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Final Report

Steel Bridge Protection Policy
Volume II of V
Evaluation of Bridge Coating System for INDOT Steel Bridges

Luh-Maan Chang
Seunghyun Chung

May 1999

Indiana
Department
of Transportation

Purdue
University

FINAL REPORT

STEEL BRIDGE PROTECTION POLICY

VOLUME II

EVALUATION OF BRIDGE COATING SYSTEMS FOR INDOT STEEL BRIDGES

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 / PROBLEM STATEMENT

After many years of efforts to improve the paint quality of steel bridges, in 1996, Indiana Department of Transportation (INDOT) has decided to conduct further research in search for more efficient coating systems. INDOT's current steel bridge coating system of inorganic zinc and vinyl, a two coat system, has been accepted. But due to growing environmental concerns, such as the high Volatile Organic Compound (VOC) present in the vinyl paint system and the relatively short useful life of the system left more to be desired.

The revised environmental regulations require the identification and removal of lead-based paints, containment and disposal of lead paint debris, reduction of VOC level in paints, and increased efforts toward worker safety. These tougher regulations have forced INDOT to identify and utilize a different coating system for their steel bridges.

In choosing a bridge coating system, numerous environmental and economical concerns must be addressed. The main goal for painting of bridges are for long-lasting corrosion protection and improvement of its aesthetics at a minimum cost. The selection of right coating system for the particular bridge involves careful consideration of numerous aspects such as the type of bridge, environmental surroundings, use of the bridge, location of the bridge, and economic concerns to mention but a few.

The first objective of the coating system is to prevent or slow down the corrosion of the steel. The primer in a coating system serves as the main protector from corrosion attacks. It usually contains rust inhibitive pigments that reduce corrosion. The intermediate coat and the topcoat are used to provide a barrier of protection from moisture permeation, UV protection, and constant attacks from the environment. The second objective of the coating system is for aesthetics. The color of the topcoat is usually selected to harmonize with the adjacent topographic features. An important quality for a topcoat in a coating system is the ability to retain the original color and gloss.

With today's technology many paint materials and coating systems are available for various condition and location of the bridge. Therefore, it can be said that the efficiency and the effectiveness of the coating system are mainly dependent on the owner's needs, wants, and budget. Today's paint technology allows the owner to customize the bridge coating system to meet his/her needs. An economically attractive coating system will only give a short amount of protection but the short protecting duration might equal the bridge's useful life. There is no need for a coating system that will last over 30 years when the bridge only has 15 years of its useful life. Choosing the right coating system for a particular bridge is difficult. By these reasons, nowadays, many endeavors are poured into the decision making process of selecting that "perfect" coating system.

1.1 OBJECTIVE

With growing concern over environmental issues, the bridge owners are faced with tougher regulations set by the government for environmental protection. These include the identification and removal of lead-based paints and the reduction of VOC level in paints. The new, tougher, regulations have forced many bridge owners to seek alternative advanced bridge coating systems in order to satisfy the requirements.

In selecting the right coating system, many aspects of the bridge must be carefully considered. The remaining useful life of the bridge, environmental impacts of the surrounding areas, its main use, economic concerns, etc. are some of the things that an owner must review in the selection process.

The objective of this study is to identify and recommend an advanced steel bridge coating system for INDOT. Various bridge coating systems will be presented and analyzed. This will be accomplished through extensive literary search, expert interviews, evaluation of test result from government agencies and information collected from various bridge owners. By comparing the advantages and disadvantages of each coating system, a recommended coating system for INDOT will be made.

1.2 SCOPE OF STUDY

This study evaluates various bridge-coating systems and recommends an alternative coating system to meet all environmental regulations and satisfy INDOT's performance requirement. The identified coating systems will be compared with INDOT's current system of inorganic zinc and vinyl to verify benefits of the newly recommended system. The analysis procedure will be performed through extensive literature search, expert interviews, test results from government agencies, discussion with paint manufacturers, and collection of experiences from bridge owners across the country. The problems facing the current system are observed and the evaluation of overcoating alternative is presented. The scope of this study is as follows.

1. The identification of advanced coating systems were accomplished through various publications, interviews with paint manufacturers and bridge owners in all places.
2. The performance verification of the presented coating systems was accomplished through the test results from the Steel Structure Painting Council, the Turner-Fairbank Highway Research Center, and expert interviews.
3. Although many steel bridge coating systems have been evaluated, some were not considered for the comparison in this study. Areas with similar weather and environment conditions to Indiana were chosen for the comparison. The coating systems for the evaluation were selected from Ohio Department of Transportation (ODOT), Illinois Department of Transportation (IDOT), and Michigan Department of Transportation (MDOT).

1.3 METHOD OF STUDY

In this report, evaluations of various bridges coating systems are presented. Indiana's need for a new bridge coating system will be stated and the current coating system's performance will be analyzed. Indiana's bridge coating system will serve as a base for comparison with other neighboring states. Bridge coating systems from Ohio, Michigan and Illinois will be evaluated. Through literary search, interviews with the bridge owners and paint manufacturers the coating systems will be studied and its merits and demerits will be discussed. The costs associated with some of the painting systems will also be presented. Also, other aspects of coating system, such as the need for a new coating system and the issue of full-removal versus overcoating are discussed. This report will be evaluated and consulted with INDOT committee members to prescribe a coating system suitable for INDOT's applications.

CHAPTER II

INDOT'S CURRENT COATING SYSTEM

Currently the inorganic zinc and vinyl two-coat coating system is being utilized by INDOT for many years. It has replace the antiquated lead-based system but is now facing problems concerning the environment and its questionable performance. Many years ago, the vinyl coating system replaced the lead-based system due to problems relating to the lead-based paints. But now, with growing concerns over the high VOC level of the vinyl, INDOT has decided to search for a new coating system for their bridges.

2.1 INORGANIC ZINC AND VINYL COATING SYSTEM

As mentioned above, INDOT is currently using the inorganic zinc and vinyl two-coat coating system for their bridges. With the high VOC level of the vinyl paint, relatively short useful life, and due to performance problems such as pinholes and poor color retention, INDOT has decided to search for a new bridge coating system. In this section, characteristics of vinyl will be discussed. A detailed observation of the inorganic zinc will be presented in chapter 3.

There are, generally, three types of vinyl binders available: PVB, Polyvinyl butyral resins, Polyvinyl Chloride and Polyvinyl Acetate, and Vinyl-Alkyd. When PVB or Polyvinyl butyral resins are combined with zinc chromate pigments and phosphoric acid, the adhesion characteristic of the paint in improved greatly. With some vinyl paint systems which may be sensitive to surface conditions but offer excellent resistance and durability the adhesion enhancing characteristic of PVB is critical.[1]

For extreme conditions such as marine or corrosive environments, the Polyvinyl Chloride and Polyvinyl Acetate resins offer great protection by producing lacquers that dry rapidly from solvent evaporation. An extremely durable coatings is produced as a result of this reaction which act as a barrier against any harsh environments. The Polyvinyl Chloride and Polyvinyl Acetate resins are low is solids which necessitates for multiple coats and are very sensitive to surface preparation. Vinyl are extremely resistant (except to strong solvents), durable in most environments and can also be used for lining tanks for water immersion service.[1]

For most environments, a combination of hydroxyl modified vinyl and alkyd resin, the Vinyl-Alkyd will be recommended. It is less sensitive to surface preparation, it is easier to apply, it has higher solid content and it offers excellent exterior durability. However, they are not recommended for highly corrosive environments.[1]

Numerous advantages and disadvantages of vinyl can be realized. The following are the advantages:

1. Vinyls have excellent stability during use.[1]
2. Vinyls have excellent flexibility characteristics.[1]
3. Vinyls have very good resistance to abrasion, acid, water, and alkali.[1]
4. Vinyls have low moisture permeability.[1]
5. Vinyls offer excellent protection to normal, marine, and corrosive exposure.[1]

The following are the disadvantages of using the vinyl:

1. Vinyl topcoat fade unevenly.[2]

2. Vinyls have poor brushability.[1]
3. Vinyls have poor resistance to strong solvents.[1]
4. Vinyls only scored fair in the adhesion test.[1]
5. Vinyls will chalk upon UV exposure.[3]
6. Vinyls do not have very good color and gloss retention.[4]
7. Vinyls do not have good performance record against chalk resistance.[4]
8. Vinyls have high VOC.[4]
9. When applied to inorganic zinc, if no miss coat, a thin coat of vinyl applied before full application to help the vinyls react and bond with the inorganic zincs, is applied the surface will bubble.[4]

Many states, including Indiana, have utilized or are still utilizing the inorganic-zinc/vinyl bridge coating system. Some states had good results with this coating system while others felt that it was inadequate. Some positive aspects of the vinyl coating system include the fact that it is less costly when compared to other coating systems. According to a study performed by Turner-Fairbank Highway Research Center, "in relation to other industrial maintenance coatings, vinyls are generally the least expensive."[3] The vinyls are also noted for their easy handling characteristics. In Clive Hare's book about painting of steel bridges, he states, "West Virginia expects thirty years of service from the system. Apart from some early delamination problems, West Virginia has so far not needed to repaint any structures. ... In most cases, the service life of these inorganic zinc / vinyl topcoat systems is most excellent; even in relatively demanding zones. ... Claims are made of fifteen years and more of service."[3]

Although the service life of around 15 years seemed adequate during the late 1970's to early 1980's, by today's standard it fall below par of 25 to 30 years predicted for more recent coating systems available, such as the inorganic/organic zinc, epoxy, and urethane three coat system. The general consensus is that the coating system of inorganic zinc and vinyl fall short when compared to other coating systems. From the test results performed by the Turner-Fairbank Highway Research Center, they have stated that, "vinyls exhibit reduced gloss-retention performance compared to acrylics and tend to turn yellow with age. Vinyls under UV exposure will chalk with time, absorbing soils and particles that will cause discoloration."[3] They also added, "the performance over SP-3 and SP-2 prepared surfaces was much poorer in comparison to other barrier coatings tested over these surfaces."[3] Clive Hare commented in his book that, "one problem that has haunted the West Virginia as well as that of several other states, such as Maine, Tennessee, and Missouri (using similar vinyl topcoats), has been topcoat chalking and fading. The phenomenon is reported to depend on color and may well be related to specific pigments or pigmentation levels."[5]

INDOT's own experience with the inorganic zinc and vinyl coating system has not been positive. For most part, INDOT was only able to get a useful life of around 15 years. Todd Tracy, a chemist for INDOT, stated, "we were only able to get about 15 years for this coating system. The useful life depended heavily on the surface preparation."[4] He also added, "with the vinyl it is very important that a miscoat be applied. This thin layer of vinyl paint is applied on top of the inorganic zinc. It reacts with the inorganic zinc to allow good bonding between the vinyl and the inorganic zinc. If this procedure is ignored or not done properly, the life of the coating will be significantly effected."[4] INDOT has also experienced pinholes and poor color and gloss retention characteristics. Most importantly, the most significant reason for the need for a new bridge coating system is due to the high VOC level of vinyl.

2.2 PROBLEMS FACING THE VOLATILE ORGANIC COMPOUND

The Volatile Organic Compound (VOC) in the paint has been a hot debating issue between the paint manufacturers and the environmental protection agencies. Todd Tracy said that "in the past, the VOC level of the paint had no specific or defined limit. But in 1990, the Clean Air Act initially proposed to reduce the VOC level in the paint."[4] VOC is an environmental hazard that needs to be controlled. Todd Tracy also commented that "VOC evaporates and mixes in the air as the paint cures. The VOC reacts with the ozone layer to break it down."[4] Although there has been numerous talks by the government about the acceptable VOC level, there has been no set limit, as of now. Thus far, the approximate proposed limit for the VOC is around 2.0 - 3.5 lb/gal. In January of 1998, this lowered VOC law will be in effect.

2.3 PROBLEMS WITH THE LEAD-BASESD PAINTS

Traditionally steel bridges in the United States have been protected by the lead-based coating systems but due to the recent regulations on the identification and removal of lead-based paints, many states are seeking alternative coating systems to replace the old lead-based system. Clive Hare stated in this book that "the most recent revolution in bridge-paint systems may be summarized best as an abandonment of the inhibitive lead-based systems for the zinc rich and barrier systems. This change was fostered not only by the bridge authorities' desire for better paint-system performance, but also by environmental pressures to (1) initially curtail the use of photochemically reactive solvents (e.g., aromatics, olefinics, branch-chained ketones, etc.) and then to curtail the general use of solvents once other solvent types were also found to be photochemically reactive and (2) to eliminate lead and hexavalent chromium."[5] He also added that "there is little doubt that if carefully selected and properly applied in any given environment (particularly more demanding environments), the best of the new systems will produce substantially better and more cost-effective protection than will the systems they replace. Each year, the protection of more and more bridges is consequently being converted from the lead- and chromate-based inhibitive approach to zinc and barrier systems."[5]

> The old 'red lead' (four-coat red lead alkyd) system was unacceptable for five reasons:[5]
>
> 1) It contained lead. Whether in the form of red lead (white lead being the unacceptable form) or not was not the issue; it contains lead and the use of lead nationwide is being discouraged or prohibited.
>
> 2) It contained chromate. The problems with chromate are very similar to those of lead.
>
> 3) It was deceptively tolerant of specification violations such as inadequate preparation and priming so that, in some cases, long-term system effectiveness was substantially reduced below that of a properly applied system.
>
> 4) The system so resembled simple household paint that the inspection process was perceived as being simple; if it looked good, it was good.
>
> 5) The system, at best, is not good enough. The maximum possible paint life is about 20 years. The current funding levels allow us to paint a bridge approximately every 100 years.

