system warranting against defects as stated in said contract for a period(s) of two years from the date(s) of final inspection by the Engineer, of ____________________ (Contractor) work under said contract.

INDIANA
DEPARTMENT OF TRANSPORTATION

2 of 2
WARRANTY
PAINT QUALITY

NOW, THEREFORE, is consideration of the foregoing, warrantor hereby agrees and warranties that in every case in which any defect, as described in contract No. ____ ________________________________ occurs within said two year period(s), warrantor shall, forthwith upon receipt of written notice of such defect, repair said defective area.

It is expressly understood and agreed that the warranty and obligations herein set forth are made and undertaken by warrantor to and for the benefit for the Department.

IN WITNESS WHEREOF, ______________ day of ____________ , 19___

____
(Contractor)

ATTEST: ________________________ BY: ________________________

TITLE: ______________________

INDIANA
DEPARTMENT OF TRANSPORTATION

SUPPLEMENTAL REFORMANCE BOND

KNOW ALL MEN BY THESE PRESENTS, That we ______________________ as principal, and ____ as surety, a corporation duly organized and existing under and by virtue of the laws of the State of ____________________________________ and duly authorized to transact the business of surety in the State of Indiana, are jointly and severely held and bound unto the Indiana Department of Transportation in the sum of______________________________ __________________ Dollars, for the payment for which we jointly and severely bind ourselves, our heirs and executors, administrators, successors and assigns firmly by these presents.

Whereas, the principal herein has, on the ______________________ day of _______________, 19____, made and entered into a certain agreement with the State of Indiana, by and trough the Indiana Department of Transportation, which agreement is more fully described as____, Contract No. _______________________________, under which agreement the principal agrees to furnish certain materials and to perform certain work which he agrees to do in accordance with the terms, conditions, and requirements as set out in said agreement, and whereas, in connection with said contract, the principal has executed a written warranty, a copy of which warranty is attached hereto and by this reference made a part thereof;

INDIANA
DEPARTMENT OF TRANSPORTATION

SUPPLEMENTAL REFORMANCE BOND

And, whereas, the principal has therein undertaken to warrant the work of cleaning and painting structural steel against any defects, as therein defined, for a period(s) of at least two years from the date(s) of final inspection of the project by the Engineer.

NOW, THEREFORE, THE CONDITION OF THIS BOND IS SUCH THAT if the principal herein shall faithfully and truly observe and comply with the terms of such warranty and shall well and truly perform all matters and things by him/her undertaken to be performed under said warranty upon the terms proposed therein and shall do all things required of said principal by the laws of this state and shall indemnify and save the harmless the State of Indiana and Indiana Department of Transportation against any direct or indirect damages of every kind and description that shall be suffered or claimed to be suffered in connection with or arising out of the performance of the said warranty by the Contractor or subcontractor, then this obligation is to be void, otherwise to remain in full force and effect.

In no event shall the obligations under this bond terminated without written consent of Indiana Department of Transportation.

Signed and sealed this __________ day of ______________, 19 _________ .

SURETY ___________________________ PRINCIPAL ________________________

BY ______________________________ BY ______________________________

Attorney-in-fact Official Capacity

Countersigned:

______________________________ Attest: ___________________________

Resident Agent Secretary

Appendix B: IDOT and MDOT warranty Clauses.

State of Illinois
Department of Transportation

SPECIAL PROVISION
FOR
CLEANING AND PAINTING EXISTING STEEL STRUCTURES
COMPLETE REMOVAL (MODIFIED SSPC SP10) SURFACE PREPARATION

The Following Special Provision replaces Article 509.06 of Section 509 of the Standard Specifications.

Performance Warranty. The Contractor shall unconditionally warrant to the Department the paint system applied to the bridge to be free of defects, as hereinafter defined and determined by visual inspection and paint thickness measurements, for a period of 2 years from the date of final inspection by the Engineer. The warranty called for shall be on a warranty form furnished by the Department (attached). This warranty shall be submitted to the Engineer prior to the start of work.

The paint system will be considered defective if any of the following conditions are discovered within the 2 year warranty period:

1. The occurrence of visible rust or rust breakthrough, paint blistering, peeling, or scaling.

2. Paint applied over dirt, debris, blasting debris, or rust products not removed during blast cleaning.

3. Incomplete coating or coating thicknesses less than the minimums specified in the painting specifications.

4. Damage to the coating system caused by the Contractor while removing scaffolding or performing other work.

The Engineer will inspect the bridge thoroughly for the paint system defects listed no later than the month before the end of the warranty period. The Contractor may accompany the Engineering during this inspection.

Acceptance by the Engineer of any portion of the work during the original contract cleaning and painting will not relieve the Contractor of the requirements of this warranty.

All defective areas identified by the Engineer shall be repaired by the Contractor. The repair procedures and Progress Schedule shall be submitted in writing within 10 working days of notice of defective areas to the Engineer for review and approval. All paint repair work will be done the same season as the inspection. The Engineer shall be given at least 2 weeks notification before the Contractor begins the corrective work and shall be allowed full inspection of all operations and provided safe access to the areas being repaired.

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The Contractor shall supply verification to the Engineer that the required liability insurance is in effect during the period the corrective work is being done.

The Contractor shall furnish, in addition to the regular performance and lien bonds for the contract, a supplemental performance bond to the Department. The bond shall be in the sum of 15 percent of the original total contract amount. The bond is to secure the performance by the Contractor of correction work on any paint system defects that he/she is directed by the Engineer to perform and shall be in force for the period covering the two year warranty and the time required to perform any corrective work covered by the warranty. The Contractor shall use the form provided by the Department, a copy of which is attached, and executed in accordance with the requirements of this special provision.

Upon completion of the work and final inspection of the project, the supplemental performance bond shall become effective and shall continue in full force and effect until such time as the Department advises the Contractor that there are either no paint system defects, or if the Contractor has been notified that there are paint system defects, that the paint system defects have been repaired by the Contractor to the satisfaction of the Engineer. The Engineer will withhold in reserve an amount equal to 15 percent of the total contract amount until the Supplemental Performance Bond has been received.

All costs associated with performance of this warranty, the required maintenance of traffic, and the required supplemental performance bond, will not be paid for separately but will be considered to be included in the cost of Cleaning and Painting Existing Steel Structures.

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

Special Provision
for
Performance Warranty on Bridge Painting

Performance Warranty

The Contractor shall unconditionally warrant to the Michigan Department of Transportation (MDOT) the paint system applied to the bridge to be free of defects, as hereinafter defined and determined by visual inspection and paint thickness measurements, for a period of two years from the date of final inspection by the Engineer. On projects that extend over more than one year in contract duration, the Engineer may accept portions of the painting at the end of each annual work period and the warranty period shall be for two years from the acceptance date for each portion respectively. The warranty called for shall be on a warranty form furnished by the state, a copy of which is attached. This warranty shall be submitted to the MDOT Financial Services Division prior to the award of the contract.

The paint system will be considered defective if any of the following conditions are discovered within the two year warranty period:

1. The occurrence of visible rust or rust breakthrough, paint blistering, peeling, or scaling.

2. Paint applied over dirt, debris, blasting debris, or rust products not removed during blast cleaning.

3. Incomplete coating or coating thicknesses less than the minimums specified in the painting specifications.

4. Damage to the coating system caused by the Contractor while removing scaffolding or performing other work.

Warranty Evaluation

During the month before the end of the two end warranty period(s), or earlier, the Engineer will inspect the bridge thoroughly for the paint system defects listed. This inspection will be done using Department maintenance personnel and equipment. The Contractor may accompany the Engineer during this inspection. The Engineer will determine if there are defective areas present as defined above.

Acceptance by the Engineer of any portion of the work during the original contract cleaning and painting will not relieve the Contractor of the requirements of this warranty.

Corrective Work

All defective areas identified by the Engineer shall be repaired by the Contractor in accordance with the painting specifications. The repair procedures and Progress Schedule shall be submitted in writing to the Engineer for review and approval prior to any work. All paint repair work will be done the same season as the inspection, unless the seasonal limitations stated in the painting specifications prevents the completion that season. In this case the corrective work will be completed the following season. The Engineer shall be given at least two weeks notification before the Contractor begins the corrective work and shall be allowed full inspection of all operations and provided safe access to the areas being repaired.

The Contractor shall supply verification to the MDOT Financial Services Division that the required liability insurance is in effect during the period the corrective work is being done.

Special Supplemental Performance and Lien Bonds

The Contractor shall furnish, in addition to the regular performance and lien bonds for the contract, a supplemental performance bond to the Department. The bond shall be in the sum of 15 percent of the original total contract amount. The bond is to secure the performance by the Contractor of correction work on any paint system defects that he/she is directed by the Department to perform and shall be in force for the period covering the two year warranty and the time required to perform any corrective work covered by the warranty. The Contractor shall use the form provided by the Department, a copy of which is attached, and executed in accordance with the requirements of this special provision. If corrective work is required the Contractor shall provide a supplemental lien bond (form provided by the department) that is in effect for the duration of the corrective work. The supplemental performance and lien bonds must be in all respects satisfactory and acceptable to the Department, executed by a surety company authorized to do business in the State of Michigan.

Upon completion of the work and final inspection of the project, the supplemental performance bond shall become effective and shall continue in full force and effect until such time as the Department will, in accordance with the Paint Quality Warranty, advise the Contractor that there are either no paint system defects, or, if the Contractor has been notified that there are paint system defects, said paint system defects have been repaired by the Contractor to the satisfaction of the Department as specified under the Paint Quality Warranty. The Engineer shall withhold in reserve an amount equal to 15 percent of the total contract amount until the Supplemental Performance Bond has been received.

Measurement and Payment

All costs associated with performance of the work and the required maintenance traffic, described under the Performance Warranty on bridge painting and the required supplemental performance bond, will not be paid for separately but will be considered to be included in the Contractor's overhead and administrative costs.

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION
FOR
PERFORMANCE WARRANTY ON BRIDGE PAINTING

C:GJB

07-18-94
APPR:C:PAL:EDW:7-19-24

Performance Warranty

The Contractor shall unconditionally warrant to the Michigan Department of Transportation (MDOT) the paint system applied to the bridge to be free of defects, as hereinafter defined and determined by visual inspection and paint thickness measurements, for a period of two years from the date of final inspection by the Engineer. On projects that extend over more than one year in contract duration, the warranty period shall be for two years from the project acceptance date. The warranty called for shall be on a warranty form furnished by MDOT, a copy of which is attached. This warranty shall be submitted to the MDOT Financial Services Division prior to the award of the contract.

The paint system will be considered defective if any of the following conditions are discovered within the two year warranty period:

1. The occurrence of visible rust or rust breakthrough, paint blistering, peeling, scaling, or unremoved slivers.

2. Paint applied over dirt, debris, blasting debris, or rust products not removed during blast cleaning.

3. Incomplete coating or coating thicknesses less than the minimums specified in the painting specifications.

4. Damage to the coating system caused by the Contractor while removing scaffolding or performing other work.

Warranty Evaluation

During the month before the end of the two year warranty period(s), or earlier, the Engineer will inspect the bridge thoroughly for the paint system defects listed. This inspection will be done by MDOT personnel using MDOT equipment. The Contractor may accompany the Engineer during this inspection. The Engineer will determine if there are defective areas present as defined above.

Acceptance by the Engineer of any portion of the work during the original contract cleaning and painting will not relieve the Contractor of the requirements of this warranty.

Corrective Work

All defective areas identified by the Engineer shall be repaired by the Contractor in accordance with the painting specifications. The repair procedures and Progress Schedule shall be submitted in writing to the Engineer for review and approval prior to any work. All paint repair work will be done the same season as the inspection, unless the seasonal limitations stated in the painting specifications prevents the completion that season. In this case the corrective work will be completed the following season. The Engineer shall be given at least two weeks notification before the contractor begins the corrective work and shall be allowed full inspection of all operations and provided safe access to the areas being repaired.

The Contractor shall supply verification to the MDOT Financial Services Division that the required liability insurance is in effect during the period the corrective work is being done.

When completing any identified corrective work the contractor shall maintain traffic as described in the original contract documents.