CHAPTER III

ATERNATIVE COATING SYSTEMS FOR STEEL BRIDGES

A bridge coating system is a combination of surface preparation, primer, intermediate coat, and topcoat. It may have more or less than three coats to achieve the desired thickness. In choosing a coating system for a steel bridge numerous factors must be considered and studied. The coating system must be suitable for the climate of the surrounding environment, it must be easy to apply, it must provide great protection from corrosion, it must aesthetically beautify the bridge, and it must be cost effective. Clive Hare comments in his book that "each new system brings its own particular requirements for surface preparation and application as well as its own peculiarities that relate not only to its film-formation methodology and its mechanism of protection but also to its resistance to moisture, sunlight, corrodents, and physical abuse."[5]

3.1 INORGANIC / ORGANIC ZINC, EPOXY, AND URETHANE COATING SYSTEM

A popular trend in implementing a new bridge coating system is the use of inorganic/organic zinc primer, epoxy intermediate, and urethane topcoat. This three-coat system has gained popularity of numerous department of transportations (DOT), such as, Ohio DOT, Michigan DOT, Pennsylvania DOT, for the protection of their bridges. Dave Spagnolli, a project manager for the Pennsylvania Department of Transportation (Penn DOT) stated that, "we did a lot of research on costs and materials, nationally and locally, and determined the best system for this bridge would be inorganic zinc-rich primer over bare steel, a high-build epoxy intermediate coat and a polyurethane enamel topcoat."[5]

3.1.1 INORGANIC / ORGANIC ZINC PRIMER

Primers prevent corrosion of steel due to moisture penetrating to the steel surfaces through miscellaneous defects that might have formed either during the manufacturing process or during the application of the paint to the steel surface. In order for a primer to be effective, primers must be in direct contact with steel. Generally, primers are not formulated to be exposed to the environment therefore requiring a topcoat for protection. The primer utilized most frequently utilized is the inorganic zinc and the organic zinc primers. An article from the Modern Metals publication simply states that "the zinc-rich primer helps protect against corrosion because the metal will sacrificially react to protect exposed base steel from future damage."[6]

INORGANIC ZINC PRIMER:

The inorganic zinc primers may be the most frequently used primer for all bridge coating systems. Most often they are applied to new steels. They are applied in the steel fabricator's shop under a controlled environment for the painting process. The reason for this is that the inorganic zinc primers require a careful application process and a meticulous cleaning of the steel in order to be highly effective as a protecting agent from corrosion.

The inorganic zinc coatings are reactive materials. They are in state of constant change which depends on their exposure. This slow, continuing process is continued until the zinc is inactivated by an accumulation of zinc salts on the coating surface. The inorganic zinc coatings are composed of powdered metallic zinc mixed into a reactive silicate solution. The first reaction that takes place is the concentration of silicate zinc mixture by evaporation of most of the solvent. The solvent can take on a form either as water or as organic solvents. Once evaporated, environmental reactions take place and chemical curing of the coating begins.[7]

In the past, typically, the solvent was organic but due to numerous advantages of water-based solvents, this trend is changing. Water-based solvents have lower VOC level, easier cleaning after application, provides greater worker safety when applying, and does not contribute to any fire hazard. On the other hand, the water-based solvents are sensitive to low temperature and humidity. If applied at low temperature, the water will freeze and provide a poor protection. Also, if the water-based solvents are curing too quickly, then bubbling and blistering may occur. Both types of solvents are comparable in application and protection.[4] According to Todd Tracy, "the main reason for the change to water-based solvents is because it is more environmentally friendly. Clean up are done by spraying water, which contributes to cleaner environment and is less hazardous for workers. Lower VOC level is the main contributor to the change from organic to water-based solvents."[4]

Some typical zinc reactions are shown below.[1]

$\text{Zn (metal)} + H_2O \rightarrow Zn^{++} + 2e^-$

This is the normal corrosion reaction for zinc.

$Zn + H_20 + \rightarrow Zn\,(OH)_2 + H_2$

$Zn + H_20 + CO_2 \rightarrow Zn\,CO_3 + H_2$

$2\,Zn + 2NaCl + 3H_20 \rightarrow ZnOZnCl_2 + 2NaOH + 2H_2$

The corrosion protection of the steel if provided in the flowing way. The humidity, the condensation of moisture on inorganic surface and the carbon dioxide all work together to create an acid condition resulting in continuous hydrolysis of the vehicle and ionization of zinc. The zinc ions are diffused into the gel structure until a zinc silicate cement or matrix is formed around each of the zinc particles. These bind the coating together and also bind to the steel surface. The resulting zinc silicate cement is hard, insoluble, durable, and rock-like. It is the ionization of the surface of zinc particles which provides electrons to protect the steel from corrosion attacks. [1]

> Inorganic zinc coatings have very high zinc loading, typically between 75 and 95 percent zinc. The higher the zinc contents the more electrically conductive the coating. This feature allows the zinc metal within the inorganic zinc coating to sacrificially corrode and preserve the underlying steel substrate at the site of any breach or defect in the coating system. The lower the zinc content, the less conductive the coating and the less protection the coating will provide through "sacrificial" corrosion of the zinc within the coating itself. [1]

A very important characteristic of an inorganic zinc coating is the electrical conductivity of the matrix. Electrons formed by the ionization of zinc can migrate to the steel substrate to provide cathodic protection to the exposed steel area. [1]

> Of all liquid applied coating systems tested over blasted surface preparations, those incorporating a zinc-rich primer performed better than barrier coating systems without zinc-rich primers. In general, the use of inorganic zinc primers (IOZ) resulted in better overall corrosion protection performance than the use of organic zinc (OZ) primers such as zinc-rich epoxy and zinc-rich polyurethane. While both types of zinc-rich systems showed good corrosion protection over SP-10 near-white blasted surfaces, the resistance to scribe undercutting was significantly better for those systems with IOZ primers than

for systems with organic zinc primers. These results were consistent in both the 6.5-year Sea Isle City exposure testing and the 5-year field exposure testing.[3]

There are numerous advantages of inorganic zinc primers. Some of these are:

1. Inorganic zinc is unaffected by weather, sunlight, ultraviolet radiation, rain, dew, bacteria, fungus or temperature. The coating does not chalk or change with time. The inorganic zinc film remains intact with essentially the same thickness, even after many years of exposure.[1]

2. The chemical bond formed by the reaction of inorganic binder and the underlying steel surface prevents the undercutting of coating by corrosion.[1]

3. The chemical bond formed between the inorganic binder and the underlying steel surface does not allow underfilm corrosion.[1]

4. Inorganic zinc does not shrink while drying or curing.[1]

5. Inorganic zinc coated steel may be welded without any reduction in strength of the steel joint, because the zinc silicate matrix reacts with the welding flux and prevents zinc occlusions in the weld.[1]

6. The very strong film and chemical adhesion of inorganic zinc coatings form a base with outstanding friction characteristics therefore providing high coefficient of friction.[1]

7. Surface formed by inorganic zinc coatings is very hard, metallic and abrasion resistant.[1]

8. Chemical resistance of inorganic zinc coatings is excellent.[1]

Some limitations of inorganic zinc primers are also realized:

1. Inorganic zinc primer requires high degree of surface cleanness and extensive surface preparation.[1]

2. Inorganic zinc primer will not tolerate application over organic material and will immediately check, crack and chip off organic surfaces.[1]

3. Inorganic zinc coatings should never be applied over old paint.[1]

4. Inorganic zinc is not effective in freezing conditions.[1]

5. Inorganic zinc is not effective in high humidity.[1]
6. Inorganic zinc requires reactions with the atmosphere. If overcoated too quickly, a premature failure may occur due to the gases trapped underneath.[1]
7. Inorganic zinc have a rapid drying time and time-to-water insolubility.[1]
8. Inorganic zinc needs direct metal-to-metal contact (zinc to steel) at the coating / substrate interface therefore a good surface preparation is a must.[3]
9. The high-pigment (zinc dust) loading of inorganic zinc coatings gives them poor binder-to-substrate adhesion when compared to organic resin-based systems.[3]
10. Inorganic zinc dries fairly quickly, usually within 15 minutes. After this initial drying stage, the coating is porous and will not provide a "barrier" sufficient to control corrosion.[3]
11. Improper application over inorganic zinc will result in pinholes and blistering of the topcoat.[3]

ORGANIC ZINC PRIMER

When the organic zinc primer to the inorganic zinc primer, a simple nature of the organic zinc primer is discovered. Organic zinc primers involve very little chemistry in formulation. These products are simple mixtures of zinc dust or metallic zinc pigment into the organic vehicle. Zinc is the primary pigment in these organic zinc-rich coatings, with very little addition of other pigmentation.[1]

> There are two requirements essential for effective operation of organic zinc-rich coating:
>
> 1. Zinc in the vehicle, in order to provide the cathodic protection required by zinc-rich coatings, must be in particle-to-particle contact or contain conductive filler, such as iron phosphide, to make an electrically conductive path through the organic matrix. Without

> this particle-to-particle contact, zinc in the coating essentially would be inert and surrounded by the organic vehicle, which would not allow the zinc to go into solution and provide the cathodic protection.
>
> 2. The second important consideration in organic zinc primers is that the vehicle or carrier of zinc pigment be alkali resistant. This is important since zinc, particularly under chloride environment, reacts to form a strong alkali that would adversely effect any alkali-sensitive resin or binder. The primary organic resins used to make organic zinc-rich primers are chlorinated rubbers, phenoxy resins, or catalyzed epoxy resins. While there are a number of other materials that can be used, these are the principal ones applied to steel structures. [1]

Similar to the inorganic zinc primers, the organic zincs also use a high-film loading of metallic zinc powder. This high-film loading allows the organic primers to be conductive. The goal is to create a conductive polymer coating that has the sacrificial corrosion protecting properties of the inorganic zinc with the enhanced barrier properties and applicability of the organic zinc. [3]

The most popular organic zinc coatings are the epoxy zinc-rich and the polyurethane zinc-rich coatings. The epoxy zinc-rich is based on the zinc-filled epoxy resin to which the curing agent is mixed. The polyurethane zinc-rich coatings are available in both single and two-component systems. The main difference between the single and the two-component system is in the packaging. For the two-component system the zinc dust and the vehicle is packaged in separate container. In order for reaction to take place, the zinc dust and the vehicle must be mixed prior to application. For the single component system, this is already mixed from the factory ready for use. Therefore, the single component system is packaged in only one container. According to Todd Tracy, "the main disadvantage of the single component system is that it has a short pot life, usually less than 6 months. Whereas the two-component system can have a pot life of around 18 months. Single component system also requires inhibitors to keep it from reacting. These inhibitors may have an effect on the curing of the paint. Single component system requires more idealistic application condition, in regards to temperature and humidity. The only advantage of a single component system is that it may be more convenient to use since it requires no mix of components. The two-component system is preferred due to greater stability in terms of storage. The performance between the two is comparable."[4]

Many attributes of organic zinc primer are realized:

1. Organic zinc-rich primer proved to be successful in arresting the pit-based corrosion characteristics of chloride-contaminated weathering steel. This system added the extra benefit of a high gloss, low chalking topcoat that is resistant to dirt pickup and aesthetically pleasing to the traveling public.[8]

2. Organic zinc primers are less subject to critical surface preparation than inorganic zinc materials.[1]

3. Organic zinc primers are more compatible with oleoresinous topcoats than inorganic zinc coatings.[1]

4. Organic zinc has an excellent adhesion and undercutting resistance.[9]

5. Organic zincs are easier to apply than the inorganic zinc.[10]

6. "Organic zinc-rich epoxy primers are hard, tough, and solvent-resistant as well as highly adherent. Tolerance for less-than-ideal surface preparation is better than for inorganic zinc-rich primers. The zinc provides a mechanism which sacrifices itself, delaying the corrosion of the base steel."[8]

7. The recoatability of organic zinc primer is better than inorganic zinc primers.[8]

8. Humidity conditions are less critical for organic coatings which depend on moisture to cure.[8]

9. Normally, no gassing or pinholes occur in the intermediate coat or in the polyurethane topcoat due to less porous nature of the organic primer coat, a common problem with inorganic primers.[8]

10. Because curing time is predetermined by temperature, dry spray of the primer will not be a problem as it is with inorganic coatings sprayed in very warm temperature.[8]

11. Organic zinc primers may be used for spot repair to provide a zinc-based coating directly over bare steel and yet provide a tie between the old and new organic coating.[1]

Some disadvantages of organic zinc primers are as follows:

1. Organic zinc-rich primers are subject to the difficulties of any organic material applied directly over steel surfaces. This means they are subject to undercutting, blistering and similar adhesion problems not normally encountered with the inorganic zinc-rich primers.[1]

2. A light rust coloration on the steel surface may be more easily tolerated by an inorganic zinc coating than by an organic based material due to the possibility of the inorganic thoroughly wetting the oxide and reacting with it.[1]

3. Organic zinc primer provides less overall protection when compared to inorganic applied with ideal surface preparation.[10]

4. Organic zinc primers shrink while drying or curing, therefore not good for overcoating rough, pitted, corroded surfaces or rough welds.[1]

5. A majority of organic coating failure under severe corrosion conditions is by underfilm corrosion, starting at small breaks in the coating.[1]

Table 3.1 Inorganic Zinc vs. Organic Zinc

	Inorganic Zinc Primer	**Organic Zinc Primer**
Surface preparation		Less subject to critical surface preparation than inorganic zinc materials
Application		Easier to apply than inorganic
Overall Protection	Inorganic films show better protection than most organics	
Aging	The matrix of the inorganic primer film is not subject to age-related deterioration as are organic primers. Weathering may actually improve its physical properties.	
Adhesion	Organic zinc primers are subject to the difficulties of any organic material applied directly over steel surfaces. This means they are subject to undercutting, blistering and similar adhesion problems not normally encountered with the inorganic zinc primers.	
Recoatability		Recoatability of organic zinc is better than inorganic zinc.
Compatibility		Organic zinc primers are more compatible with oleoresinous topcoats than inorganic zinc coatings. Recoatability of organic zinc primer is better than inorganics.
Underfilm Corrosion	Chemical bond formed between the inorganic binder and the underlying steel surface does not allow underfilm corrosion whereas the majority of organic coating failure occur by underfilm corrosion, starting at small breaks in the coating	
Gassing or pinholes		Normally, no gassing or pinholes occur in the intermediate coat or in the polyurethane topcoat due to less porous nature of the organic primer coat, a common problem with inorganic primers.

3.1.2 EPOXY INTERMEDIATE COAT

When a coat of paint is applied, mostly likely there will be missed spots or faults with the first layer therefore an intermediate or second coat is applied to further protect the bridge from harsh environments or application faults. Also, since the primer and topcoat perform different functions, it is usually best to apply the paints in three coats to give it the thickness required for optimal protection.

> Epoxy binders are available in three types: epoxy ester, epoxy lacquer resin and two-component epoxy.
>
> Epoxy Ester
> These are vegetable oil-modified epoxy resins. Consequently, they are similar to alkyds except they are more expensive and produce films that are harder and somewhat more alkali resistant. Generally, they have less gloss retention when exposed. Epoxy esters are sometimes used where slightly more alkali resistance than provided by alkyds is desired, but at a lower cost than two-component epoxies.
>
> Epoxy Lacquer
> Very high molecular weight epoxies can be formulated as lacquer-type binders by solution in a mixture of strong solvents. They are sometimes used in organic zinc-rich primers because they dry quickly at low temperatures and can be recoated with topcoats, such as two-component epoxy paints. The two-component epoxies contain strong solvents that will soften the primer slightly and improve intercoat adhesion.
>
> Two-Component Epoxy
> Epoxy resins of this type cure by chemical reaction. The epoxy is generally combined with either of two types of hardners: polyamine or polyamide. Epoxy-polyamine blends are more resistant to chemicals and solvents and are often used for lining tanks. Epoxy-polyamides exhibit longer pot life, superior flexibility and durability, and have adequate chemical resistance under most conditions. Furthermore, they enable packaging of the epoxy and hardener in separate equal size packages. Epoxy-polymide

> paints are the most popular of all epoxy binders for use on structural steel. When exposed to weathering, they chalk quickly, but retain their excellent chemical resistance properties. [1]

Generally, high-build epoxy intermediate coats are applied over the organic/inorganic zinc primer. According to Clive Hare, "the high-build epoxy midcoats are subsequently recoated with urethane or another coat of epoxy, although once formed, bubbling and its resultant catering tend to telegraph from coat to coat. Epoxy midcoat solids normally range between 55% and 70% by volume. Resin systems at this time are most often based on medium molecular weight Bisphenol-A type epoxy resins with polyamide cures, although the use of lower molecular weight epoxies is increasing. Pigment Volume Concentration (PVC) is higher than the urethane finish coats and gloss is often reduced to semigloss or eggshell to improve intercoat adhesion and disguise gloss reduction in application where urethane finish coats are not used." [5]

The advantages and disadvantages of using epoxy are discussed. The advantages are:

1. Epoxies has excellent adhesion and resistance to the alkalinity of the inorganic zinc coating.[1]
2. Epoxies have good resistance against chemical fumes and splashes. [6]
3. PVCs of epoxy are higher than the urethane finish coats and gloss is often reduced to semigloss or eggshell to improve intercoat adhesion and disguise gloss reductions in applications where urethane finish coats are not used. [5]
4. Epoxies have very good resistance to abrasion. [1]
5. Epoxies offer excellent resistance against water and strong solvents. [1]

Some disadvantages of using epoxy as an intermediate coat are:

1. Epoxies have different expansion/shrinkage rate at freeze/thaw therefore causing splitting. [4]

2. Epoxies are somewhat less sensitive to topcoat bubbling than the vinyls.[5]
3. Epoxies are not recommended for colder temperatures.[1]
4. Epoxies showed poor performance in color retention test.[1]
5. Epoxies has a poor rating for gloss retention.[1]
6. Epoxies offer poor resistance against chalking.[1]

3.1.3 URETHANE TOPCOAT

The primer, intermediate, and topcoat all perform different functions and have different characteristics. Since a flaw in workmanship in the application of the paint process is always a big concern, it usually is best to apply three coats of paint to ensure maximum protection from the environment. Also, it is generally accepted at a minimum of 5-6 mils of total dry film thickness (dft) is necessary to provide a good protection of exposed steel. Since most paints normally achieve a dry film thickness of about 2 mils, three coats usually are needed to achieve the desired total dry film thickness.

There are two types of urethanes, aliphatic and aromatic. These two types can be in a form of following three types of binders.

> Urethane or polyurethane binders are available in three types:
>
> ***Oil-Modified Urethane*** These are also called uralkyds, since they are similar to alkyds in processing, method of cure (oxidation), and use. However, they produce coatings that are harder and more resistant to abrasion than alkyds. Unfortunately, although uralkyds have excellent durability as clear finishes, pigmented uralkyd coatings are not durable enough to be used on exposed structural steel.
>
> ***Moisture-Cured Urethane*** The moisture-cured urethane react uniquely with air moisture to cure. They produce the

> hardest, toughest coatings available in one package. Pigmentation is extremely difficult because of their moisture sensitivity, so they are used primarily as clear finishes. They can be pigmented, provided moisture-free materials are used and proper precautions are taken during manufacture and use.
>
> ***Two-Component Urethane*** Urethane can also be reacted with products such as polyols, polyethers, polyesters or acrylics to produce extremely hard, resistant and durable coatings. These are binders of major interest for use as topcoats on structural steel exposed in marine or corrosive environments.[1]

Generally, for the three coat coating system of organic/inorganic zinc primer, epoxy intermediate, and urethane topcoat, two principal types of polyols are used in the urethane systems: a hydroxylated acrylic or a hydroxylated polyester. According to Clive Hare, "the acrylic polyols, however, seem to have at least as large a share of the young market at this time as do the polyesters. While the polyester-based products have the edge in chemical, solvent, and abrasion resistance, the acrylics have slightly better UV resistance and faster initial drying profiles. They are also less costly. Conventional volume-solids ranges for the urethane finish coats are between 50% and 60%."[5]

Numerous merits of urethane can be realized.

1. Urethanes provide an extra protection from corrosion.[7]
2. Urethanes offer good chemical resistance qualities.[7]
3. Urethanes have good abrasion resistance.[7]
4. Urethanes provide excellent color and gloss retention.[7]
5. Urethanes provide excellent resistance against ultraviolet (UV) rays.[10]
6. Urethanes have very low moisture permeability qualities.[1]

7. Urethanes have excellent chalk resistance.[1]

The disadvantages of urethane are also listed:

1. Urethanes have higher material cost when compared to other paint materials.[10]
2. Urethanes are generally used only for UV protection and appearance of the bridge.[10]

3.1.4 COMMENTS

The three-coat bridge coating system of inorganic/organic zinc primer, epoxy intermediate, and urethane topcoat have generally received positive feedbacks from its users. Michigan Department of Transportation (MDOT) commented that "the second type of coating system tested, which is our current system, was an organic zinc-rich epoxy primer with a polyamide epoxy intermediate coat and an aliphatic polyurethane topcoat. The organic zinc-rich primer proved to be successful in arresting the pit-based corrosion characteristics of chloride-contaminated weathering steel. This system added the extra benefit of high gloss, low chalking topcoat that is resistant to dirt pickup and aesthetically pleasing to the traveling public."[11] "After years of use, the coating, which consists of three DuPont maintenance finishes (Ganicin inorganic zinc primer, Corlar high-build epoxy and Imron polyurethane enamel), still has a fresh, wet look."[6]

> After experimenting with various coating systems, the current system, an organic epoxy zinc-rich primer, an epoxy intermediate coat, and a urethane topcoat, evolved. This system is used both for coating new bridge steel members in the shop, prior to shipping to the job site, and for repainting existing structures after the old red lead system has been removed. The advantages of the new system are:

1) The new system has displayed substantially improved durability and corrosion protection in laboratory tests and field applications to date have been most satisfactory.

2) Tests indicate that even when poorly applied, the new coating system lasts longer and provides better protection than the corresponding lead-based system.

3) The new system employs a 'time-independent primer', which rapidly stabilizes and does not deteriorate with age, unlike the lead-based system whose primer resin remains chemically active and eventually becomes so brittle that it peels off the structure.

4) The FHWA will now fund only the new generation of coatings developed to replace the red lead system.

5) The cost of the new system is lower on an initial basis and significantly cheaper in the long run on a cost per square foot per year of service basis. [12]

The expected life expectancy of the inorganic/organic zinc primer, epoxy intermediate, and urethane topcoat coating system ranges anywhere from 20 to 40 years. The Pennsylvania Department of Transportation (PennDOT) stated that, "we expect this system to last 20 to 25 years, which is more than twice the normal life of conventional coating systems. ... The alkyd-based paints generally begin to deteriorate after eight or nine years, and after 12 years they need repainting." [6] MDOT also added that, "although the organic zinc-rich primer, epoxy intermediate coat, and the urethane topcoat have been exposed to a variety of environmental conditions for a fairly limited time (about 7 years), their condition is excellent and in line with the projected 30 to 40 year life of the system. With the field evidence collected over the past several years, we expect the coating system to continue to perform satisfactorily with minor maintenance repairs, and it remains the system of choice for new and exsisting." [11] The Ohio Department of Transportation concluded that "the organic zinc system, we are starting to see it pay for itself. It used to be that once you paint a bridge, you would have to come back eight or nine years later and repaint it. We are expecting to get at least 15 years out of this new system. As far as the inorganic zinc on new bridges, we have been using that probably since 1978, around that neighborhood, and we never had to repaint the bridge that had that system on it. It has been almost 20 years. Therefore, the system seems to be a pretty good system." [10]

With this system, cost savings can also be realized. PennDOT expects that, "because of the expected 25-year service life of the new three-tiered coating system, the bridge (with an expected 50-year service life) will require only one maintenance painting instead of three, lowering maintenance costs considerably." [6]

> Reducing the number of necessary repaintings from three to one could save PennDOT millions of dollars. "Labor usually runs about 60 to 70% of the total painting costs," said Spagnolli. "While we have no way of knowing future labor costs, we can look at some records and get an idea." He cited the Fort Pitt Bridge, which cost $240,000 to paint about 10 years ago. When the bridge was repainted in 1979-80, the cost was $2.4 million." [6]

A record of the painting cost history using this coating system is shown below.