Special Supplemental Performance and Lien Bonds

The Contractor shall furnish, in addition to the regular performance and lien bonds for the contract, a supplemental performance bond to MDOT. The bond shall be in the sum of 20 percent of the original total contract amount for "Cleaning Existing Steel Structure (Type 4)" & "Coating Existing Steel Structure (Type 4). The bond is to secure the performance by the Contractor of correction work on any paint system defects that he is directed by MDOT to perform and shall be in force for the period covering the two year warranty and the time required to perform any corrective work covered by the warranty. The Contractor shall use the form provided by the MDOT, a copy of which is attached, and executed in accordance with the requirements of this special provision. If corrective work is required the Contractor shall provide a supplemental lien bond (form provided by MDOT) that is in effect for the duration of the corrective work. The supplemental performance and lien bonds must be in all respects satisfactory and acceptable to MDOT, executed by a surety company authorized to do business in the State of Michigan.

Upon completion of the work and final inspection of the project, the supplemental performance bond shall become effective and shall continue in full force and effect until such time as MDOT will, in accordance with the Paint Quality Warranty, advise the Contractor that there are either no paint system defects, or, if the Contractor has been notified that there are paint system defects, said paint system defects have been repaired by the Contractor to the satisfaction of the MDOT as specified under the Paint Quality Warranty. The Engineer shall withhold in reserve an amount equal to 20 percent of the total contract amount for "Cleaning Existing Steel Structure (Type 4)" & "Coating Existing Steel Structure (Type 4)" until the Supplemental Performance Bond has been received.

Permit

If corrective work is required the contractor shall apply to the District Utility-Permits Engineer for a permit to work within MDOT right-of-way (Form 2205). The permit fee and an individual permit performance bond shall not be required. The permit insurance requirements however, shall apply.

Measurement and Payment

All costs associated with performance of the work, the required maintaining traffic, the required supplemental performance and lien bonds, and the required permit insurance will not be paid for separately but will be considered to be included in the Contractor's overhead and administrative costs.

Appendix C: Second Interim Report about the Performance of MDOT Warranty Clause.

OFFICE MEMORANDUM

DATE: January 11, 1996

TO: Jon W. Reincke
Engineer of Research

FROM: Dave Long
Supervisor
Chemical Technology Unit

SUBJECT: **Second Interim Report - Performance Warranty for Bridge Painting Research Project 90 TI-1515**

This report updates the status of structures completed or inspected since the February 4, 1994 report (Table 1). At this report date, all structures in the study have been coated. The last two warranty projects were coated in 1995 and will have their two-year inspections in 1997. After any needed repairs have been made to these structures, the final report will be written in 1998 and the research project closed out.

The most common deficiencies noted during the two-year inspections conducted in 1994 and 1995 were: pinpoint rust on bottom edge of bottom flange, runs, sags, and top coat peeling (see attached field reports for details). None of these deficiencies were major, but all projects require some spot repair by the original contractor or MDOT maintenance forces.

The initial conclusion from the previous report still holds true: a warranty provision does not ensure higher initial quality. Seven warranty and control pairs have had their two-year inspections with no significant differences between the quality of warranty and non-warranty jobs. It appears that repairs will be needed within the first two years of any major coating job. However, the warranty provision does provide the department with an easy mechanism to perform initial repairs at the contractor's expense and not have to rely on maintenance forces.

Cost on all projects in the study ranged from a low of \$3.48 to a high of \$10.95 per square foot, and covered the time period from 1989 to 1994. Inflation and changing containment requirements probably had more of an impact on cost than the warranty provision. There was no correlation between cost and warranty provisions: warranty costs ranged from being equal to, higher or lower than control projects. A warranty is just one of many factors that determine the final project cost, such as time of year, how

Jon W. Reincke
Page 2
January 11, 1996

busy the contractor is, etc. Since warranty provisions do not seem to change the final costs and provide an additional benefit to the department, they should be used on as many coating projects as possible.

MATERIALS & TECHNOLOGY DIVISION

DC Long

DCL:nc
Attachments
cc FHWA Administrator
G. Bukoski
S. Kulkarni
K. Whelton
R. E. Nordlund

TABLE 1. Updated status of warranty bridges - 11/95

Dist	Type	Control Section	Structure	Cost/Ft^2	Status	Comments
1	Warranty Control	B01 of 31012 None	US-41/Portage Lake	NA	Completed 1995*	Initial due in 1996
2	Warranty	B01 of 49023	US-2/Cut River	10.95	2-year inspection*	A few areas of topcoat peeling; very few runs & sags; pack rust under scaffolding support points; damaged coating from moving scaffolding; deficient coating on missed rivet heads.
2	Control	B03 of 51021	US-55/Pine River	6.40	2-yr. inspection	Small areas of pinhole rust; limited paint over debris; limited staining.
3	Warranty Control	B01 of 15012 None	US-31/Island Lake Outlet	13.61	Completed 1995*	Initial due in 1996
4	Warranty	R01 of 20014	I-75 SB/D&M RR	6.95	2-yr. inspection	Limited peeling, staining, paint over debris, & thick paint over mill scale.
4	Warranty	R02 of 20014	I-75 NB/D&M RR	6.95	2-yr. inspection	No peeling; limited staining, paint over debris, & thick paint over mill scale.
4	Control	R01 of 49025	I-75/Soo Line RR	8.24	2-year inspection*	Replaces R01 of 16091. Random runs & sags throughout; some pinpoint rust on edges of flanges and bottom of bottom flange; pack rust on top end of diaphragms on random joints.
4	Warranty	S01 of 20015	I-75/N. Down River Road	6.95	2-yr. inspection	Limited peeling, paint over debris & rust; limited staining at joints.
4	Control	S06 of 76023	I-69/Vernone Road	8.02	2-yr. inspection	Peeling in EB lane; very limited rusting.
5	Warranty	S19 of 41027	I-196/Eastern Ave.	NA	Completed 1993	2-yr. inspection in 1996.
5	Control	S11 of 41029	I-196/M-45	6.80	2-yr. inspection	Very limited rusting; peeling areas repaired.

Dist	Type	Control Section	Structure	Cost/Ft^2	Status	Comments
5	Warranty	S20 of 41027	I-196/Diamond Ave.	NA	Completed 1993	2-yr. inspection in 1996.
5	Control	S12 of 41029	I-196EB/M-45	6.80	2-yr. inspection	Very limited rusting; peeling limited to two square feet.
6	Warranty	S04 of 73171	I-75/Busch Rd.	6.50	2-yr. inspection	Limited peeling; rust at almost every rivet & crevice.
6	Warranty	S05 of 73171	I-75/E. Townline Rd.	6.50	2-yr. inspection	No peeling visible from the ground; rust at almost every rivet & crevice.
6	Control	S01 of 73111	I-75/Baker Rd.	9.28	2-year inspection*	Pinpoint rust on bolts, slivers, & burs, bottom of bottom flange & over areas of heavy corrosion; deficient top coat on south fascia.
6	Warranty	S06 of 73171	I-75/Curtis Rd.	6.50	2-yr. inspection	Limited peeling; paint thickness insufficient in some areas; limited paint over debris.
6	Control	S03 of 73111	I-75/Hess Rd.	9.28	2-year inspection*	Top-coat peeling on south fascia; pinpoint rust on a few slivers & burs on bottom flange; paint over debris at bearings over piers.
7	Warranty	S04 of 13082	I-94/F Drive NW/I-94 BL	5.15	Completed 1994*	Two-year inspection in 1996.
7	Warranty	X01 of 13082	I-94/Conrail W/I-94 BL	5.15	Completed 1994*	Two-year inspection in 1996.
7	Control	S01 of 13083	I-94/Old US-27	6.81	2-year inspection*	Pinpoint rust at bottom of bottom flange & some rivet heads; pack rust at sole plates & built girders; random runs & sags.
8	Warranty	S08 of 23152	EB I-96/Canal Rd.	5.53	2-yr. inspection	No peeling; extremely limited rust & paint over debris.

Dist	Type	Control Section	Structure	Cost/Ft^2	Status	Comments
8	Control	R01 of 41061	M-11/M-21BR	3.48	2-yr. inspection	Very limited rusting & staining in crevices.
9	Warranty	S24 of 50111	I-94/Harper Road	7.42	2-yr. inspection	No peeling; extremely limited areas of painting over debris; extremely limited staining.
9	Control	S22 of 50111	I-94/14 Mile Road	7.42	2-year inspection*	Small amount of pinpoint rust on bottom of bottom flange, along weldment at cover plate, & on slivers & burs.

*Status updated November 1995.

Appendix D: INDOT"S Pavement Warranty Clause.

ASPHALT PAVEMENT, WARRANTED

1. DESCRIPTION. This work will consist of the construction of warranted asphalt pavement in conformance with the lines and grades shown on the plans as directed by the Department and as follows.

The Contractor will be responsible for the warranted asphalt pavement for a period of five (5)-years after the date all warranted asphalt pavement is complete and open to unrestricted traffic. The pavement shall be designed for a 15 year life with an anticipated 15,000,000 ESAL loading over the design life.

The Contractor will establish the Job Mix Formula (JMF) and select all materials. Aggregates must meet requirements as listed in Asphalt Institute Publication SP-2, Superpave Mix Design for New Construction and Overlays which are as follows for this project:

Mixtures within 100 mm of the pavement surface:

% crushed one face	100% min.
% crushed two face	100% min.
fine aggregate angularity	45% min.
clay content (sand equivalent)	45 min
thin elongated particles	10% max.

Mixtures below 100 mm of the pavement surface:

% crushed one face	95% min.
% crushed two faces	90% min.
fine aggregate angularity	40% min.
clay content (sand equivalent)	45 min.
thin elongated particles	10% max.

For coarse aggregates the following additional requirements apply:

Los Angeles abrasion [1]	40% max.
Soundness (AASHTO T103, Procedure A)	12% max.
Deleterious	
Clay lumps / friable (AASHTO T112)	0.2% max.
Non Durable [2]	4.0% max.
Coke and iron [3]	
Chert [4]	3.0% max.

For fine aggregates the following additional requirements apply:

Soundness (AASHTO T103, Procedure A)	10% max.
Acid Insoluble Content (ITM 202)	
Sand	40% min.
Blast Furnace Slag	25% min.

1 Los Angeles abrasion (AASHTO T96) requirements shall not apply to blast furnace slag.

2 Includes soft particles as determined by ITM 206 and other particles which are structurally weak, such as soft sandstone, shale, limonite concretions, coal, weathered schist, cemented gravel, ocher, shells, wood, or other objectionable material. Determination of non-durable

particles shall be made from the total weight of material retained on the 9.5 mm sieve.

[3] Air cooled blast furnace slag and steel slag coarse aggregate shall be free of objectionable amounts of coke and iron.

[4] The bulk specific gravity of chert shall be based on the saturated surface dry condition. The amount of chert less than 2.45 bulk specific gravity, shall be determined on the total weight of material retained on the 9.5 mm sieve.

Alternately aggregate can be used which meet Indiana Class A aggregate requirements.

The minimum grade of binder to be used on this project is *PG 64-28*. The mixture within the top 25mm of the finished surface will have a maximum nominal top size aggregate of 12.5mm. When slag is furnished as an alternate to natural aggregate, adjustments shall be made to compensate for the difference in specific gravity of the slag compared to natural aggregate as outlined in section 904.02(a).

The Contractor will develop a Quality Control Plan which meets the requirements as outlined in the "Contractor Quality Control Plan Requirements for Performance Warranty Asphalt Concrete" and which is to be submitted to the Department.

The provisions of the warranty work will apply to all asphalt mixtures placed as mainline pavement including the construction joint between the mainline pavement and adjacent materials (shoulders, tapers, and ramps). Section 400 and Section 900 of the Standard Specifications are exempted except 904.02(a). Shoulders, ramps, acceleration lanes and deceleration lanes are not included in the warranty requirements and will be constructed under Sections 400 and 900 except density control as per 401.12(a) shall be required.

2. WARRANTY. Upon completion of all warranted asphalt pavement and opening of the warranted pavement to unrestricted traffic, the Warranty Bond will be in effect for a total of five (5)-years. The warranty bond must be properly executed by a surety company satisfactory to the Department and be payable to the State of Indiana and submitted with the bid.

The warranty bond is <u>$900,000.00</u> for the warranted asphalt pavement. The bond is intended to insure completion of required warranty work, including payments for all labor, equipment, materials and closure periods used to remediate any warranted pavement distresses.

Upon the final acceptance of the project, the contractual obligations of the contractor are satisfied as long as the pavement continues to meet or exceed the warranted values as defined herein.

All warranty work will be in accordance with Section 5. At the end of the warranty period, the Contractor will be released from further warranty work or responsibility, provided all previous warranty work has been satisfactorily completed and accepted by the Department.

3. CONFLICT RESOLUTION TEAM (TEAM). The scope of the Team includes all issues concerning the warranted pavement relative to distress rate, remediation plan, material selection, and quality control plan.