TABLE 3.2 OZEU Bridge Painting Cost History[13]

CAL. YEAR	PROJECTS	BRIDGES	SQ. FT.	LOWBID* ($/ft^2)	TOTAL COST
1990	7	40	499,742	$7.29	$3,646,100
1991	25	133	3,128,437	$6.96	$21,779,900
1992	27	134	3,350,000	$6.66	$22,311,000
1993	26	141	2,870,900	$5.24	$15,043,600
1994	16	85	1,696,200	$5.83	$12,667,100
1995	14	49	1,157,000	$4.43	$4,769,200

(THESE COST INCLUDE EVERYTHING EXCEPT TRAFFIC CONTROL)

Note: $/ft^2 = 10.76 $/m^2

* $/ft^2 are estimated by dividing the total cost of the project by the total surface area of steel to be painted. The total surface area of steel to be painted may vary depending on whether the owner decides to paint the inner side of the steel girder.[5]

TABLE 3.3 1996 Bridge Paint Costs Lowbid[13]

PROJECT NO.	SQ. FT X(1000)	SURFACE PREP.	PRIME COAT	INTER COAT	FINISH COAT	TOTAL	NO. OF BRIDGES
20	129	$1.55	$0.50	$0.60	$0.50	$3.15	8
21	59	$2.72	$0.30	$0.30	$0.30	$3.62	6
70	114	$2.00	$0.50	$0.50	$0.50	$3.50	8
90	77	$2.00	$1.00	$0.50	$0.50	$4.00	3
105	28	$1.50	$0.60	$0.60	$0.60	$3.60	1
469	32	$3.00	$0.55	$0.55	$0.55	$4.65	1
147	218	$2.20	$1.10	$0.50	$0.50	$4.30	5
291	86	$1.94	$0.70	$0.70	$0.70	$4.04	1
340	229	$2.25	$0.50	$0.50	$0.50	$3.75	16
390	94	$2.76	$0.55	$0.55	$0.55	$4.41	4
408	34	$2.50	$0.50	$0.50	$0.50	$4.00	1
412	9	$4.00	$0.75	$0.75	$0.75	$6.25	1
419	17	$2.10	$1.10	$0.53	$0.53	$4.26	1
425	5	$4.75	$1.00	$1.00	$1.00	$7.75	1
434	243	$2.75	$0.50	$0.50	$0.50	$4.25	9
445	46	$1.65	$0.50	$0.50	$0.50	$3.15	3
494	123	$2.50	$0.50	$0.50	$0.50	$4.00	6

17 PROJECTS 1,543,000 sq. ft. $4.28 / sq. ft. 75 BRIDGES

Note: $\$/\text{ft}^2 = 10.76\ \$/\text{m}^2$

Appendix A contains the sample specification for the inorganic / organic zinc, epoxy, and urethane coating system. Appendix B contains the prequalified product list and appendix C compares the specification from INDOT, MDOT and ODOT.

3.2 INORGANIC ZINC AND WATERBORNE ACRYLIC COATING SYSTEM

Another frequently used bridge coating system is the inorganic zinc, and waterborne acrylic three-coat system. The Illinois Department of Transportation (IDOT) is currently using this system with good results. According to IDOT, "we are satisfied with our coating system. It is more cost effective than the urethane system and we expect it to last around 15 to 20 years without major service." [14] IDOT also added that, "we also use the inorganic zinc, epoxy, and urethane system for cold weather applications. We would not object to a contractor using the epoxy and urethane system when the temperature falls below 50° F." [14] IDOT was also concerned with the high VOC level of the vinyl coating systems. IDOT stated that, "before the waterborne acrylics, we were using the vinyls. But do to the high VOC level, we made the switch to acrylics." [14] IDOT also added that "we are anticipating 25 years for our coating system. But we haven't had the chance to prove that since we've only used the acrylics for about two years. We were only getting about 10 to 15 years for the vinyl system." [14]

> The resins in the waterborne acrylic system give high gloss, very fast drying systems with rapid development of film properties. These properties are similar to those obtained from conventional acrylics made from solvent-based thermoplastics. Paint formulation is also different. No external thickeners are usually required. For the resin formulations, the polymers generally bear carboxylic acid groups copolymerized into their backbone. These groups are neutralized at the formulation stage with amines. The resultant salt can be solvated, which increases the viscosity of the resin. This eliminates the need for thickener in the formulation and enables the resin to be used for pigment dispersion. For good film formulation, both coalescents and sometimes plasticizers are used. The fast evaporating systems give short tack-free drying times,

and the slower solvents give the best coalescence. Flash rusting inhibitors are used to diminish flash rusting of steel. Flow agents are often used in balanced amounts with a defoamer. This use gives optimum resistance to cratering and bubbling and eliminates flow problems such as orange peel.[5]

The advantages of acrylics are as follows:

1. Acrylics are less expensive than urethane.[14]
2. Acrylics have good UV resistance.[3]
3. Acrylics exhibit little yellowing and maintain their clarity for long periods of exposure.[3]
4. Acrylic coatings are potentially less hazardous to personnel than polyurethanes and are not as prone to moisture-related difficulties.[3]
5. Acrylics exhibit excellent flexibility characteristics.[1]
6. Acrylics have good color and gloss retention.[4]

The disadvantages of acrylics are as follows:

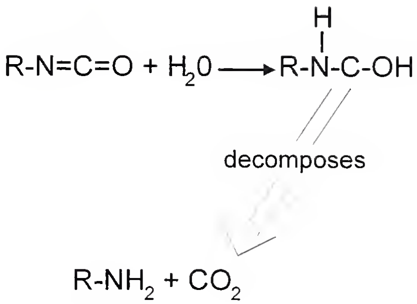
1. Acrylic coatings will soften and sometimes disbond if exposed to aromatic naphtha. For these reasons, most acrylic coatings should not be overcoated with coatings containing aromatic naphtha.[3]
2. The solvents in epoxies and polyurethanes will dissolve acrylic coatings, and overcoating acrylics with solvent-borne epoxies or polyurethanes can result in swelling, blistering, and disbondment of the acrylic.[3]
3. Due to the thinner coats, it requires more application of paints contributing to the increase in labor and material costs.[14]
4. Acrylics only performed fair for the resistance to abrasion, water, strong solvents, and acids.[1]
5. Acrylics only showed fair rating in the corrosive exposure test.[1]

3.3 MOISTURE CURE URETHANE COATING SYSTEM

As an alternative to the three-coat bridge coating system of inorganic/organic zinc primer, epoxy intermediate, and urethane topcoat, a moisture cure coating technology is also available. Moisture cure coatings offer years of steel protection while requiring less sensitivity toward surface preparation and application process. Although the moisture cure coatings seem superior to other coating systems, the need for moisture in the curing process of the paint leads limits its use to environments with high moisture content for ideal performance.

3.3.1 COMPOSITION

Moisture cure coatings are single package compositions that cure by the reaction of residual isocyanate groups with atmospheric moisture to form disubstituted urea and biuret-linked polymers. They are prepared by reacting excess diisocyanates with a hydrogen donor having a functionality of two or more to give an isocyanate-terminated product that can be subsequently used for crosslinking with water. The reaction of these products with atmospheric water in the filed involves a two-stage process with the water and the isocyanate groups first producing the unstable carbamic acid, which immediately dissociates to form an amine and carbon dioxide. The carbon dioxide leaves the film by evaporation, and the amine reacts with a second group giving a urea.[5] An example of this reaction is given below.[5]

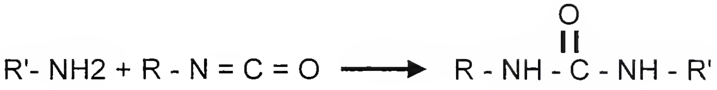


$$\text{R-N=C=O} + \text{H}_2\text{0} \longrightarrow \text{R-}\overset{\overset{\text{H}}{|}}{\text{N}}\text{-C-OH}$$

decomposes

$$\text{R-NH}_2 + \text{CO}_2$$

The R-NH_2 reacts again with R-N=C=O to form



$$\text{R'- NH2} + \text{R - N = C = O} \longrightarrow \text{R - NH - }\overset{\overset{\text{O}}{||}}{\text{C}}\text{ - NH - R'}$$

UREA

3.3.2 COMMENT

Moisture cure urethane coatings have been utilized in Europe for over 30 years. Although the history of the use of moisture cure coatings in the United States is rather short, many important and famous bridges across the country have already applied moisture cure technology for their protection. These bridges include the Tacoma Narrows Bridge, the George Washington Bridge, the Golden Gate Bridge, and many more. Currently numerous department of transportation (DOT) of various states are using the moisture cure technology for the protection of their bridges. The moisture cure coating system is currently used by the Wisconsin DOT, Alaska DOT, Maine DOT, Vermont DOT, New Hampshire DOT, New York DOT, Kentucky DOT, and Minnesota DOT to name just a few. Moisture cure urethane coating has a life expectancy of around 20 to 30 years.[15]

The moisture cure coatings offer numerous advantages when compared to the conventional system mentioned above. Moisture cure coatings require less surface preparation, which leads to considerable, cost savings.[15] According to a study performed by Juergen Schwindt, "abrasive blasting of the steel to white metal is, without question, the best method of surface preparation. But, it also is the most expensive method. By comparison, power-tool cleaning requires less effort and saves money. Power-tool cleaning is achieved with a high-pressure needle-gun, or grinding and abrasive tools. A newly developing hand-tool-cleaning technique uses an inductive delamination apparatus. With any of these methods, waste and costs can be reduced. Compared to abrasive blasting, the amount of generated waste is dramatically decreased. Expenses related to shrouding, blasting media, and waste disposal are reduced as well."[16] A table of costs involved in the surface preparation is shown below.

TABLE 3.4 Costs of Surface Preparation[16]

Associated Costs	White Metal	Handtool Cleaning
Housing	√	X
Dust collection	√	X
Blasting media	√	X
Waste disposal	√	1/10 ~ 1/100
Climatization	√	X
Wages	√	√
Paint	√	√

√ = Costs
X = No costs

> One example of the use of MC-PUR coatings to reduce costs associated with the refurbishment of a bridge, was overcoating the Homestead High Level Bridge in Pittsburgh in 1978. The bridge had an estimated 20% surface rust. After a spot commercial blast, a spot primer and intermediate coat based on MC-PUR were applied.
>
> The topcoat was a two-component polyurethnae-based formulation. After 14 years with this polyurethane system, an inspection revealed less than 5% rust. At today's cost, including containment, it has been estimated this overcoat system would be at least 30%, and maybe as much as 75%, less expensive than full paint removal. [16]

> A bridge in Tarentum, Pennsylvania provides another example of savings achievable with MC-PUR. The $450,000 saved was due in part to the fact that the surface preparation was only SSPC 6 - commercial blast - and the MC-PUR could be applied inside the containment structure even when the temperature varied between -15 and -29.4°C (5 and -22°F) or when it was snowing and raining outside the structure. The air in the containment structure was maintained at 4.4°C (40°F) during cold weather. Rapid dry times meant recoat times were shortened and blasting on adjacent areas could be started sooner. [16]

Clive Hare stated that "the principal advantages of the moisture curing polyurethane are its single package and its ability to be applied by brush, roller, trowel, squeegee, or spray without great demands on the applicator. … The final films are typified by the same general property profiles that characterize all polyurethanes, great harness without brittleness, toughness combined with excellent elongation, and excellent resistance to acids, alkalis, halogens, sulphates and other salts, solvents, and other strong chemicals." [5]

Other significant advantages of moisture cure urethane is that less thickness is require for each coat. [15] Usually only 3 mils for each layer is required. [15] Therefore the total thickness required for a three coat coating system is only 9 mils. When compared to conventional system, such as the inorganic/organic, epoxy and urethane three-coat system, which require a total thickness of around 15 mils, this relates to considerable savings in the paint usage.[17] Also, with moisture cure urethane, recoating time is reduced due to its faster curing.[16] Reduced recoating time leads to decrease in down time such as holding of traffic or other inconveniences experienced by the public due to the painting of the bridge. Lastly, moisture cure urethane coatings remain elastic and resistant to UV-radiation, ensuring the long-term durability of the coating.[16]

Some disadvantages of moisture cure urethane are reviewed. The most significant disadvantage is that it requires moisture for the curing of the paint. Therefore, if moisture cure urethane is used in a dry sunny environment, it will result in devastating cracking and splitting of the paint. Moisture cure urethane is only suitable for environments with high humidity of moisture, it is not effective on dry environment.[4] Clive Hare also added that "the curing and quality of the final product is greatly dependent upon atmospheric humidity during application. Below 30 percent humidity, cure will occur too slowly. Above 75 percent relative humidity, cure may be too fast and result in films bubbling as the carbon dioxide generated by the reaction is trapped in the set-up film."[5] The material cost for the moisture cure urethane is higher than conventional paints normally used. Wasser High-Tech Coating company quoted that "the material cost can be expected to be around 10% higher than regular paints."[15] Clive Hare concluded in his book that "bubbling becomes a more severe problem as film thicknesses increase. High film thicknesses may also entrap solvent. This phenomenon is aggravated by high humidities, although temperature will have somewhat less effect."[5]

Table 3.5 A Comparison of Various Paints Used in Coating Systems

	Epoxy	Polyurethane	Vinyl	Water-borne Acrylics
Chemical resistance	Epoxies have good resistance against chemical fumes, splashes, and strong solvents.	Urethanes offer good chemical resistance	Vinyls have poor resistance against strong solvents	Acrylics only performed fair for the resistance to strong solvents and acids.
Flexibility			Vinyls have excellent flexibility characteristics	Acrylics exhibit excellent flexibility characteristics.
Color and gloss retention	Epoxies showed poor performance in color and gloss retention tests.	Urethanes provide excellent color and gloss retention.	Vinyls do not have very good color and gloss retention	Acrylics have good color and gloss retention.
Chalk resistance	Epoxies offer poor resistance against chalking.	Urethanes have excellent chalk resistance.	Vinyls do not have good performance record against chalk resistance.	
Abrasion	Epoxies have good resistance to abrasion.	Urethanes have good abrasion resistance.	Vinyls have very good resistance to abrasion.	
UV protection		Urethanes provide excellent resistance against UV rays.	Vinyls will chalk upon UV exposure.	Acrylics have good UV resistance.
Moisture permeability		Urethanes have very low moisture permeability qualities.	Vinyls have low moisture permeability.	Acrylic coatings are not as prone to moisture related difficulties.

3.4 DISCUSSIONS

Due to the increased pressure from the environmental protection agencies to abolish lead-based paints and decrease VOC level, INDOT has decided to search for a new bridge coating system. This paper has already reviewed various coating systems utilized by neighboring states such as, Illinois, Ohio, and Michigan. This paper has also presented other coating technology such as the moisture cure urethane coating system.

In review of all coating systems presented above, it is recommended that INDOT use the inorganic zinc, epoxy, and urethane coating system for new bridges and organic zinc, epoxy, and urethane for existing bridges. The justification for the recommendation is as follows. The inorganic zinc should be used for new bridges because the surface preparation for the inorganic zinc is critical for long life. The inorganic zinc requires high degree of cleanness and extensive surface preparation therefore it should be applied at the shop where a controlled painting environment is possible. The organic zinc should be used for existing bridges since it is less sensitive to the surface preparation than the inorganic zinc. Although the inorganic zinc may offer slightly better protection, due to the uncontrollable painting environment at the field the organic zinc will offer better protection for application environment that is less than ideal.

The table shown below compares the bridge coating systems mentioned above.

Table 3.6 Comparison of Coating Systems[5]

	Estimated Expected Useful Life (Years)	Typical Film Thickness (Dry Mils)	Surface Preparation (Minimum SSPC-SP)	Adaptability to Poor Surfaces	Probability of Early Failure from Deviations in Application	Recoat Times (Days)	Compatibility with Old Coatings	Ease of Spot Repair
Inorganic / organic zinc, epoxy, urethane	~25 to 30	9	6	Poor (Inorganic) Fair (Organic)	High	1	Poor	Poor
Inorganic zinc, vinyl	~15	8	6	Poor	High	1	Poor	Poor to Fair
Moisture cure urethane	~25 to 30	9	6	Fair	High	1	Fair	Fair

As it can be seen from the table, the inorganic / organic zinc, epoxy, and urethane system and the moisture cure urethane system offers the longest useful life. Moisture cure urethanes require moisture to cure. Unless there is a lot of humidity or moisture in the air, the moisture cure urethanes will not cure properly. Therefore, the moisture cure urethanes are not suitable for Indiana's hot, dry, blistering sun.

The inorganic / organic zinc, epoxy, and urethane system is currently being used by both Ohio and Michigan. It is also being used be Illinois for their projects with application temperature less than 50° F. From expert interviews, it is concluded that both Ohio and Michigan are very satisfied with their results. They are expecting about 25 to 30 years from this system. Although some have noted that the initial material cost of the urethane system may be higher, the projected life will cover any additional expense occurred during the initial painting of the bridge. The long-term benefit of the urethane system is superior to any other coating systems presented in this report that is suitable for Indiana's climate conditions.

CHAPTER IV

OVERCOATING VS. FULL-REMOVAL

With the high cost of bridge painting, increased pressure from the environment protection agencies to get rid of the old lead paint, and limited funding from the government for bridge maintenance and protection, many bridge owners are searching for alternative strategies involved with the maintaining and protecting of the bridge against corrosion. Bernard Appleman stated in his article that "repainting structures coated with lead-based paint challenges highway agencies and other public and private owners to balance corrosion protection, environmental protection, worker protection, legal protection, and aesthetics and public perception." [18]

Overcoating can simply be defined as spot cleaning and priming degraded areas, cleaning intact paint, and applying the new lead-free coating system over the existing system. Bernard Appleman states that "Overcoating typically includes preparing rusted or degraded areas by mechanical, chemical or water cleaning methods; feathering the edges of the existing paint to provide a smooth transition at the interface between existing sound paint and cleaned areas; spot cleaning and priming of rusty areas; low-pressure water washing of the entire structure to remove loose chalk, dirt, dust, grime, and other debris; applying full intermediate coat over existing and repaired areas; and applying full topcoat over the entire structure (optional, but recommended in most instances)." [18]

In deciding whether to overcoat or perform full removal of the paint, many factors must be carefully evaluated before a decision is made. A common decision making checklist is given below. These areas must be reviewed extensively before an effective judgment is made.

Check List for Decision-Making[18]

1. Condition of Structure
    - Extent of metal corrosion and pitting
    - Percent of surface requiring mechanical preparation
    - Age and average thickness of existing coating

2. Structure Usage
    - Additional service life of structure
    - Rehabilitation or related work planned

3. Exposure Environment
    - Presence of chlorides or other chemicals
    - Proximity to industrial fallout
    - Areas prone to splash, spillage, or high humidity

4. Coating Factors
    - Evidence of early failure of previous coating system
    - Evidence of compatibility problems
    - Presence of soluble salts, grease, or oil

5. Sensitivity of Location
    - Proximity to residence, schools, day care centers
    - Height of structure (prevalent wind patterns)
    - Proximity to navigate waterway, reservoir, or other sensitive body of water

6. Constraints
    - Limited access (e.g., requiring traffic control)
    - Limited time to perform work (e.g., during turnaround or due to weather)
    - Specific environmental regulations
    - Application restrictions (e.g., on spraying)
    - Surface preparation restrictions (e.g., to eliminate dust contamination of machinery or products)

Numerous aspects play as a factor in determining the cost of full removal on a bridge. Bernard Appleman states that “the cost of a fully contained lead removal project depends on each structure, differences in access, the impact of shutdown, variability of enforcement of regulations, and inconsistency in quality and detail of specification. Also, contractors may have different means for achieving these requirements and varying degrees of willing to accept risks such as low productivity, a lesser degree of cleaning, environmental spills, elevated blood lead levels, and fines or penalties.”[18] According to a study done by the Steel Structures Painting Council (SSPC), the cost of full paint removal on a bridge ranges from \$3 per square feet to \$14 per square feet (from \$32.28/m^2 to \$150.64/m^2). A comparison between costs for the full removal vs. overcoating is represented in the table below.

TABLE 4.1 COMPARISON OF COSTS FOR FULL-REMOVAL VS. OVERCOATING[18]

			Full Removal	Overcoating
	Structure ID	**sq. ft**	**$ / sq. ft**	**$ / sq. ft**
1	Bridge over river	40,000	4.95	2.00
2	Highway overpass	10,000	8.50	3.00
3	Highway overpass	18,000	5.50	2.75
4	Bridge over wharf	20,000	3.00	2.00
5	Riveted girder span	8,000	13.13	3.00
6	Rail bridge trusses	300,000	7.00	2.00
7	Deck truss	1,000,000	10.00	5.00
8	3 span I beam	N/A	11.25	N/A
9	Plate girder	14,000	2.72	N/A
10	Plate girder	1,336,000	3.17	N/A
11	Plate girder	520,000	2.95	N/A
12	Rolled beam	2,953,000	3.55	N/A
13	Girder over river	500,000	4.00	N/A
14	Girder overpass	180,000	6.75	N/A
15	Tied arch over river	220,900	11.21	N/A
16	General, recyclable	N/A	12.00	N/A
17	General disposable	N/A	10.00	N/A
18	7 spans over water	100,000	18.00	N/A
19	Overpass	10,000	3.30	1.05
20	Overpass	20,000	8.50	N/A
21	Girder, double deck	350,000	8.00	4.00
22	Suspended cable/river	300,000	12.00	N/A
	Average		**7.47**	**2.76**
	Median		**7.50**	**2.75**

Note: $/ft^2 = 10.76 $/m^2

The following table compares the cost distribution of full removal versus overcoating. As it can be seen from the table, the cost of overcoating is more than half of the full removal process. Eric Kline and William Corbett stated in their article that "although the cost comparisons are based on the same methods form different sources, it has been discovered that total lead removal/containment projects undertaken in the early 1990's may cost as much as \$5 and \$10 per sq ft (\$53.8/m^2 and \$107.60/m^2). It becomes apparent that minimal surface preparation, followed by upgrading with one or more of the materials discussed, would provide substantial savings by making coating costs of \$2 per sq ft (\$21.52/m^2) achievable."[19] Due to this significant cost savings and a limited budget, many states are pursuing the overcoating approach.

TABLE 4.2 COST DISTRIBUTION - FULL-REMOVAL VS. OVERCOATING[18]

COST FACTOR	COST DISTRIBUTION		COST RANGE (per sq ft)	
	Full-Removal	Overcoating	Full-Removal	Overcoating
Coating materials	$0.35	$0.35	$0.40 ~ $0.65	$0.25 ~ $0.55
Mechanical surface preparation		$0.10		$0.05 ~ $0.25
Surface preparation	$0.95	$0.10	$0.75 ~ $1.30	$0.05 ~ $0.35
Application	$0.70	$0.50	$0.40 ~ $1.05	$0.30 ~ $0.70
Environmental monitoring	$0.50		$0.00 ~ $2.00	
Containment and disposal	$2.00	$0.50	$1.00 ~ $4.00	$0.50 ~ $2.00
Worker health	$1.50	$0.80	$1.00 ~ $2.00	$0.50 ~ $2.00
Overhead/miscellaneous	$1.00	$0.50	$0.40 ~ $2.00	$0.25 ~ $1.00
Total	**$7.00**	**$2.85**	**$4.00 ~ $13.00**	**$1.90 ~ $6.85**

Note: $/ft^2 = 10.76 $/m^2

There are advantages and disadvantages with both the full removal and the overcoating. For the full removal procedure, some merits might be that there is a less risk of premature coating failure, Bernard Appleman said that "the likely of the coating enduring 15 or more years is extremely high for a three-coat zinc-rich or other high-technology system applied over blast cleaned steel," [18] and the bridge will be forever be safe from lead contamination and that the owner will have no pressure from the EPA to contain the lead contamination.

Some disadvantages of full removal are that it is expensive, it presents a substantial risk of environmental contamination, it poses a health threat to workers, and it draws criticism from the public because the lead removal process is highly visible.

Numerous advantages of overcoating are realized. The biggest advantage is that overcoating is much economical than the full removal process. Eric Kline and William Corbett said that "simply coating over the old system after removing obviously loose paint by hand tool methods may be an effective approach. This is of special interest when lead paint is present. The objective is to extend the life of the lead paint system, with the expectation that the lead paint removal costs will be lower in the future, due to advances in the technology of lead paint removal, containment, and disposal." [19] With overcoating, the risks of contaminating the environment are much less than those for full removal. The risk to workers is significantly reduced, because most lead is not disturbed and less fracturing of the paint occurs.

> Overcoating has some potential advantages compared to full removal with containment. It minimizes the disturbance of the existing paint which, in turn, limits the generation of (possibly hazardous) wastes and, minimizes precautions necessary for preventing waste

> discharge, worker exposure to lead and efforts required to dispose of generated wastes. Repair and overcoating operations do not require expensive containment enclosures. Costs for repair and overcoating are low (typically one-fifth to one-third that for full removal with containment) and overcoating may extend the service life of the in-place coating system lives of overcoating systems exceeding 15 years. Low initial painting costs coupled with potentially significant extension of service life are very attractive to state highway agencies strapped with limited painting budgets and large backlogs of bridges needing to be repainted.[20]

Some disadvantages of overcoating are as follows. The major disadvantage is the possibility of early failure of the coating system. This is usually due to the incompatibility between paints, osmotic blistering from soluble salts under the coating, or excessive undercutting on overcoated rust. Bernard Appleman concluded that "because of the variability of the substrate, it is costly and time consuming to evaluate the potential overcoat materials for all anticipated conditions. For example, compatibility may not be evident until seasonal changes occur, such as after 6 months of service. ... Because overcoating does not eliminate lead, it defers some risks. Presumably, the lead paint will need to be removed and disposed of sometime. Some agencies want to remove the lead as soon as possible rather than in the future when regulations may be more stringent or better enforced."[18]

The estimation of the useful life of the overcoat system is difficult. Many factors contribute to the early failures of the system.