The Team will consist of two Contractor representatives, two Department (District & Central Office) representatives, and a fifth person mutually agreed upon by both the Department and the Contractor. Any costs for the fifth person will be equally shared between the Department and the Contractor. The Team members will be identified in writing at the pre-construction meeting and will be knowledgeable in the terms and conditions of this warranty and the methods used in the measurement and calculation of pavement distress. Should any impasse develop, the Team will render a final recommendation to the Chief Engineer by a majority vote. Each member has an equal vote.

4. WARRANTY WORK. During the warranty period remedial work will be performed at no cost to the Department and will be based on the results of pavement distress surveys. Remedial work to be performed and materials to be used will be the joint decision of the Contractor and the Department. Prior to proceeding with any warranty work or monitoring, a Miscellaneous Permit shall be obtained from the Department.

Costs for lane closure will be applied for peak and non-peak closure periods using the rates contained in this contract.

During the warranty period, the Contractor may monitor the warranted asphalt pavement using nondestructive procedures. All proposed remedial action(s) will be coordinated with the Department.

Coring, milling or other destructive procedures may not be performed by the Contractor, without prior consent of the Department. The Contractor will not be responsible for damages to the pavement as a result of coring, milling or other destructive procedures conducted by the Department.

The Contractor will have the first option to perform the remedial work. If, in the opinion of the Department, the problem requires immediate attention for safety of the traveling public and the Contractor cannot perform the remedial work within twenty-four (24) hours, the Department has the option to have the remedial work performed by other forces. The Contractor will be responsible to pay for all the costs incurred. Remedial work performed by other forces will not alter the requirements, responsibilities, or obligations of the warranty.

5. PAVEMENT DISTRESS INDICATORS, THRESHOLDS AND REMEDIAL ACTION. The Department will use the following pavement distress indicators:

- International Roughness Index (IRI)
- Rut Depth
- Friction Number
- Longitudinal Cracking

The Department procedures contained in the manual "Measurement and Calculation of Pavement Distress Indicators for Warranted Asphalt Pavements" will be used for distress measurements and calculation of pavement distress indicators.

The Department will conduct an initial pavement condition survey within 45 calendar days after substantial completion of the project and annual pavement condition surveys between April 15 and May 15 at no cost to the Contractor. The Contractor will be advised of the survey schedule and the results will be made available to the District, Central Office, Contractor and FHWA within 14 days after completion of the survey. If the Contractor disputes the survey findings, written notification of the dispute will be provided within 30 days. Any such dispute must be based on appraisals of data supplied or additional information performed by a licensed professional engineer in the State of Indiana.

The final condition survey will occur by September 1, 2002. Remedial work, if required, will be completed by October 15, 2002. Written acceptance by the Department will be given following satisfactory completion of any remedial work.

If any of the threshold levels are met or exceeded the Contractor will recommend remedial action. After the remedial action is approved by the Department, the Contractor will perform the remedial work according to the following minimum standards:

Alligator Cracks
Remove and replace distressed layer(s). The removal area to be 150% of the distressed area to a depth not to exceed the warranted pavement

Flushing
Remove and replace distressed surface layer full lane width. The removal area to be 150% of the distressed area.

Longitudinal Cracks
Rout and seal all cracks with rubber crack filling material, or agreed upon equal

Longitudinal Distortion
Remove and replace distressed layer(s). Removal area to be 110% of the distressed area to a depth not to exceed the warranted pavement

Potholes, Slippage Areas, Raveling, Segregation and Other Disintegrated Areas
Remove and replace the distressed area(s). The removal area to be 150% of the distressed area to a depth not to exceed the warranted pavement

Rutting
Remove and replace distressed layers full lane width.

Low Friction
Micro-surfacing distressed area full lane width.

Warranty requirements for all remediation work will be limited to the life of the original contract warranty.

If any of the threshold levels are met or exceeded and the Contractor does not agree to the pavement distress survey results or, the Department does not agree with the proposed remedial action, the Team will provide a recommendation within 30 days.

Remedial action will be performed on all segments of the project where the threshold levels are met or exceeded. If areas of warranted pavement which are not within the measured area are suspected of meeting or exceeding a threshold level, the Department will conduct a distress survey to see if a threshold level has been met or exceeded. Remedial action will be taken by October 1 of the same calendar year as the survey that indicated the threshold level is met or exceeded. If, anytime during the warranty period, 30 percent or more of the project segments require, or have received remedial action, then the entire project will receive a remedial action as determined by the Contractor and the Department. If an impasse develops, the Team will make a final recommendation.

If remedial action work or elective/preventive action work performed by the Contractor necessitates a corrective action to the pavement markings, adjacent lane(s) or roadway shoulders, then such corrective action to the pavement markings, adjacent lane(s) and shoulders will be the responsibility of the Contractor.

The threshold values for each 100 meter evaluation section are as follows:

International Roughness Index	2.1 m/km (133 in/mi.)
Rut Depth	9.0 mm (0.35 in)
Longitudinal Cracking (severity 2 or greater)	0 m

Friction Number 25

The friction number must average 35 with no individual value less than 25.

The Contractor will not be held responsible for distresses which are caused by factors beyond the control of the Contractor. For example, the Contractor will be relieved of the responsibility for IRI remedial action if the roughness is caused by alligator cracking providing the pavement in question is of proper thickness (not thinner than 15 mm from plan thickness) and the recovered binder is of acceptable stiffness and one of the following is true: the base is at least 50 mm thinner than plan thickness, or the subgrade density is less than 90% of optimum, or the actual number of Class 5 or higher trucks are 50% above the projected five year number of Class 5 or higher trucks. The five year projected number of Class 5 or higher trucks for this project is 19,800,000.

The rutting threshold level is waived when the accumulated number of Class 5 or higher trucks is 50% above the projected fifth year accumulated number of Class 5 or higher trucks. If the rutting is assumed to be caused by the base or subgrade, coring (or cross sectional sampling) will be conducted to determine the cause of the rutting. The Contractor will only be responsible for mixture and placement problems.

6. ELECTIVE/PREVENTIVE ACTION. Elective/preventive action will be the Contractor's option with the concurrence of the Department. For elective/preventive actions, lane closure periods are not charged.

7. DEPARTMENT MAINTENANCE. The Department will perform routine maintenance during the warranty period such as plowing, applying de-icing chemicals, repairs to safety appurtenances, pavement markings, mowing and sign maintenance. No routine pavement surface maintenance activities will be performed by the Department during the warranty period.

8. METHOD OF MEASUREMENT. Warranted asphalt pavement will be measured for payment by the megagram of mixture based on the quantity of mixture placed. Asphalt mixture will be paid for at the contract unit price for Asphalt Pavement Mixture, Warranted, which will include full compensation for furnishing, preparing, hauling, mixing and placing all materials and compacting the mixtures. The Warranty Bond, warranty work, Job Mix Formula, Quality Control Plan and all testing, record keeping, sampling and traffic control are included in the contract unit prices.

9. BASIC OF PAYMENT. The accepted quantities of asphalt pavement mixtures will be paid for at the contract unit price per megagram for asphalt pavement mixtures warranted which payment will be full compensation for furnishing, preparing, hauling, mixing and placing all materials and compacting the mixtures. The Warranty Bond, warranty work, Job Mix Formula, Quality Control Plan and all testing, record keeping, sampling and traffic control are included in the contract unit price.

Payment will be made under:

Pay Item	Pay Unit
Asphalt Pavement Mixtures, Warranted	Megagram (ton)

Appendix E: ASTM Standards.

Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces[1]

This standard is issued under the fixed designation D 610; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This method has been approved for use by agencies of the Department of Defense to replace Method 6451 of Federal Test Method Standard No. 141A. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers the evaluation of the degree of rusting on painted steel surfaces using visual standards. These visual standards[2] were developed in cooperation with the Steel Structures Painting Council (SSPC) to further standardization of methods.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

2.1 *Adjunct:*
D610 Degree of rust (four photos)[2]

3. Significance and Use

3.1 The amount of rusting beneath or through a paint film is a significant factor in determining whether a coating system should be repaired or replaced. This test method provides a standardized means for quantifying the amount of rust present.

4. Interferences

4.1 The colored photographic reference standards that are part of this test method and the associated rust-grade scale cover only rusting not accompanied by blistering and evidenced by visible rust.

4.2 The use of the photographic reference standards[2] requires the following cautions:

4.2.1 Some finishes are stained by rust. This staining must not be confused with the actual rusting involved.

4.2.2 Accumulated dirt or other material may make accurate determination of the degree of rusting difficult.

4.2.3 Certain types of deposited dirt that contain iron or iron compounds may cause surface discoloration that should not be mistaken for corrosion.

4.2.4 Failure may vary over a given area and discretion must therefore be used when selecting a single grade that is to be representative of a large area or structure.

4.2.5 The color of the finish coating should be taken into account in evaluating surfaces as failures will be more apparent on a finish that shows color contrast with rust, such as used in these reference standards, than on a similar color, such as an iron oxide finish.

5. Procedure

5.1 Visually compare the surface with the photographic reference standards to determine the percentage of the area rusted. As a guide use Fig. 1 and the scale and verbal descriptions shown in Table 1.

NOTE 1—The numerical rust grade scale is an exponential function of the area of rust so that slight amounts of first rusting have the greatest affect on lowering the rust grade; the rust grade versus area of rust is a straight line plot on semilogarithmic coordinate from rust grade 10 to rust grade 4. The slope of the curve was changed at 10 % of the area rusted to 100 % rusted to permit inclusion of complete rusting on the 0 to 10 rust scale.

NOTE 2—The pictorial representations illustrated in Fig. 1[3] show examples of area percentages that may be helpful in rust grading.

5.2 The photographic reference standards are not required for use of the rust-grade scale since the scale is based upon the percent of the area rusted and any method of assessing area rusted may be used to determine the rust grade.

6. Precision and Bias

6.1 No precision or bias statement can be made for this test method.

7. Keywords

7.1 corrosion; rusting

[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.46 on Industrial Protective Coatings.
This test method has been jointly approved by ASTM and the Steel Structures Painting Council.
Current edition approved Sept. 15, 1995. Published November 1995. Originally published as D 610 – 41. Last previous edition D 610 – 85 (1989)$^{\epsilon 1}$.

[2] The colored photographic reference standards are available at a nominal cost from ASTM Headquarters (request Adjunct No. 12-406100-00), and from the Steel Structures Painting Council, 4518 Henry St., Suite 301, Pittsburgh, PA 15213.

[3] Original source is *Steel Structures Painting Manual*, Vol 2, Steel Structures Painting Council, Pittsburgh, PA.

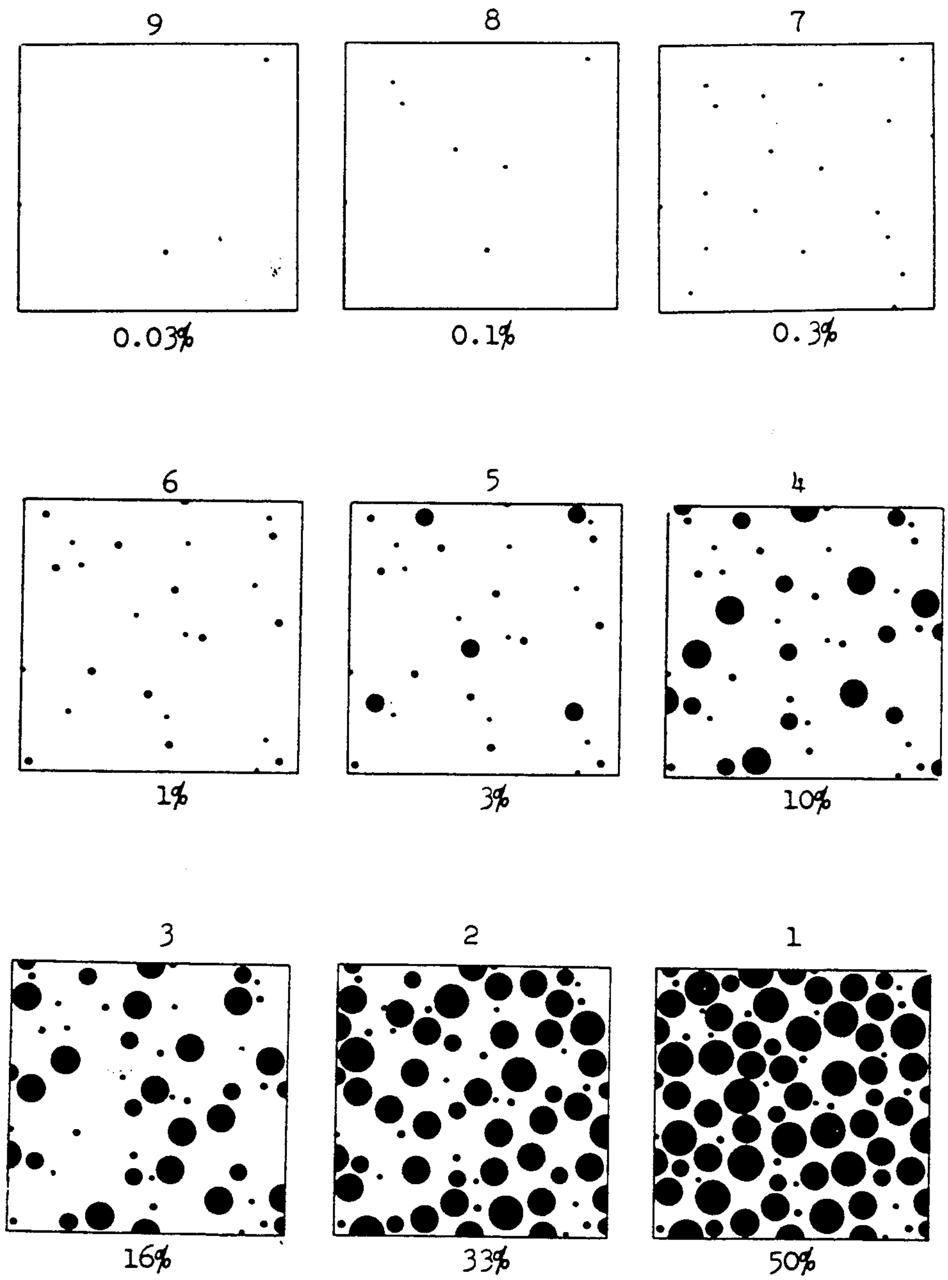


FIG. 1 Examples of Area Percentages

TABLE 1 Scale and Description of Rust Grades

NOTE—SSPC Initial Surface Conditions E, F, G, and H are described in "Systems and Specifications, Surface Preparation Commentary," Vol 2 of the *Steel Structures Painting Manual*, 6th Edition, 1991.

Rust Grades[A]	Description	ASTM-SSPC Colored Photographic Standard
10	no rusting or less than 0.01 % of surface rusted	unnecessary
9	minute rusting, less than 0.03 % of surface rusted	No. 9
8[B]	few isolated rust spots, less than 0.1 % of surface rusted	No. 8
7	less than 0.3 % of surface rusted	none
6[C]	extensive rust spots but less than 1 % of surface rusted	No. 6
5	rusting to the extent of 3 % of surface rusted	none
4[D]	rusting to the extent of 10 % of surface rusted	No. 4
3[E]	approximately one sixth of the surface rusted	none
2	approximately one third of the surface rusted	none
1	approximately one half of the surface rusted	none
0[F]	approximately 100 % of surface rusted	unnecessary

[A] Correspond to Swedish Pictorial Standards for Rusting (1955) (black and white).
[B] Corresponds to SSPC Initial Surface Conditions E and British Iron and Steel Research Assn (BISRA) 0.1 %.
[C] Corresponds to SSPC Initial Surface Conditions F and BISRA 1.0 %.
[D] Corresponds to SSPC Initial Surface Condition G.
[E] Rust grades below 4 are of no practical importance in grading performances of paints.
[F] Corresponds to SSPC Initial Surface Condition H.

Standard Test Method for Evaluating Degree of Cracking of Exterior Paints[1]

This standard is issued under the fixed designation D 661; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense to replace Method 6471 of Federal Test Method Standard No. 141A. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers the evaluation of the degree of cracking of exterior paints by comparison with photographic standards.

2. Referenced Documents

2.1 *ASTM Standards:*

D 660 Test Method for Evaluating Degree of Checking of Exterior Paints[2]

2.2 *Other Standards:*

Pictorial Standards of Coating Defects Handbook[3]

3. Terminology

3.1 *Definition:*

3.1.1 *cracking*—that phenomenon manifested in paint films by a break extending through to the surface painted. Where this is difficult to determine, the break should be called a crack only if the underlying surface is visible. The use of a magnification of 10 diameters is recommended in cases where it is difficult to differentiate between cracking and checking (see Test Method D 660).

4. Significance and Use

4.1 Cracking failure of paint films can occur in use. This test method provides a means of evaluating the degree of the failure by comparing the pictorial standards.

5. Types of Cracking

5.1 Three types of cracking are recognized:

5.1.1 *Irregular Pattern Type*—Cracking in which the breaks in the film are in no definite pattern.

5.1.2 *Line Type*—Cracking in which the breaks in the film are generally arranged in parallel lines, usually either horizontally or vertically, over the surface of the film. These breaks often follow the line of brush marks.

5.1.3 *Sigmoid Type*—Cracking in which the breaks in the film form a pattern consisting of curves meeting and intersecting, usually on a relatively large scale.

6. Use of Photographic Reference Standards

6.1 The photographic reference standards that are part of this test method and are provided in the *Pictorial Standards of Coating Defects Handbook* are representative of the degree of cracking of exterior paint films. Figures 1 and 2 are for illustration purposes only and should not be used for evaluation.

6.2 The use of the photographic reference standards[3] illustrated in Fig. 1 requires the following precautions:

6.2.1 The accompanying photographic reference standards show line-type cracking only. Irregular and sigmoid-type cracking may also be interpreted from these photographs.

6.2.2 Care must be taken not to confuse various types of failure that may be present on the same surface. This is particularly true in observing cracking and checking. Cracking may very often be an advanced stage of checking and is very often in evidence along with checking and other failures.

6.2.3 It must be realized that the degree of failure will vary over any given area. Therefore, an average portion of the film should be used for comparison. On larger surfaces it is recommended that ratings be made at several locations and the mean and range reported.

6.2.4 Paint films may collect excessive quantities of dirt, which may mask the type and degree of failure. If necessary, dirt should be removed by careful and gentle brushing with a moderately soft brush.

6.2.5 In examining wood panels for cracking failure, the possibility of wood failure should be recognized. This takes the form of a cracking or splitting of the wood itself with a resultant rupture of the paint film. Also, some panels will develop "resin spewing" which will cause early failure by cracking. These points should be taken into consideration in any evaluations.

6.3 For convenience in recording the data obtained, the records should be kept on forms agreed upon between the purchaser and the seller.

7. Precision and Bias

7.1 No precision or bias statement has been established for this test method.

[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.25 on Pictorial Standards of Coating Defects.

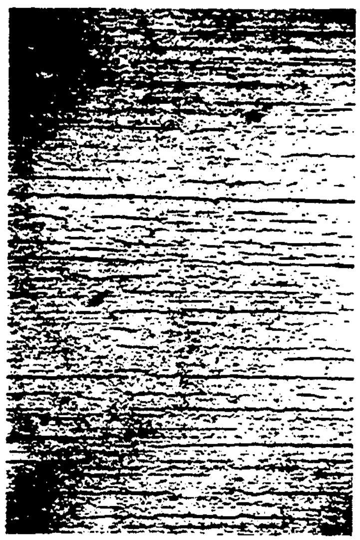
Current edition approved May 15, 1993. Published July 1993. Originally published as D 661 – 42 T. Last previous edition D 661 – 86$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 06.01.

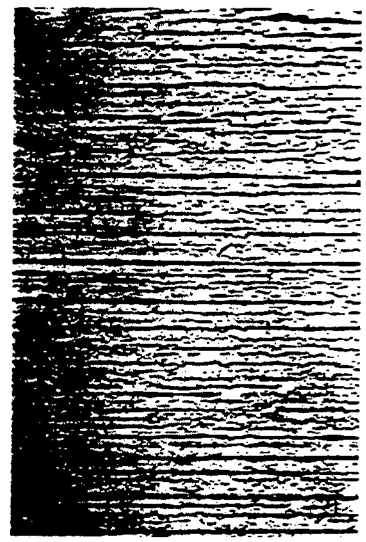
[3] Copies of the pictorial photographic reference standards are contained in the publication *Pictorial Standards of Coatings Defects* and may be obtained from the Federation of Societies for Coatings Technology, 492 Norristown Rd., Blue Bell, PA 19422. The silver halide-gelatin photographs are intended to be the only primary reference standards for this method. The reproductions of them in this test method are for the purpose of illustration only.

No. 8

No. 6



No. 4



No. 2

FIG. 1 Degrees of Cracking

Designation: D 662 – 93

Standard Test Method for Evaluating Degree of Erosion of Exterior Paints[1]

This standard is issued under the fixed designation D 662; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense to replace Method 6431 of Federal Test Method Standard No. 141A. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers the evaluation of the degree of erosion of exterior paints by comparison with photographic standards.

2. Referenced Documents

2.1 *ASTM Standards:*

D 4214 Method for Evaluating Degree of Chalking of Exterior Paint Film[2]

2.2 *Other Standards:*

Pictorial Standards of Coating Defects Handbook[3]

3. Terminology

3.1 *Definition:*

3.1.1 *erosion*—that phenomenon manifested in paint films by the wearing away of the finish to expose the substrate or undercoat. The degree of failure is dependent on the amount of substrate or undercoat visible. Erosion occurs as the result of chalking. (See Method D 4214 for evaluation of chalking.)

4. Significance and Use

4.1 Erosion failure of paint films can occur in use. This test method provides a mean of evaluating the degree of failure by comparing to pictorial standards.

5. Types of Erosion

5.1 Only one type of erosion is recognized, as defined in Section 3.

6. Use of Photographic Reference Standards

6.1 The photographic reference standards that are part of this test method and are provided in the *Pictorial Standards of Coating Defects Handbook* are representative of the degree of erosion of exterior paint films. Figure 1 is for illustration purposes only and should not be used for evaluation.

6.2 The use of the photographic reference standards[3] illustrated in Fig. 1 requires the following precautions:

6.2.1 Care must be taken not to confuse various types of failure that may be present on the same surface.

6.2.2 It must be realized that the degree of failure will vary over any given area. Therefore, an average portion of the film should be used for comparison. On larger surfaces it is recommended that ratings be made at several locations and the mean and range reported.

6.2.3 The photographic standards used represent various degrees of erosion of a white brushing type paint over a dark primer. This system was necessary to provide sufficient contrast for photographic purposes. The erosion of a film to its normal substrate is, however, readily visible to the naked eye so it may easily be compared to the standards and given a numerical rating.

6.2.4 In doubtful cases, erosion is sometimes more visible in a damp film than in a dry film. Also, with severe erosion, it is often easier to rate the degree of erosion in a damp film than in a dry film.

6.2.5 While erosion of a sprayed film is more regular in its wearing away, a numerical rating can be given to it by interpreting the amount of erosion in terms of these standards.

6.3 For convenience in recording the data obtained, the records should be kept on forms agreed upon between the purchaser and the seller.

7. Precision and Bias

7.1 No precision or bias statement has been established for this test method.

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[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.25 on Pictorial Standards of Coating Defects.

Current edition approved May 15, 1993. Published July 1993. Originally published as D 662 – 42 T. Last previous edition D 662 – 86$^{\epsilon 1}$

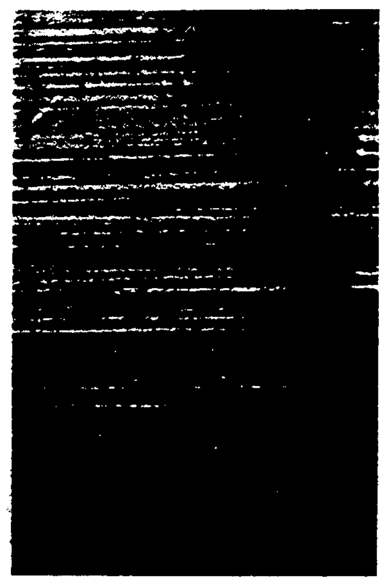
[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] Copies of the pictorial photographic reference standards are contained in the publication *Pictorial Standards of Coatings Defects* and may be obtained from the Federation of Societies for Coatings Technology, 492 Norristown Rd., Blue Bell, PA 19422. The silver halide-gelatin photographs are intended to be the only primary reference standards for this method. The reproductions of them in this test method are for the purpose of illustration only.

No. 8

No. 6

No. 4



No. 2

FIG. 1 Degrees of Erosion

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

Standard Test Method for Evaluating Degree of Blistering of Paints[1]

This standard is issued under the fixed designation D 714; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense to replace Method 6461 of Federal Test Method Standard No. 141 A and for listing in the DoD Index of Specifications and Standards.