> Many people have tried to estimate lifetimes of coating systems in various kinds of environments. ... However, as they and others point out lifetime varies widely with

> - exposure environments
> - coating performance within a generic class
> - coating batch
> - surface preparation and application methods and conditions, and
> - the definition and assessment of lifetime.
>
> Thus, estimating lifetime is difficult, even for a coating system applied to a surface conforming to SSPC-SP 6 or SP 10. Estimating lifetimes for coatings over previously painted steel is even more precarious because of
>
> - the variable condition of existing paint (e.g., brittleness, adhesion, and thickness),
> - interactions between the new and existing coatings,
> - the variability of conditions and extent of rusted areas, and
> - the effects of retained soluble salts and other contaminants. [18]

Generally, an overcoating system can be expected to last around 12 to 15 years before maintenance is needed. Bernard Appleman stated that "under the most favorable conditions, an overcoat system may last 12 to 15 years before it reaches a rust rating of 7 over 20 percent of the surface. There may, however, also be a 25 percent chance that the system will fail after 3 or 4 years. Unfortunately, there are seldom enough test results or historical data to quantify the risks or early failure. It is therefore useful to develop ranges of lifetimes for different systems under different exposures. For example, at the SSPC workshop mentioned earlier, a range of lifetimes for lead-free alkyds was estimated at 3 to 8 years over tight rust and 4 to 10 years over intact alkyd paint. Estimated service life of some selected overcoat coating systems are presented in the table below." [18]

TABLE 4.3 Selected Coating System Lifetimes from SSPC PACE Project [18]

		Lifetime (months)	
Coating System (coats)	**mils**	**Hand Tool**	**Blast Clean**
Oil-alkyd-lead/alkyd (3)	10.1	29	>52
Alkyd-chromate/alkyd (3)	8.5	20	52
Oil-alkyd-zinc oxide/alkyd (3)	9.6	20	52
Water-borne acrylic (3)	8.7	42	>52
Water-borne acrylic (3)	9.6	14	43
Epoxy-polyamide-lead (3)	6.9	9	28
Calcium sulfonate wax (2)	9.4	>52	>52
Chlorinated rubber-chromate	6.7	14	>52
Water-borne epoxy-chromate (3)	6.5	20	42

In order to get the most out of an overcoat system, the user must carefully select the best performing coating system for the job. Factors such as the adhesion/cohesion characteristics, surface contamination, surface preparation, and compatibility with the old system play a significant role in the determination of the service life and the ability to perform. The factors affecting performance and durability of overcoating system is given in appendix D. Kline and Corbett mentions that "the selection of upgrade coating systems should focus on materials that have low shrinkage characteristics during curing and high solids content to minimize solvent penetration and softening of the underlying system. …

the selection criteria should also include a substantial measure of resistance to atmospheric exposure and appearance." [19]

In a laboratory test performed by Kline and Corbett[21], a few overcoat coating systems were evaluated. These were

- vinyl zinc-rich/high-build vinyl (7.5 mils),
- urethane zinc-rich/urethane topcoat (5 to 8 mils),
- zinc-aluminum-pigmented epoxy (7 to 9 mils),
- two-coat epoxy mastic (10 to 16 mils), and
- 2 coats of an aluminum-epoxy-urethane mastic (10 mils).

The results from the experiment showed that under 500 hours of accelerated weathering tests the new coating systems were compatible with the well-cured, thick, aged alkyd and that the existing coating was still able to withstand the curing stresses and rigors of laboratory test exposure. [19]

The results from the field exposure test showed that all coating systems performed well over surfaces prepared in accordance with SSPC-SP 10. With thin film, less than 10 mils, coating systems, a slight evidence of underfilm corrosion was noticed. All areas cleaned in accordance with SSPC-SP 10 performed better than ones cleaned in accordance with SSPC-SP 2 or SSPC-SP7. The areas prepared using only air blow-down performed as well or even better than areas that have been Brush-off blast cleaned.

In a in field test, two overcoat coating systems, urethane system and epoxy sealer system, werc evaluated. In a thirteen-year field history test, the urethane performed very well. Kline and Corbett comments that "in each of these cases, the vast majority of the old alkyd was allowed to remain on the steel surface. The coating system used on these 2 structures consisted of an aluminum-filled, moisture-cured urethane spot primer; a full intermediate coat of aluminum-filled moisture-cured urethane; and a plyester-aliphatic-polyurethane topcoat. The Homestead and Glenwood bridge projects are in good condition after 13 years' exposure, because the structures exhibit little corrosion and virtually no signs of coating disbondment within the old alkyd system." [19]

In a three-year exposure test using the epoxy sealer system, it showed excellent results. "A 100 percent solids penetrating epoxy primer (sealer) was applied. The coating manufacturer claims that the sealer penetrated into cracks between the islands of intact coating and served as a barrier to moisture ingress. An epoxy intermediate and urethane topcoat was also applied. … The coating remains intact and adherent, and no spontaneous disbonding within the old coating layers is occurring, even in areas abraded by the impact of gravel or stones." [19]

CHAPTER V

CONCLUSIONS

In this report, various advanced steel bridge systems have been presented. These were compared according to their merits and faults. INDOT's current steel bridge coating system of inorganic zinc and vinyl was evaluated and its problems and weakness were identified. For the recommendation of new steel bridge coating system for INDOT, different aspects of selection criteria was considered. These include the evaluation of the problems facing the lead-based paints, the need for a reduced VOC level in the paint, the useful life, the cost aspects and the applicability of the coating system with regard to Indiana's demanding constraints. New advanced coating systems such as the moisture cure urethane were introduced. All coating systems presented in this report also consist various comments recorded by the bridge owners who have utilized the system and/or by paint experts such as the Turner-Fairbank Research Center.

As presented in the discussion section of this report, the three-coat system of inorganic/organic zinc primer, epoxy intermediate coat and polyurethane topcoat is recommended for INDOT's new steel bridge coating system. Evaluation factors that were considered for this conclusion include the useful life, environmental issues, cost and comments from other bridge owners with similar climate conditions as to Indaian's.

Also in this report, an alternative to full-removal of bridge coating system, overcoating, was reviewed. Overcoating might provide a good provide a good protection for less than half the cost for a full-removal but it only delay the hazardous lead removal process which does not solve the environmental concerns facing the lead removal.

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Appendix A

SS 910 (Supplemental Specification 910)[24]

Epoxy Intermediate Coat

This coating shall be a two-part product composed of a base component and a curing agent suitable for application over the epoxy-polyamide zinc rich primer.

The base component shall contain an epoxy resin together with color pigments, mineral fillers, gellant, leveling agent, and volatile solvents. the curing agent component shall contain a liquid polyamide resin and volatile solvent. The coating shall also meet the following:

A. Physical requirements
   1. Color : White, meeting or exceeding, FS-595A-37875 as per ASTM E97
   2. Components: Two, mixed prior to application
   3. Volume Solids: 50.0% minimum
   4. Potlife: 6 hours, minimum @ 77° F
   5. Curing Time:
      a. Set-to-touch: 4 hours minimum @ 77° F
      b. To Recoat: 24 hours minimum @ 77° F
      c. Fully cured: 7 days @ 50° F
   6. Fineness of Grind, Hegman 3 minimum
   7. V.O.C. maximum - 3.5 lbs./gal., as applied

B. Material Quality Assurance

Test		Variance*
1. Weight per gallon		± 0.2 lbs.
2. Viscosity,	Kreb Units	± 5
	Ford Seconds	± 5
3. Total Solids, % by weight		± 2
4. Pigment, % by weight		± 2
5. Nonvolatile Vehicle, % by weight		± 2

* Variance shall be within the noted range based upon the test average of the previously submitted sample.

Urethane Finish Coat

This coating shall be a two component polyester and/or acrylic aliphatic urethane and shall be suitable for use as a finish coat over the white epoxy polyamide intermediate coat.

A. Physical Requirements

1. Color : Specular Gloss, 60 degrees: 85% Minimum; 70% Minimum after 3000 hours weathering resistance
2. Volume Solids: 42% Minimum
3. Potlife: 4 hours, Minimum @ 77 degrees F
4. Cure (Dry) Time at 77 degrees F and 50% RH
   To-touch: 30 Minutes, Minimum
   Full Cure: 2 Hours, Maximum
5. V.O.C. maximum - 3.5 lbs./gal., as applied
6. Colors*
   a. Gray FS-595A - 16440
   b. Green FS-595A - 14260
   c. Blue FS-595A - 15450

* Contractor's choice unless specified on plans.

B. Material Quality Assurance*

1. Analysis (for each component)

Test	Variance*
a. Weight per gallon	± 0.2 lbs.
b. Viscosity, Kreb Units	± 5
Ford Seconds	± 5
c. Total Solids, % by weight	± 2
d. Pigment, % by weight	± 2
e. Nonvolatile Vehicle, % by weight	± 2

* Variance shall be within the noted range based upon the test average of the previously submitted sample.

Performance Requirements

The coating system, which consists of the inorganic zinc prime coat, the epoxy intermediate coat, and the urethane topcoat, shall be tested prier to use.

Three panels for each of the specified tests shall be prepared to the requirements of the ASTM D 609 except that the thickness shall be 1/8 inch minimum and the steel shall be ASTM A-36 hot rolled steel. The surface shall be blast cleaned (using coal slag abrasive) to equal, as nearly as is practical, the standard Sa 2-1/2 of ASTM D 2200 (Steel Structures Painting Council SSPC-SP10 meets this requirement), and the surface shall have a nominal height of profile of 1 to 3.5 mils verified by using appropriate replica tape. The panels shall be coated and permitted to cure in accordance with the manufacturer's printed instructions. The dry film coating thickness in the system to be tested shall be as follows:

Inorganic Zinc: 3.0 - 5.0 Mils
Epoxy: 5.0 - 7.0 Mils
Urethane: 2.0 - 4.0 Mils

The coating system shall pass each of the following tests:

(A) Fresh water resistance (ASTM D 870). The panels shall be scribed as per ASTM D 1654 to the depth of the base metal in the form of an "X" having at least 2-inch legs and then immersed in fresh tap water at (75 degrees ⇧ 5 degrees F). After 30 days of immersion, the panels shall show no rusting nor shall the coating show any blistering, softening or discoloration. Blistering shall be rated by ASTM D 714.

(B) Salt water resistance (ASTM D 870). The panel shall be scribed as specified in "A" above and then immersed in a water solution of 5 percent sodium chloride at 75 degrees F ⇧ 5 degrees F. The panels shall show no rust nor shall the coating exhibit any blistering or softening after 7, 14, and 30 days. Blistering shall be rated by ASTM D 714. The sodium chloride solution shall be replaced with a fresh solution after examination at 7 and 14 days.

(C) Weathering resistance. The panels shall be tested in accordance with ASTM D 4587 Method D, utilizing UV A 340 bulbs. The panels shall be placed on test at the beginning of a wet cycle. After 3000 hours continuous exposure, the coating shall show no blistering or loss of adhesion, nor shall the panels show any rusting. The 60 degree specular gloss measurements shall be performed on the sprayed panels utilized for this test. The three initial measurements (one per panel) will be averaged together. The three final measurements also will be averaged together.

(D) Salt fog resistance. The panels shall be scribed as specified in "A" above, and then tested in accordance with ASTM B 117. After 3000 hours of continuous exposure the coating shall show no loss of bond nor shall it show rusting or blistering beyond 1/16 inch from the center of the scribe mark. Blistering shall be rated by ASTM D 714.

514.04 Shop Painting Steel

Oil and grease shall be removed from surface to be painted with a suitable solvent prior to cleaning by blasting or scraping and brushing.

Steel surfaces specified to be painted shall be prepared in conformance to ASTM D 2200 by blast cleaning to grade Sa 2 1/2 except for interior surfaces that are inaccessible to blast cleaning after fabrication which may be cleaned by scraping and brushing to grade St 3.

Cleaning shall be done with abrasive suitable to produce a surface having a nominal height of profile to or greater than 25 μm (1 mil) but not greater than 75 μm (3 mils), and having a texture similar to that obtained by use of grit or sand.

The prime coat shall be applied within the shop and the steel shall not be handled unnecessarily or removed from the shop until paint has dried sufficiently to allow thickness gaging and to resist being marred in handling and shipping.

Pins, pin holes and contact surfaces of bearing assemblies, except those containing self-lubricating bronze inserts, shall be painted with one coat of prime paint.

Erection marks shall be applied after the prime coat is dry, using a thinned paint of a type and color which will be completely concealed by and compatible with the second coat. The Fabricator's name may be applied in a similar manner by use of a stencil or by use of removable tape.

The coating system used for the shop paint shall match that specified for the field painting.