$^{\epsilon 1}$ NOTE—Keywords were added editorially in October 1994.

1. Scope

1.1 This test method employs photographic reference standards to evaluate the degree of blistering that may develop when paint systems are subjected to conditions which will cause blistering. While primarily intended for use on metal and other nonporous surfaces, this test method may be used to evaluate blisters on porous surfaces, such as wood, if the size of blisters falls within the scope of these reference standards. When the reference standards are used as a specification of performance, the permissible degree of blistering of the paint system shall be agreed upon by the purchaser and the seller.

2. Significance and Use

2.1 A phenomenon peculiar to painted surfaces is the formation of blisters relative to some system weakness. This test method provides a standard procedure of describing the size and density of the blisters so that comparisons of severity can be made.

3. Reference Standards

3.1 The photographic reference standards are glossy prints.[2] Figures 1 to 4 are reproductions of these standards and are included to illustrate two characteristics of blistering: size and frequency.

3.2 *Size*—Reference standards have been selected for four steps as to size on a numerical scale from 10 to 0, in which No. 10 represents no blistering. Blistering standard No. 8 represents the smallest size blister easily seen by the unaided eye. Blistering standards Nos. 6, 4, and 2 represent progressively larger sizes.

3.3 *Frequency*—Reference standards have been selected for four steps in frequency at each step in size, designated as follows:

Dense, *D*,
Medium dense, *MD*,
Medium, *M*, and
Few, *F*.

NOTE 1—A quantitative physical description of blistering would include the following characteristics determined by actual count:
Size distribution in terms of mensuration units,
Frequency of occurrence per unit area,
Pattern of distribution over the surface, and
Shape of blister
For the usual tests, an actual count is more elaborate than is necessary.

4. Procedure

4.1 Subject the paint film to the test conditions agreed upon by the purchaser and the seller. Then evaluate the paint film for the degree of blistering by comparison with the photographic reference standards in Figs. 1 to 4.

5. Report

5.1 Report blistering as a number (Note 2) designating the size of the blisters and a qualitative term or symbol indicating the frequency.

5.2 Intermediate steps in size or frequency of blisters may be judged by interpolation.

5.3 When the distribution of blisters over the area has a nonuniform pattern, use an additional phrase to describe the distribution, such as "small clusters," or "large patches."

NOTE 2—The number refers to the largest size blister that is numerous enough to be representative of the specimen. For example, photographic standard No. 4, "Dense," has blisters ranging in size from about No. 7 to No. 4, inclusive.

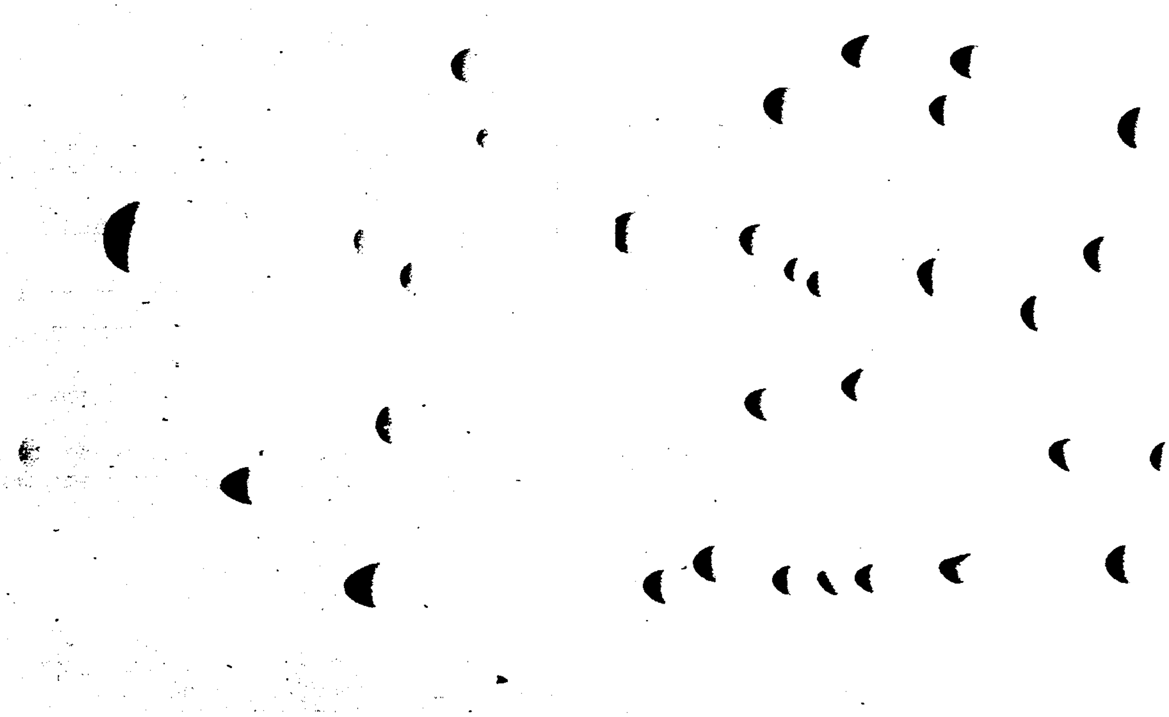
6. Keywords

6.1 blistering; corrosion

[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.25 on Pictorial Standards of Coating Defects.

Current edition approved May 29, 1987. Published July 1987. Originally published as D 714 – 43 T. Last previous edition D 714 – 56 (1981).

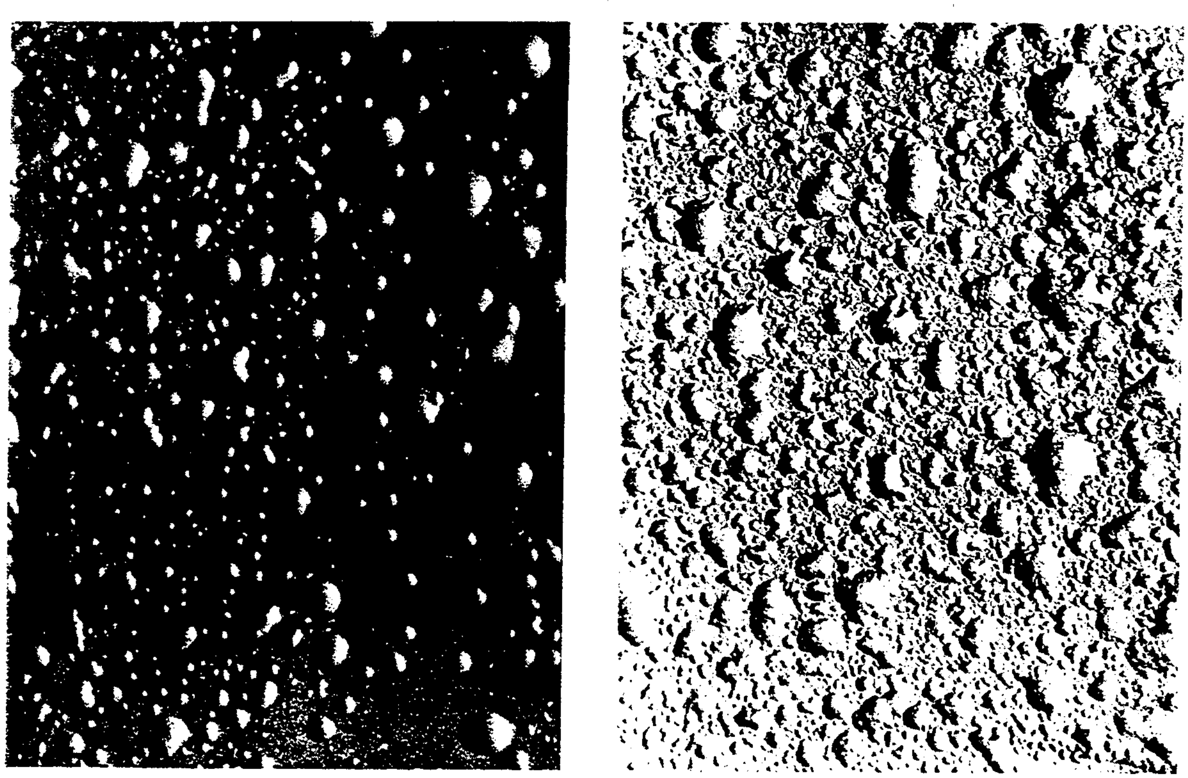
[2] Glossy prints of the photographic reference standards showing types of blistering are available at a nominal charge from ASTM Headquarters, 1916 Race St., Philadelphia, PA 19103. Request Adjunct No. 12-407140-00.



Few

Medium

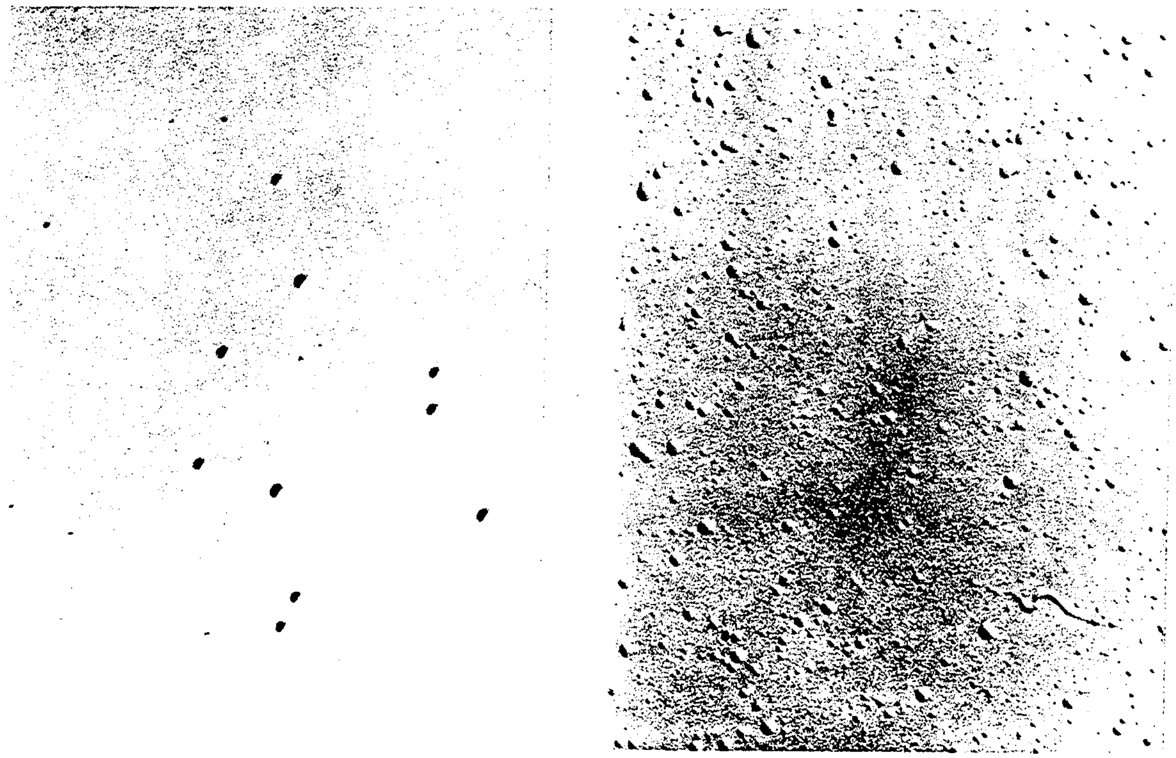
FIG. 1 Blister Size No. 2



Medium Dense

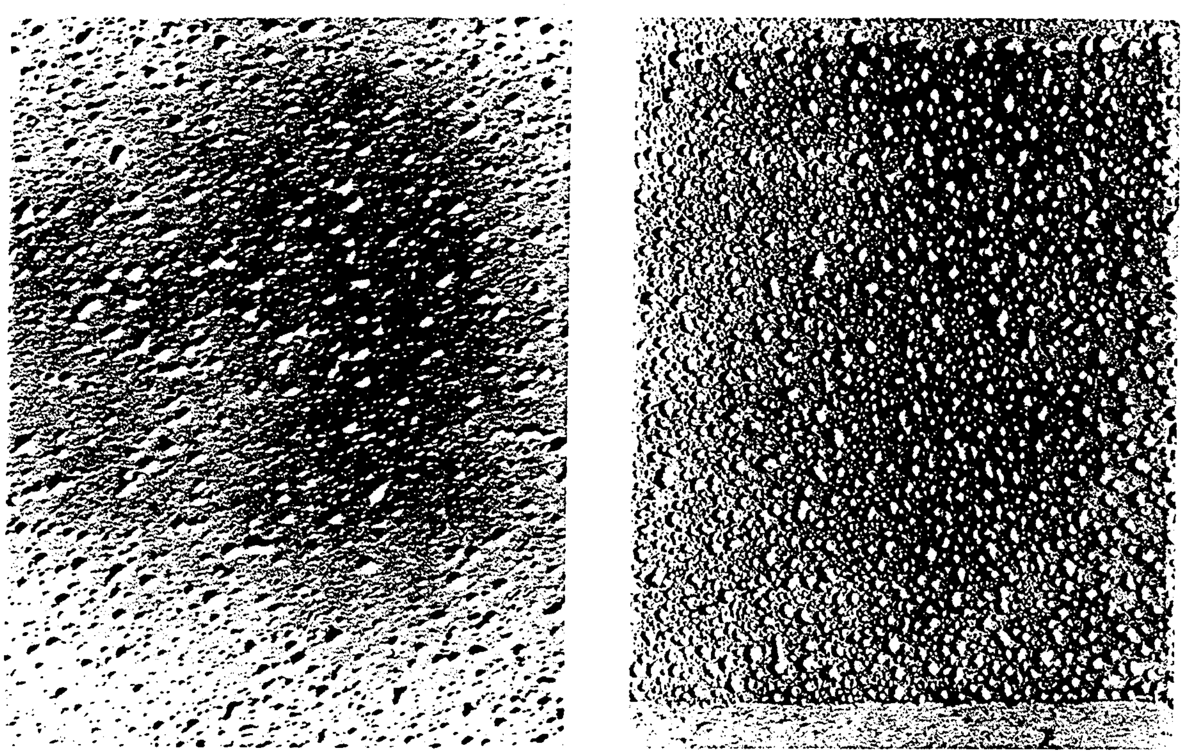
Dense

FIG. 1 *Continued*



Few Medium

FIG. 2 Blister Size No. 4



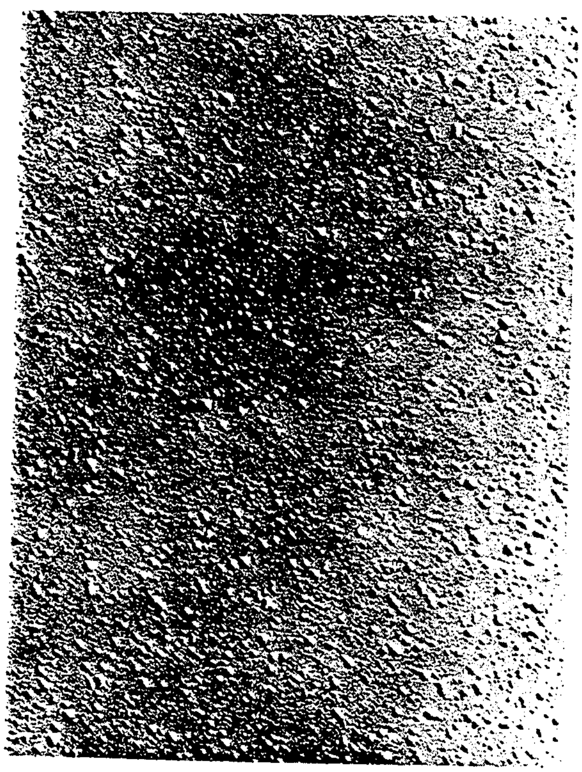
Medium Dense Dense

FIG. 2 *Continued*

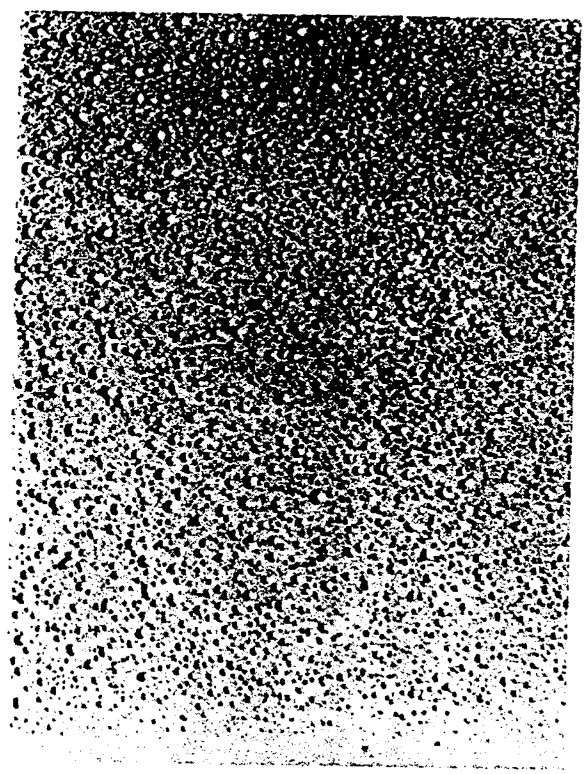
Few

Medium

FIG. 3 **Blister Size No. 6**

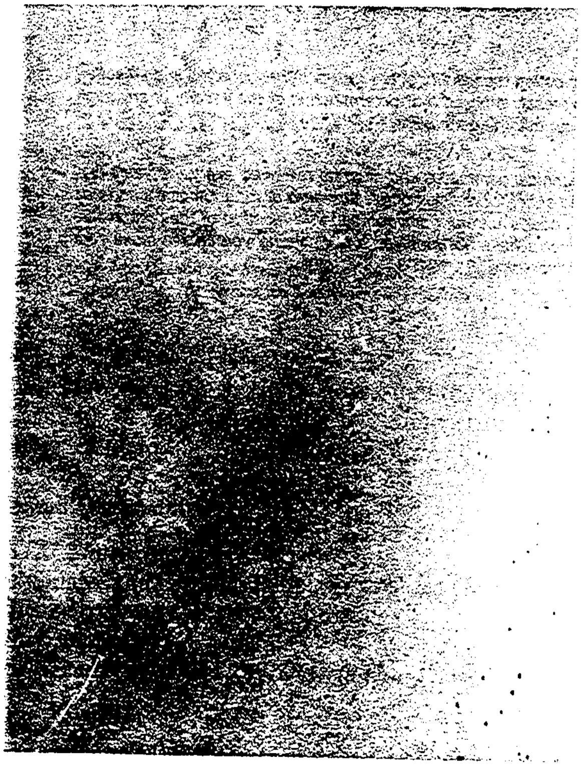


Medium Dense

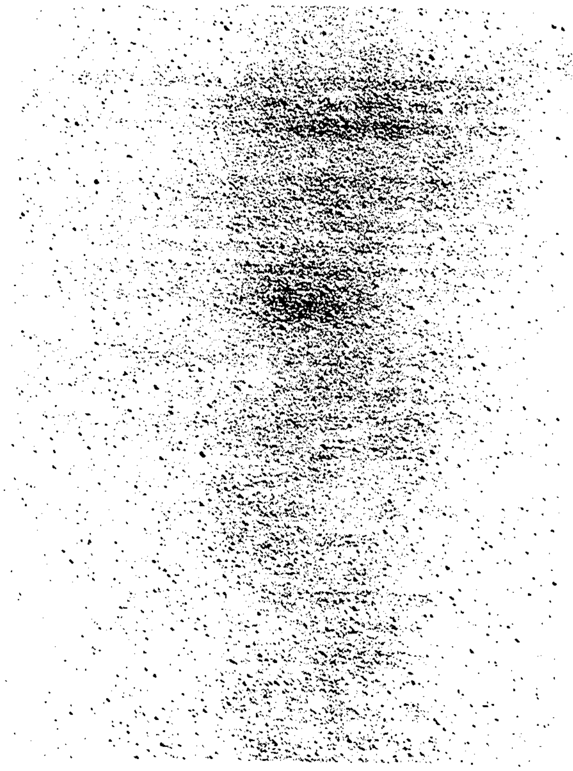


Dense

FIG. 3 *Continued*

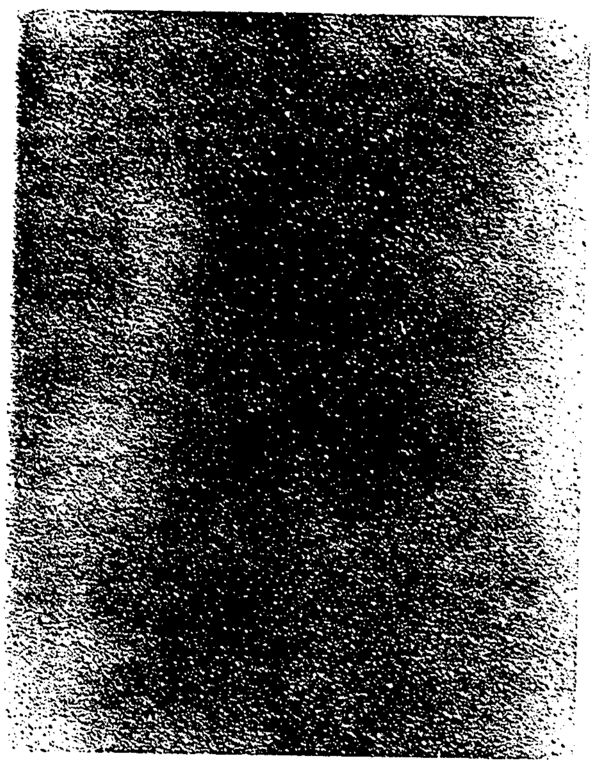


Few

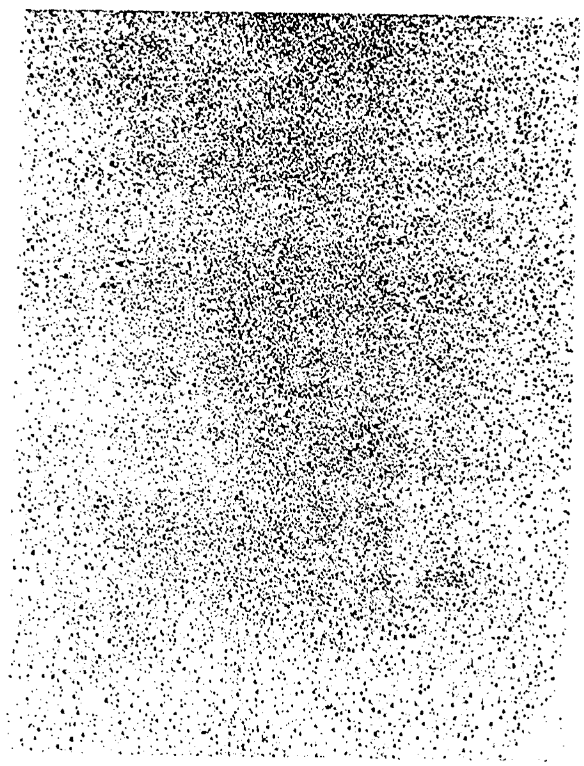


Medium

FIG. 4 **Blister size No. 8**



Medium Dense



Dense

FIG. 4 *Continued*

Standard Test Methods for Measuring Adhesion by Tape Test[1]

This standard is issued under the fixed designation D 3359; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

These methods have been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 These test methods cover procedures for assessing the adhesion of coating films to metallic substrates by applying and removing pressure-sensitive tape over cuts made in the film.

1.2 Test Method A is primarily intended for use at job sites while Test Method B is more suitable for use in the laboratory. Also, Test Method B is not considered suitable for films thicker than 5 mils (125 µm).

NOTE 1—Subject to agreement between the purchaser and the seller, Test Method B can be used for thicker films if wider spaced cuts are employed.

1.3 These test methods are used to establish whether the adhesion of a coating to a substrate is at a generally adequate level. They do not distinguish between higher levels of adhesion for which more sophisticated methods of measurement are required.

NOTE 2—It should be recognized that differences in adherability of the coating surface can affect the results obtained with coatings having the same inherent adhesion.

1.4 In multicoat systems adhesion failure may occur between coats so that the adhesion of the coating system to the substrate is not determined.