Appendix B

Michigan Department Of Transportation Qualified Product List

Low VOC Bridge Paint Qualified Products List

Producer	**Coats**	**Products**
Ameron	1st	Amercoat 68HS Epoxy
	2nd	Amercoat 385
	3rd	Amercoat 450HS
Carboline	1st	Carboline 858 Epoxy
	2nd	Carboline 890 or Carboline 893
	3rd	Carboline 134HS
Devoe	1st	Catha-Coat 303H Epoxy
	2nd	Devran 224 HS
	3rd	Devthane 359
DuPont	1st	825 HB Zinc-filled Epoxy
	2nd	DuPont 25P Epoxy Mastic
	3rd	Imron 333 Aliphatic Urethane
International	1st	Interzinc 325 HS Epoxy
	2nd	Intergard 760 HS
	3rd	8731 Hythane Ultra or Interthane 990 HS
Sherwin-Williams	1st	Zinc Clad IV Epoxy
	2nd	Bild and Finish Epoxy or Epoxy Mastic D.O.T.
	3rd	High-Solids Polyurethane
Tnemec	1st	90-97 Urethane
	2nd	69 Hi-Build Epoxoline II or Series 104 High Solids
	3rd	Series 74 Endurashield IV

Ohio Department of Transportation Prequalified OZEU Coating System

PRODUCER	**PRODUCT NAME & NUMBER**
CARBOLINE	1. Organic zinc primer coat - CARBOLINE 858 Consisting of : Component A: Resin 0300 Green Component B: Cure 0908 Component C: Zinc Filler 2A. Epoxy intermediate coat - CARBOLINE 890 Consisting of : Component A: Resin 0832 - White Fed Std 17875 Component B: Cure 0908 2B. Epoxy intermediate coat - CARBOLINE 893 Consisting of: Component A: Resin 0800 - white Component B: Cure 0908 3. Urethane finish coat - CARBOLINE D134 HS Consisting of : Component A: Resin A: fed std 1640: gray as 2738 fed std 14260: green as 0381 fed std 15450: blue as 7132 Component B: Urethane converter 900
AMERON	1. Epoxy zinc primer coat - AMERCOAT 68HS Consisting of : Component A: 68HS resin Component B: 68HS cure Component C: 68HS pwdr 2. Epoxy intermediate coat - AMERCOAT 385 Consisting of : Component A: 385 resin Color: fed std 37778 Component B: 385 cure 3. Urethane finish coat - AMERCOAT 450HS Consisting of : Component A: 450 HS Resin A: fed std 16440 fed std 15450

fed std 14260
Component B: 450 HS cure

SHERWIN-WILLIAMS

1. Epoxy zinc primer coat - ZINC CLAD IV
    Consisting of :
    Component U: Zinc and resin B69AW8
    Component V: Hardener B69VW8
2. Epoxy intermediate coat - HEAVY DUTY EPOXY
    Consisting of :
    Component C: Resin B67W301
    Component D: Cure B60V3
3. Urethane finish coat - HI-SOLIDS POLYURETHANE

Consisting of :
Component S: B65AW300 as fed spec 16440 gray
B65LW301 as fed spec 15450 blue
B65GW301 as fed spec 14260 green
Component T: Activator cure B60V30

VALSPAR

1. Epoxy zinc primer coat - MZ-4
    Consisting of :
    Component A: Resin 13F4L
    Component B: Curing agent 13F4M
    Component C: Zinc dust pigment 13F4P
2. Epoxy intermediate coat - VAL-CHEM HI-BUILD EPOXY SERIES 89
    Consisting of :
    Component A: Resin 89W9K
    Component B: Cure agent 89T1R
3. Urethane finish coat - URETHANE ENALMEL V40 SERIES
    Consisting of :
    Component A: Resin V40B132B as fed spec 15450 blue
    Resin V40F125B as fed spec 16440 gray
    Resin V40G125B as fed spec 14260 green
    Component B: Curing agent V40T2

GLIDDEN

1. Zinc rich primer - GLID-GUARD
GLID-ZINC ORGANIC
Consisting of :
Component A: Resin (base) No. 11003
Component B: Curing agent No. 11094
Component C: Zinc dust pigment No. 5528

2. Epoxy intermediate coat - GLID-GUARD
CORROSION RESISTANT HS EPOXY
Consisting of :
Component A: Resin No. 5467, white
Component B: Cure agent No. 5469
Application temperatures: Air or substrate, 60
degrees Fahrenheit or higher

3. Urethane finish coat - LID-GUARD HIGH
SOLIDS URETHANE
Consisting of :
Component A: Resin #11095
as fed spec 16440 gray
Resin #11097
as fed spec 15450 blue
Resin #11098
as fed spec 14260 green
Component B: Curing agent #11096

PORTER
INTERNATIONAL

1. Zinc rich primer - 308 ZINC-LOCK EPOXY
ZINC-RICH PRIMER
Consisting of :
Component A: Resin PART A-308A
OC419 42624
Component B: Curing agent PART B-308B
Component C: Zinc dust pigment
PART C-308C

2. Epoxy intermediate coat - 90-HYPOX HIGH BUILD
EPOXY
Consisting of :
Component A: Resin PART A-41970A off-white
Component B: Cure agent PART B-90721B

3. Urethane finish coat - HYTHANE FASTRACK
ACRYLIC ALIPHATIC

POLYURETHANE
Consisting of :
Component A: Resin PART A 40226A
as fed spec 16440 gray
Resin PART A 42606A
as fed spec 15450 blue
Resin PART A 42607A
as fed spec 14260 green
Component B: Curing agent PART B 8946B

DAVIS PAINT

1. Organic zinc rich primer -P-300 ORGANIC EPOXY ZINC PRIMER
   Consisting of :
   Component A: Resin P-300 EPOXY ZINC BASE
   Component B: Curing agent M-159 EPOXY ZINC ACTIVATOR
   Component C: Zinc dust pigment M-180 EPOXY ZINC DUST

2. Epoxy intermediate coat - P-192 POLYROX HS EPOXY INTERMEDIATE
   Consisting of :
   Component A: Resin P-192 POLYROX HS EPOXY PRIMER BASE
   Component B: Cure M-165 POLYROX HS EPOXY ACTIVATOR

3. Urethane finish coat - SHINETHANE HS ALIPHATIC ACRYLIC URETHANE
   Consisting of :
   Component A: Resin G-676 SHINETHANE
   as fed spec 16440 gray
   Resin G-677 SHINETHANE
   as fed spec 15450 blue
   Resin G-678 SHINETHANE
   as fed spec 14260 green
   Component B: Curing M-172 SHINETHANE HS ACTIVATOR

Appendix C

Specification Comparison

1) CONSTRUCTION REQUIREMENTS

INDOT	ODOT	MDOT
619.03 General Requirements: Except as modified in the plans, all surfaces to be painted shall receive either of the paint systems defined in 619.07(a) and is to be applied in accordance with the manufacturer's specification.		**915.01 General Requirements.** The contractor shall select a complete coating system form the MDOT Materials sampling Guide, Qualified Products List. The system will consists of an epoxy or urethane zinc-rich primer, a high-build epoxy intermediate, and a urethane top coat. The primer shall be tinted, the intermediate shall be white and the top coat shall match the color number , as listed on the plans or Special Provision, of the January 2, 1968 Federal Standards Number 595a. Before any coating is done, the Contractor shall supply the Engineer with the product data sheets showing mixing and thinning directions, and the recommended spray nozzles and pressures.
619.06 Pollution Control: Blasting materials, scrapings, wire brushings, and paint particles shall be contained in accordance with SSPC-Guide 6 Class 3A specifically for zinc primed bridges, and SSPC-Guide 6 Class 2A for lead primed bridges	**815.13 Pollution Control:** The contractor shall take all necessary precautions to comply with pollution control laws, rules or regulations of Federal, State or local agencies and as required in this specification. (See Appendix I)	(See Appendix II)
(a) Structural Steel Coating Systems.		

These coatings systems shall consists of an inorganic zinc primer, an epoxy intermediate paint and a polyurethane finish coat, or an inorganic zinc primer with a waterborne acrylic finish coat, for the painting of steel bridges and other structural steel. All of the coatings within any coating system shall be manufactured by the same manufacturer and shall be compatible with one another. All coatings shall be in accordance with 909.01.	Existing: A three coat paint system consisting of organic zinc prime coat, epoxy intermediate coat, and urethane finish coat. The contractor shall select a coating system meeting the requirements of Supplemental Specification 910 entitled OZEU Structural Steel Paint. The approval list of coatings meeting this specification is non file at the Laboratory and District Office. New: A three coat paint system consisting of inorganic zinc prime coat, epoxy intermediate coat, and urethane finish coat. This coating shall conform to CMS 708.17, Inorganic Zinc Silicate Primer Paint. Prime coat shall be applied in accordance with CMS 513.222 and CMS through 514.04. Thickness of the prime coat and measurement of the thickness shall conform to Dry File Thickness requirements in this specification. All bolts, nuts and washers that will be in contact with painted surfaces, shall be galvanized as per 711.02. The epoxy and urethane coatings shall be selected from the list of coatings approved for use under SS 910. Materials for each coat of the intermediate and finish coatings shall be supplied from the same manufacturer.	The system will consists of an organic epoxy or urethane zinc-rich primer, a high-build epoxy intermediate, and a urethane top coat.
All members which are inaccessible to field painting after being placed in final position shall have given all coats of paint before		

being erected.		
The pot life and induction time shall be in accordance with the manufacturer's recommendations for the existing ambient temperature.		
Drying time between coats shall be a minimum of 24 h for the primer and 8 h for the intermediate coat. The recoat time will vary depending on temperature. The manufacturer's recommendation shall be observed. The urethane coat shall be placed within 12 days of placement of the intermediate coat.	Each coat of paint shall be in a proper state of cure or dryness before the application of succeeding coats. Paint shall be considered ready for overcoating when an additional coat can be applied without the development of any detrimental film irregularities, such as lifting, wrinkling or loss of adhesion of the undercoat. The time interval between coating applications shall be in compliance with manufacturer's written instructions and no more than 30 days between the prime and intermediate coats and 13 days between the intermediate and finish coats. These maximum recoat times include weather related days. No additional time for weather delays will be allowed. Any coat which has cured more than the above allotted time without overcoating shall be removed and the steel reblasted to SP 10.	Maximum of 21 days between zinc-primer coating and the intermediate epoxy coating. If 21 days exceeded, contractor must reblast and repaint at own expense. Maximum of 21 days between the application of the intermediate coat and the topcoat.
No partially used containers of paint shall be used. No partial mixing of containers will be permitted. All paint containers shall remain closed until they are needed for mixing.	All paint and thinner shall be delivered to the project site in original, unopened containers with labels intact. Minor damage to containers is acceptable provided the container has not been punctured. All containers of paint and thinner shall remain unopened until required for use. The label information shall be legible and shall be checked at the time of use. Solvent used for cleaning equipment is exempt from the above requirements.	
Paint shall be stored in accordance with the manufacturer's recommendations.	Paint shall be stored at the temperature recommended by the manufacturer to	**Storage and Shelf Life of Coating.** The coatings must be stored according to the

	prevent paint deterioration.	manufacturer's directions and used within one year of the date of manufacture unless the product data sheets indicate a shorter time.
The paint shall be used within the manufacturer's recommended shelf life.	Paint which has livered, gelled or otherwise deteriorated during storage shall not be used: However, thixotropic materials which can be stirred to attain normal consistency may be used. The oldest paint of each kind shall be used first. No paint shall be used which has surpassed its shelf life.	See above.
Painting shall begin only when the 24 h ambient temperature is to remain above 10° C (50° F) after paint application, and the substrate temperature is between 10° C and 40° C (50° F and 100° F). Coating and curing shall be done only when the relative humidity is between 30% and 80%.	Paint shall not be applied when the temperature of the air, steel, or paint is below 10° C (50° F) (use of heaters not permitted). Paint shall not be applied when the steel surface temperature is expected to drop below 10° C (50° F) before the paint has cured for the minimum times specified below: 10° C (50° F) / 16° C (60° F) / 21° C (70° F) Primer: 4 hrs. / 3 hrs. / 2 hrs. Intermediate: 6 hrs. / 5 hrs. / 4 hrs. Finish: 8 hrs. / 6 hrs. / 4 hrs. The above temperatures and times shall be monitored with the recording thermometer.	**Conditions for Coating.** **Temperature**. For application, the air and steel temperatures must be above 10° C for the primer and the intermediate coats, and above 4° C for the top coat. In the field, continuously maintain or exceed these minimums for at least 48 hours after primer application prior to applying the intermediate coat. After applying the intermediate coat, continuously maintain or exceed these minimums for at least 24 hours prior to applying the top coat. In the fabricating shop, continuously maintain or exceed these minimums for at least 16 hours unless a longer recoat time is indicated on the manufacturer's product data sheet. Coatings shall not be applied if the air or steel temperature exceeds 40° C. The surface of the steel shall be at least 3° C higher than the dew point. **Humidity**. The coating shall not be applied when the relative humidity is greater than 90 percent, or when temperature and humidity conditions cause moisture to condense on the surface being coated. The humidity shall be measured with

		psychrometer.
Primer paints shall be applied at a minimum dry film thickness of 65 µm (2.5 mils), the waterborne finish coat with a minimum dry film thickness of 75 µm (3.0 mils), the epoxy intermediate coat with a dry film thickness of 100 µm (4 mils), and the urethane finish coat with a minimum dry film thickness of 75 µm (3 mils).	Min. Spec. Thickness / Max. Spec. Thickness / Min. Spot / Max. Spot Primer 75 µm (3.0 mils) / 125 µm (5.0 mils) / 60 µm (2.4 mils) / 188µm (7.5 mils) Intermediate 125 µm (5.0 mils) / 175 µm (7.0 mils) / 100 µm (4.0 mils) / 263 µm (10.5 mils) Finish 50 µm (2.0 mils) / 100 µm (4.0 mils) / 40 µm (1.6 mils) / 150µm (18.0 mils)	Organic Epoxy Zinc-rich Primer: • coating thickness - minimum of 100 µm Epoxy Intermediate Coating: • coating thickness - minimum of 90 µm • application of the intermediate coating shall be sufficient to provide complete coverage with uniform color and appearance. Urethane Top Coating: • coating thickness - minimum of 25 µm • application of the topcoat shall be sufficient to provide complete coverage with uniform color and appearance.
A failing spot film thickness is either less than 80% below or greater than 110% above the required minimum dry film thickness.	See Above	See Above