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products[2]

D 823 Practice for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels[2]

D 1000 Test Methods For Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications[3]

D 1730 Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting[4]

D 2092 Practices for Preparation of Zinc-Coated (Galvanized) Steel Surfaces for Painting[5]

D 2197 Test Methods for Adhesion of Organic Coatings by Scrape Adhesion[2]

D 2370 Test Method for Tensile Properties of Organic Coatings[2]

D 3330 Test Method for Peel Adhesion of Pressure-Sensitive Tape of 180° Angle[6]

D 3924 Specification for Standard Environment for Conditioning and Tesing Paint, Varnish, Lacquers, and Related Materials[2]

D 4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser[2]

3. Summary of Test Methods

3.1 *Test Method A*—An X-cut is made in the film to the substrate, pressure-sensitive tape is applied over the cut and then removed, and adhesion is assessed qualitatively on the 0 to 5 scale.

3.2 *Test Method B*—A lattice pattern with either six or eleven cuts in each direction is made in the film to the substrate, pressure-sensitive tape is applied over the lattice and then removed, and adhesion is evaluated by comparison with descriptions and illustrations.

4. Significance and Use

4.1 If a coating is to fulfill its function of protecting or decorating a substrate, it must adhere to it for the expected service life. Because the substrate and its surface preparation (or lack of it) has a drastic effect on the adhesion of coatings, a method of evaluation adhesion of a coating to different substrates or surface treatments, or of different coatings to the same substrate and treatment, is of considerable usefulness in the industry.

4.2 The limitations of all adhesion methods and the specific limitation of this test method to lower levels of adhesion (see 1.3) should be recognized before using it. The intra- and inter-laboratory precision of this test method is similar to other widely-accepted tests for coated substrates

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[1] These test methods are under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

Current edition approved Dec. 10, 1995. Published February 1996. Originally published as D 3359 – 74. Last previous edition D 3359 – 95.

[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] *Annual Book of ASTM Standards*, Vol 10.01.

[4] *Annual Book of ASTM Standards*, Vol 02.05.

[5] *Annual Book of ASTM Standards*, Vol 06.02.

[6] *Annual Book of ASTM Standards*, Vol 15.09.

(for example, Test Method D 2370 and Test Method D 4060), but this is partly the result of it being insensitive to all but large differences in adhesion. The limited scale of 0 to 5 was selected deliberately to avoid a false impression of being sensitive.

TEST METHOD A—X-CUT TAPE TEST

5. Apparatus and Materials

5.1 *Cutting Tool*—Sharp razor blade, scalpel, knife or other cutting devices. It is of particular importance that the cutting edges be in good condition.

5.2 *Cutting Guide*—Steel or other hard metal straightedge to ensure straight cuts.

5.3 *Tape*-One-inch (25-mm) wide semitransparent pressure-sensitive tape with an adhesion strength agreed upon by the supplier and the user is needed[7]. Because of the variability in adhesion strength from batch-to-batch and with time, it is essential that tape from the same batch be used when tests are to be run in different laboratories. If this is not possible the test method should be used only for ranking a series of test coatings.

5.4 *Rubber Eraser*, on the end of a pencil.

5.5 *Illumination*—A light source is helpful in determining whether the cuts have been made through the film to the substrate.

6. Test Specimens

6.1 When this test method is used in the field, the specimen is the coated structure or article on which the adhesion is to be evaluated.

6.2 For laboratory use apply the materials to be tested to panels of the composition and surface conditions on which it is desired to determine the adhesion.

NOTE 3—Applicable test panel description and surface preparation methods are given in Practice D 609 and Practices D 1730 and D 2092.

NOTE 4—Coatings should be applied in accordance with Practice D 823, or as agreed upon between the purchaser and the seller.

NOTE 5—If desired or specified, the coated test panels may be subjected to a preliminary exposure such as water immersion, salt spray, or high humidity before conducting the tape test. The conditions and time of exposure will be governed by ultimate coating use or shall be agreed upon between the purchaser and seller.

7. Procedure

7.1 Select an area free of blemishes and minor surface imperfections. For tests in the field, ensure that the surface is clean and dry. Extremes in temperature or relative humidity may affect the adhesion of the tape or the coating.

7.2 Make two cuts in the film each about 1.5 in. (40 mm) long that intersect near their middle with a smaller angle of between 30 and 45°. When making the incisions, use the straightedge and cut through the coating to the substrate in one steady motion.

7.3 Inspect the incisions for reflection of light from the metal substrate to establish that the coating film has been penetrated. If the substrate has not been reached make another X in a different location. Do not attempt to deepen a previous cut as this may affect adhesion along the incision.

7.4 Remove two complete laps of the pressure-sensitive tape from the roll and discard. Remove an additional length at a steady (that is, not jerked) rate and cut a piece about 3 in. (75 mm) long.

7.5 Place the center of the tape at the intersection of the cuts with the tape running in the same direction as the smaller angles. Smooth the tape into place by finger in the area of the incisions and then rub firmly with the eraser on the end of a pencil. The color under the transparent tape is a useful indication of when good contact has been made.

7.6 Within 90 ± 30 s of application, remove the tape by seizing the free end and pulling it off rapidly (not jerked) back upon itself at as close to an angle of 180° as possible.

7.7 Inspect the X-cut area for removal of coating from the substrate or previous coating and rate the adhesion in accordance with the following scale:

5A No peeling or removal,
4A Trace peeling or removal along incisions or at their intersection,
3A Jagged removal along incisions up to 1/16 in. (1.6 mm) on either side,
2A Jagged removal along most of incisions up to 1/8 in. (3.2 mm) on either side,
1A Removal from most of the area of the X under the tape, and
0A Removal beyond the area of the X.

7.8 Repeat the test in two other locations on each test panel. For large structures make sufficient tests to ensure that the adhesion evaluation is representative of the whole surface.

7.9 After making several cuts examine the cutting edge and, if necessary, remove any flat spots or wire-edge by abrading lightly on a fine oil stone before using again. Discard cutting tools that develop nicks or other defects that tear the film.

8. Report

8.1 Report the number of tests, their mean and range, and for coating systems, where the failure occurred that is, between first coat and substrate, between first and second coat, etc.

8.2 For field tests report the structure or article tested, the location and the environmental conditions at the time of testing.

8.3 For test panels report the substrate employed, the type of coating, the method of cure, and the environmental conditions at the time of testing.

8.4 If the adhesion strength of the tape has been determined in accordance with Test Methods D 1000 or D 3330, report the results with the adhesion rating(s). If the adhesion strength of the tape has not been determined, report the specific tape used and its manufacturer.

9. Precision and Bias[8]

9.1 In an interlaboratory study of this test method in which operators in six laboratories made one adhesion measurement on three panels each of three coatings covering

[7] Permacel 99 manufactured by Permacel, New Brunswick, NJ 08903, and available from various Permacel tape distributors, is reported to be suitable for this purpose. The manufacturer of this tape and the manufacturer of the tape used in the interlaboratory study (see RR: D01-1008), have advised this subcommittee that the properties of these tapes were changed. Users of it should, therefore, check whether current material gives comparable results to previous supplied material.

[8] Supporting data are available from ASTM Headquarters. Request RR: D01-1008.

a wide range of adhesion, the within-laboratories standard deviation was found to be 0.33 and the between-laboratories 0.44. Based on these standard deviations, the following criteria should be used for judging the acceptability of results at the 95 % confidence level:

9.1.1 *Repeatability*—Provided adhesion is uniform over a large surface, results obtained by the same operator should be considered suspect if they differ by more than 1 rating unit for two measurements.

9.1.2 *Reproducibility*—Two results, each the mean of triplicates, obtained by different operators should be considered suspect if they differ by more than 1.5 rating units.

9.2 Bias cannot be established for these test methods.

TEST METHOD B—CROSS-CUT TAPE TEST

10. Apparatus and Materials

10.1 *Cutting Tool*—Sharp razor blade, scalpel, knife or other cutting device having a cutting edge angle between 15 and 30° that will make either a single cut or several cuts at once[9]. It is of particular importance that the cutting edge or edges be in good condition.

10.2 *Cutting Guide*—If cuts are made manually (as opposed to a mechanical apparatus) a steel or other hard metal straightedge or template to ensure straight cuts.

10.3 *Rule*—Tempered steel rule graduated in 0.5 mm for measuring individual cuts.

10.4 *Tape*, as described in 5.3.

10.5 *Rubber Eraser*, on the end of a pencil.

10.6 *Illumination*, as described in 5.5.

10.7 *Magnifying Glass*—An illuminated magnifier to be used while making individual cuts and examining the test area.

11. Test Specimens

11.1 Test specimens shall be as described in Section 6. It should be noted, however, that multitip cutters provide good results only on test areas sufficiently plane[10] that all cutting edges contact the substrate to the same degree. Check for flatness with a straight edge such as that of the tempered steel rule (10.3).

12. Procedure

12.1 Where required or when agreed upon, subject the specimens to a preliminary test before conducting the tape test (see Note 3). After drying or testing the coating, conduct the tape test at room temperature as defined in Specification D 3924, unless D 3924 standard temperature is required or agreed.

12.2 Select an area free of blemishes and minor surface imperfections, place on a firm base, and under the illuminated magnifier, make parallel cuts as follows:

12.2.1 For coatings having a dry film thickness up to and including 2.0 mils (50 μm) space the cuts 1 mm apart and make eleven cuts unless otherwise agreed upon.

12.2.2 For coatings having a dry film thickness between 2.0 mils (50 μm) and 5 mils (125 μm), space the cuts 2 mm apart and make six cuts. For films thicker than 5 mils use Test Method A.[11]

12.2.3 Make all cuts about 3/4 in. (20 mm) long. Cut through the film to the substrate in one steady motion using just sufficient pressure on the cutting tool to have the cutting edge reach the substrate. When making successive single cuts with the aid of a guide, place the guide on the uncut area.

12.3 After making the required cuts brush the film lightly with a soft brush or tissue to remove any detached flakes or ribbons of coatings.

12.4 Examine the cutting edge and, if necessary, remove any flat spots or wire-edge by abrading lightly on a fine oil stone. Make the additional number of cuts at 90° to and centered on the original cuts.

12.5 Brush the area as before and inspect the incisions for reflection of light from the substrate. If the metal has not been reached make another grid in a different location.

12.6 Remove two complete laps of tape and discard.

[9] Multiblade cutters are available from a few sources that specialize in testing equipment for the paint industry. One supplier that has assisted in the refinement of these methods and of Test Methods D 2197 is given in footnote 10.

[10] A multitip cutter for coated pipe surfaces is now available from Paul N. Gardner Co., 316 NE First St., Pompano Beach, FL 33060.

[11] Test Method B has been used successfully by some people on coatings less than 5 mils by spacing the cuts 5 mm apart. However, the precision values given in 14.1 do not apply as they are based on coatings less than 5 mm in thickness.

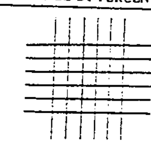
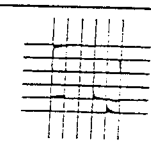
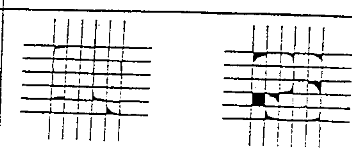
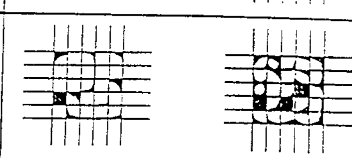
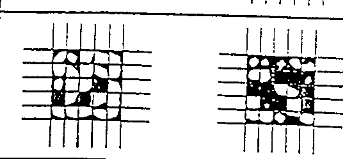
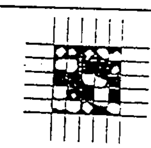
CLASSIFICATION OF ADHESION TEST RESULTS		
CLASSIFICATION	PERCENT AREA REMOVED	SURFACE OF CROSS-CUT AREA FROM WHICH FLAKING HAS OCCURRED FOR SIX PARALLEL CUTS AND ADHESION RANGE BY PERCENT
5B	0% None	
4B	Less than 5%	
3B	5 - 15%	
2B	15 - 35%	
1B	35 - 65%	
0B	Greater than 65%	

FIG. 1 Classification of Adhesion Test Results

Remove an additional length at a steady (that is, not jerked) rate and cut a piece about 3 in. (75 mm) long.

12.7 Place the center of the tape over the grid and in the area of the grid smooth into place by a finger. To ensure good contact with the film rub the tape firmly with the eraser on the end of a pencil. The color under the tape is a useful indication of when good contact has been made.

12.8 Within 90 ± 30 s of application, remove the tape by seizing the free end and rapidly (not jerked) back upon itself at as close to an angle of 180° as possible.

12.9 Inspect the grid area for removal of coating from the substrate or from a previous coating using the illuminated magnifier. Rate the adhesion in accordance with the following scale illustrated in Fig. 1:

5B The edges of the cuts are completely smooth; none of the squares of the lattice is detached.
4B Small flakes of the coating are detached at intersections; less than 5 % of the area is affected.
3B Small flakes of the coating are detached along edges and at intersections of cuts. The area affected is 5 to 15 % of the lattice.
2B The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35 % of the lattice.
1B The coating has flaked along the edges of cuts in large ribbons and whole squares have detached. The area affected is 35 to 65 % of the lattice.
0B Flaking and detachment worse than Grade 1.

12.10 Repeat the test in two other locations on each test panel.

13. Report

13.1 Report the number of tests, their mean and range, and for coating systems, where the failure occurred, that is, between first coat and substrate, between first and second coat, etc.

13.2 Report the substrate employed, the type of coating and the method of cure.

13.3 If the adhesion strength has been determined in accordance with Test Methods D 1000 or D 3330, report the results with the adhesion rating(s). If the adhesion strength of the tape has not been determined, report the specific tape used and its manufacturer.

14. Precision and Bias[8]

14.1 On the basis of two interlaboratory tests of this test method in one of which operators in six laboratories made one adhesion measurement on three panels each of three coatings covering a wide range of adhesion and in the other operators in six laboratories made three measurements on two panels each of four different coatings applied over two other coatings, the pooled standard deviations for within- and between-laboratories were found to be 0.37 and 0.7. Based on these standard deviations, the following criteria should be used for judging the acceptability of results at the 95 % confidence level:

14.1.1 *Repeatability*—Provided adhesion is uniform over a large surface, results obtained by the same operator should be considered suspect if they differ by more than one rating unit for two measurements.

14.1.2 *Reproducibility*—Two results, each the mean of duplicates or triplicates, obtained by different operators should be considered suspect if they differ by more than two rating units.

14.2 Bias cannot be established for these test methods.

15. Keywords

15.1 adhesion, tape; crosscut adhesion test method; tape adhesion test method; X-cut adhesion test method

APPENDIX

(Nonmandatory Information)

X1. COMMENTARY

X1.1 Introduction

X1.1.1 Given the complexities of the adhesion process, can adhesion be measured? As Mittal **(1)**[12] has pointed out, the answer is both yes and no. It is reasonable to state that at the present time no test exists that can precisely assess the actual physical strength of an adhesive bond. But it can also be said that it is possible to obtain an indication of relative adhesion performance.

X1.1.2 Practical adhesion test methods are generally of two types: "*implied*" and "*direct*". "Implied" tests include indentation or scribe techniques, rub testing, and wear testing. Criticism of these tests arises when they are used to quantify the strength of adhesive bonding. But this, in fact, is not their purpose. An "implied" test should be used to assess coating performance under actual service conditions. "Direct" measurements, on the other hand, are intended expressly to measure adhesion. Meaningful tests of this type are highly sought after, primarily because the results are expressed by a single discrete quantity, the force required to rupture the coating/substrate bond under prescribed conditions. Direct tests include the Hesiometer and the Adherometer **(2)**. Common methods which approach the direct tests are peel, lap-shear, and tensile tests.

X1.2 Test Methods

X1.2.1 In practice, numerous types of tests have been used to attempt to evaluate adhesion by inducing bond rupture by different modes. Criteria deemed essential for a test to warrant large-scale acceptance are: use of a straightforward and unambiguous procedure; relevance to its intended application; repeatability and reproducibility; and quantifiability, including a meaningful rating scale for assessing performance.

X1.2.2 Test methods used for coatings on metals are: peel adhesion or "tape testing"; Gardner impact flexibility testing; and adhesive joint testing including shear (lap joint) and

[12] The boldface numbers in parentheses refer to the list of references at the end of this test method.

direct tensile (butt joint) testing. These tests do not strictly meet all the criteria listed, but an appealing aspect of these tests is that in most cases the equipment/instrumentation is readily available or can be obtained at reasonable cost.

X1.2.3 A wide diversity of tests methods have been developed over the years that measure aspects of adhesion **(1–5)**. There generally is difficulty, however, in relating these tests to basic adhesion phenomena.

X1.3 The Tape Test

X1.3.1 By far the most prevalent test for evaluating coating "adhesion" is the tape-and-peel test, which has been used since the 1930's. In its simplest version a piece of adhesive tape is pressed against the paint film and the resistance to and degree of film removal observed when the tape is pulled off. Since an intact film with appreciable adhesion is frequently not removed at all, the severity of the test is usually enhanced by cutting into the film a figure *X* or a cross hatched pattern, before applying and removing the tape. Adhesion is then rated by comparing film removed against an established rating scale. If an intact film is peeled cleanly by the tape, or if it debonds just by cutting into it without applying tape, then the adhesion is rated simply as poor or very poor, a more precise evaluation of such films not being within the capability of this test.

X1.3.2 The current widely-used version was first published in 1974; two test methods are covered in this standard. Both test methods are used to establish whether the adhesion of a coating to a substrate is at an adequate level; however they do not distinguish between higher levels of adhesion for which more sophisticated methods of measurement are required. Major limitations of the tape test are its low sensitivity, applicabiity only to coatings of relatively low bond strengths, and non-determination of adhesion to the substrate where failure occurs within a single coat, as when testing primers alone, or within or between coats in multicoat systems. For multicoat systems where adhesion failure may occur between or within coats, the adhesion of the coating system to the substrate is not determined.

X1.3.3 Repeatability within one rating unit is generally observed for coatings on metals for both methods, with reproducibility of one to two units. The tape test enjoys widespread popularity and is viewed as "simple" as well as low in cost. Applied to metals, it is economical to perform, lends itself to job site application, and most importantly, after decades of use, people feel comfortable with it.

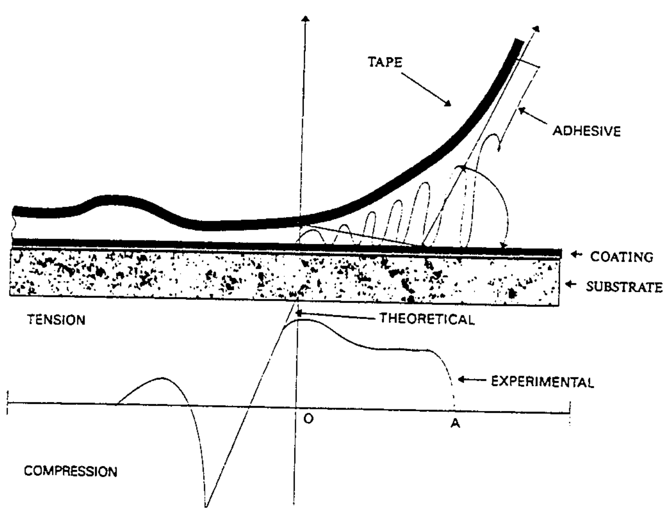


FIG. X1.1 Peel Profile (6)

X1.3.4 When a flexible adhesive tape is applied to a coated rigid substrate surface and then removed, the removal process has been described in terms of the "peel phenomenon," as illustrated in Fig. X1.1.

X1.3.5 Peeling begins at the "toothed" leading edge (at the right) and proceeds along the coating adhesive/interface or the coating/substrate interface, depending on the relative bond strengths. It is assumed that coating removal occurs when the tensile force generated along the latter interface. which is a function of the rheological properties of the backing and adhesive layer materials, is greater than the bond strength at the coating-substrate interface (or cohesive strength of the coating). In actuality, however, this force is distributed over a discrete distance (O-A) in Fig. X1.1, which relates directly to the properties described, not concentrated at a point (O) in Fig. X1.1 as in the theoretical case—though the tensile force is greatest at the origin for both. A significant compressive force arises from the response of the tape backing material to being stretched. Thus both tensile and compressive forces are involved in adhesion tape testing.

X1.3.6 Close scrutiny of the tape test with respect to the nature of the tape employed and certain aspects of the procedure itself reveal several factors, each or any combination of which can dramatically affect the results of the test as discussed **(6)**.

X1.4 Peel Adhesion Testing on Plastic Substrates

X1.4.1 Tape tests have been criticized when used for substrates other than metal, such as plastics. The central issues are that the test on plastics lacks reproducibility and does not relate to the intended application. Both concerns are well founded: poor precision is a direct result of several factors intrinsic to the materials employed and the procedure itself. More importantly, in this instance the test is being applied beyond its intended scope. These test methods were designed for relatively ductile coatings applied to metal substrates, not for coatings (often brittle) applied to plastic parts **(7)**. The unique functional requirements of coatings on plastic substrates cause the usual tape tests to be unsatisfactory for measuring adhesion performance in practice.

X1.5 The Tape Controversy

X1.5.1 With the withdrawal from commerce of the tape specified originally, 3M No. 710, current test methods no longer identify a specific tape. Differences in tapes used can lead to different results as small changes in backing stiffness and adhesive rheology cause large changes in the tension area. Some commercial tapes are manufactured to meet minimum standards. A given lot may surpass these standards and thus be suitable for general market distribution; however, such a lot may be a source of serious and unexpected error in assessing adhesion. One commercially available tape test kit had included a tape with adhesion strength variations of up to 50 % claimed by the manufacturer. Also, because tapes change on storage, bond strengths of the tape may change over time **(7, 8)**.

X1.5.2 While there are tapes available that appear to deliver consistent performance, a given tape does not adhere equally well to all coatings. For example, when the peel removal force of the tape (from the coating) used earlier by Task Group D01.23.10 to establish precision of the method, by 3M No. 710 was examined with seven different electromagnetic interference/radio frequency interference (EMI/RFI) coatings, it was found that, while peel was indeed consistent for a given coating, the value varied by 25 % between the highest and lowest ratings among coatings. Several factors that contribute to these differences include coating composition and topology: as a result, no single tape is likely to be suitable for testing all coatings. Further, the tape test does not give an absolute value for the force required for bond rupture, but serves only as an indicator that some minimum value for bond strength was met or exceeded (**7, 8**).

X1.6 Procedural Problems

X1.6.1 The tape test is operator intensive. By design it was made as simple as possible to perform, and requires a minimum of specialized equipment and materials that must meet certain specifications. The accuracy and precision depend largely upon the skill of the operator and the operator's ability to perform the test in a consistent manner. Key steps that directly reflect the importance of operator skill include the angle and rate of tape removal and the visual assessment of the tested sample. It is not unexpected that different operators might obtain different results (**7, 8**).

X1.6.2 *Peel Angle and Rate:* The standard requires that the free end of the tape be removed rapidly at as close to a 180° angle as possible. If the peel angle and rate vary, the force required to remove the tape can change dramatically. Nearly linear increases were observed in peel force approaching 100 % as peel angle was changed from 135 to 180, and similar large differences can be expected in peel force as peel rate varies. These effects are related as they reflect certain rheological properties of the backing and adhesive that are molecular in origin. Variation in pull rate and peel angle can effect large differences in test values and must be minimized to assure reproducibility (**9**).

X1.6.3 *Visual Assessment:* The final step in the test is visual assessment of the coating removed from the specimen, which is subjective in nature, so that the coatings can vary among individuals evaluating the same specimen (**9**).

X1.6.3.1 Performance in the tape test is based on the amount of coating removed compared to a descriptive scale. The exposure of the substrate can be due to factors other than coating adhesion, including that arising from the requirement that the coating be cut (hence the synonym "cross-hatch adhesion test"). Justification for the cutting step is reasonable as cutting provides a free edge from which peeling can begin without having to overcome the cohesive strength of the coating layer.

X1.6.3.2 Cutting might be suitable for coatings applied to metal substrates, but for coatings applied to plastics or wood, the process can lead to a misleading indication of poor adhesion due to the unique interfacial zone. For coatings on soft substrates, issues include how deep should this cut penetrate, and is it possible to cut only to the interface?

X1.6.3.3 In general, if adhesion test panels are examined microscopically, it is often clearly evident that the coating removal results from substrate failure at or below the interface, and not from the adhesive failure between the coating and the substrate. Cohesive failure within the coating film is also frequently observed. However, with the tape test, failures within the substrate or coating layers are rare because the tape adhesive is not usually strong enough to exceed the cohesive strengths of normal substrates and organic coatings. Although some rather brittle coatings may exhibit cohesive failure, the tape test adhesion method does not make provision for giving failure locality (**7, 8**).

X1.6.4 Use of the test method in the field can lead to variation in test results due to temperature and humidity changes and their effect upon tape, coating and substrate.

X1.7 Conclusion

X1.7.1 All the issues aside, if these test methods are used within the Scope Section and are performed carefully, some insight into the approximate, relative level of adhesion can be gained.

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