2) EPOXY SPECIFICATIONS

INDOT	ODOT	MDOT
Epoxy intermediate paint shall be a two component coating consisting of an epoxy resin and a curing agent, together with prime and filler pigments, colorants, gellant, leveling agents and solvents. This coating when mixed shall be suitable for application over inorganic and organic zinc primers and shall be compatible with a polyurethane finish coat. The color of this coating shall be such that a definite contrast between the coating and other coatings within the coating system shall be readily apparent.	This coating shall be a two-part product composed of a base component and a curing agent suitable for application over the epoxy-polyamide zinc rich primer. The base component shall contain an epoxy resin together with color pigments, mineral fillers, gellant, leveling agent, and volatile solvents. The curing agent component shall contain a liquid polyamide resin and volatile solvent.	This paint shall meet the same requirements as the primer except that it shall contain a contrasting shade of red iron oxide and /or be tinted or shaded to produce a distinct contrast of at least 10 Hunter Delta E. Units compared with the primer. (Primer: This paint shall meet the requirements of Section 4 (composition) and Section 5 (properties) of the Steel Structures Painting Council's Paint Specification No. 25 for red iron oxide, zinc oxide, raw linseed oil and alkyd primer as outlined in Volume 2, Systems and Specifications, Third Edition.)
V.O.C. ASTM D3960 ....336 g/L max.	V.O.C........................... 3.5 lbs./gal. max as applied.	This paint shall meet the requirements of Section 4 (composition) and Section 5 (properties) of the Steel Structures Painting Council's Paint Specification
Volume Solids, ASTM D 697 ....60% min.	Volume Solids .... 50.0% min.	
Set-to-touch .... 4 hours max. (25 ± 1 °C).	Set-to-touch .... 4 hours min. (77° F).	
Potlife ....6 hours min.	Potlife ....6 hours min. (77° F).	

(25 ± 1 °C).		
Mass per liter variance from the initially approved batch, ASTM D 1275 ……………………………0.060 kg/L max. (25 °C).	Weight per gallon ………………………………… ± 0.2 lbs.	
Total Solids variance from the initially approved batch, ASTM D 2369 ………………………………… 3.0% max.	Total Solids ………………………… ± 2 % by weight	

2) POLYURETHANE SPECIFICATIONS

INDOT	ODOT	MDOT
Polyurethane finish coat shall be a two component polyester and/or acrylic aliphatic polyurethane suitable for use as a finish coat over epoxy intermediate paint.	This coating shall be a two component polyester and/or acrylic aliphatic urethane and shall be suitable for use as a finish coat over the white epoxy polyamide intermediate coat.	This paint shall meet the requirement of Section 4 (composition) and Section 5 (properties) of the Steel Structures Painting Council's Paint Specification No. 21 for lead free white or colored silicone alkyd paint, Type 1, high gloss as outlined in Volume 2, Systems and Specifications, Third Edition. The color of the paint shall match the specified Munsell Color Standard within 2 Hunter Delta E. Units and shall pass the following accelerated weathering tests.
Color and Color No.: 14260 Green 15450 Lt. Blue 17886 White 17038 Black 13711 Buff 13538 Yellow	Colors: 16440 Gray FS-595A 14260 Green FS-595A 15450 Blue FS-595A	The color of the paint shall match the specified Munsell Color Standard within 2 Hunter Delta E. Units.
Specular Gloss, ASTM D523 ....75% min. (60°).	Specular Gloss .... 85% min. (60°) (70% min. after 3000 hours weathering resistance.)	

V.O.C. ASTM D 3960 .... 336 g/L max.	V.O.C... .... 3.5 lbs./gal. max as applied.	
Volume Solids, ASTM D 2697..............................60% min.	Volume Solids ....42.0% min.	
Set-to-touch ....30 minutes min. (25 ± 2 °C, 50 ± 10% Relative Humidity). Dry Hard .... 24 hours max. (25 ± 2°C, 50 ± 10% Relative Humidity).	Set-to-touch .... 30 minutes min. (77° F, 50% Relative Humidity). Full Cure .... 2 hours max. (77° F, 50% Relative Humidity).	
Total Solids, ASTM D 2697 .... 70% min.	Total Solids .... ± 2%.	
Viscosity, ASTM D 562 .... 100 Kreb Units max.	Viscosity ....± 5 Kreb Units.	
Contrast Ratio, ASTM D 2805,127 µm wet film thickness dried 24 hours @ 25 ± 2 ° C on Leneta Form 2A or 2C ....0.95 min.		
	Potlife ....4 hours min. (77° F).	
	Weight per gallon .... 0.2 lbs.	
	Pigment .... ± 2% (by weight).	
	Nonvolatile Vehicle .... ± 2%.	

3) COATING SYSTEM CHEMICAL AND RESISTANCE REQUIREMENTS

INDOT	ODOT
Toxicity: The cured film of each coating within the structural steel coatings system shall not contain any toxic heavy metals above the limits of the regulatory levels of 40 CFR 261.24, table 1, when tested in accordance with EPA Toxicity Characteristics Leaching Procedures, or contain any other material which will require characterization as a hazardous waste for the disposal of the dried film.	
Resistance: The test panels for all resistance tests shall be prepared in accordance with section 4.6.4 of AASHTO M 300. After the curing of the zinc primer in accordance with section 4.6.4 of AASHTO M 300, the epoxy intermediate paint and the polyurethane finish coat or the waterborne acrylic finish coat shall be applied and permitted to cure in accordance with manufacturer's printed product data sheets. Three panels for each of the resistance tests shall be prepared and tested. Each panel shall be reported for the coating system. Inorganic Zinc Primer: 3.0 - 3.5 Mils. Organic Zinc Primer: 3.0 - 3.5 Mils. Epoxy Intermediate: 3.0 - 4.0 Mils. Polyurethane: 2.5 - 3.5 Mils.	Resistance: Three panels for each of the specified tests shall be prepared to the requirements of the ASTM D 609 except that the thickness shall be 1/8 inch minimum and the steel shall be ASTM A_36 hot rolled steel. the surface shall be blast cleaned 9using coal slag abrasive) to equal, as nearly as is practical, the standard Sa 2-1/2 of ASTM D 2200 (Steel Structures Painting Council SSPC-SP10 meets this requirement), and the surface shall have a nominal height of profile of 1 t0 3.5 mils verified by using appropriate replica tape. The panels shall be coated and permitted to cure in accordance with the manufacturer's printed instructions. Organic Zinc: 3.0 - 5.0 Mils. Epoxy: 5.0 - 7.0 Mils

Waterborne Acrylic: 2.5 - 3.5 Mils.	Urethane: 2.0 - 4.0 Mils
1. Fresh Water Resistance: ASTM D 870. Scribed panels immersed in fresh tap water at 75 ± 5 °F for 30 days.	1. Fresh Water Resistance: ASTM D 870. The panels shall be scribed as per ASTM D 1654 to the depth of the base metal in the form of an "X" having at least 2-inch legs and then immersed in fresh tap water at (75 ± 5 °F). After 30 days of immersion, the panels shall show no rusting nor shall the coating show any blistering, soften or discoloration. Blistering shall be rated by ASTM D 714.
2. Salt Water Resistance: ASTM D 870. Scribed panels immersed in a solution of 5% sodium chloride at 75 ± 5 °F for 30 days.	2. Salt Water Resistance: ASTM D 870. The panel shall be scribed as specified in "A" above and then immersed in a water solution of 5% sodium chloride at 75 ± 5 °F. The panels shall show no rust nor shall the coating exhibit any blisterin gor softening after 7, 14, and 30 days. Blistering shall be rated by ASTM D 714. The sodium choloride solution shall be replaced with a fresh solution after examination at 7 and 14 days.
3. Weathering Resistance: ASTM D 4587 Method D utilizing UV A 340 bulbs. The unscribed panels shall be placed at the beginning of a wet cycle for 3000 hours of continuous exposure.	3. Weathering Resistance: The panels shall be tested in accordance with ASTM D 4587 Method D, utilizing UV A 340 bulbs. The panels shall be placed on test at the beginning of a wet cycle. After 3000 hours continuous exposure, the coating shall show no blistering or loss of adhesion, nor shall the panels show any rusting. the 60 degree specular gloss measurements shall be performed on the sprayed panels utilized for this test. the three initial measurements (one per panel) will be averaged together. the three final measurements also will be averaged together.
4. Cyclic Salt Fog Resistance: ASTM G85 Annex A5.	4. Salt Fog Resistance:

The scribed panels shall be exposed for 4000 hours of continuous exposure.	The panels shall be scribed as specified in "A" above, and then tested in accordance with ASTM B 117. After 3000 hours of continuous exposure the coating shall show no loss of bond nor shall it show rusting or blistering beyond 1/16 inch from the center of the scribe mark. Blistering shall be rated by ASTM D 714.
5. Relative Humidity Resistance: ASTM D 2247. The scribed panels shall be exposed for 4000 hours of continuous exposure.	
	6. Elcometer adhesion test: ASTM D 4551. The panel shall be tested in accordance with the following: lightly sand the coating surface and aluminum dolly, and apply a quick set adhesive. Allow adhesive to cure overnight. Scribe the coating and adhesive around the dolly prior to testing. Make a minimum of four trials to failure and report the four trials. No trials shall be less than 400 psi. Fracture at the primer-blast interface shall be cause for rejection.

4) APPROVAL OF STRUCTURAL STEEL COATING SYSTEMS

INDOT	ODOT
The manufacturer shall obtain approval of each structural steel coating system prior to furnishing any of these coatings. An approved list of Structural Steel Coating System will be maintained by the Department. The list will specify the manufacturer's designation of each coating of the structural steel coating system. Manufacturers who desire to have products added to the List of Structural Steel Coating Systems shall submit the following documentation to the Materials and Tests Division. a) A certified test report from an independent testing laboratory which provides test results for all quantitative requirements and resistance test requirement for each coating and for the coating system in these specifications. The test report shall include the manufacturer's name , brand name of each coating, formulation identification of each coating, batch numbers, beginning and ending dates of each test, date of manufacture for each coating, and the exact mass and volume ratio of each component used for mixing multiple component coatings. b) Material safety data sheet for each coating. c) Product data sheet for each coating. The product data sheets shall be in accordance with NEPCOAT specification criteria for protective coatings dated June 15, 1994. d) Quality control plan which includes all aspects of the	Prior to approval, copies of the manufacturer's certified test data showing that the coating system complies with the performance requirements of this specification shall be submitted to the Engineer of Tests, 1600 W. Broad St., Columbus, Ohio 44223. The certified test data shall also state the following physical properties for each coatings: 1) Weight per gallon 2) Solids, % by weight 3) Solids, % by volume 4) Viscosity 5) Drying time 6) V.O.C. content, lb. per gallon The test data shall be developed by an independent testing laboratory approved by the Director and shall include the brand name of the paint, name of manufacturer, number of lots tested, and date of manufacture. The following items shall also be submitted to the Director prior to approval: 1) Manufacturer's technical data sheet for each coating 2) Material Safety data Sheet for each coating 3) Enough components to produce a one gallon sample of each coating

production process for each coating, starting with raw materials and concluding with the shipment of the finished products. The quality control plan shall include sampling and testing frequency and specific test used for the quality control of each product. e) Documentation of quality assurance within the manufacturer's laboratory. f) Performance history indicating that the specific coating system has performed successfully for a minimum of three years. The performance history shall include the name, address and telephone number of the structure owner including the name of a responsible contact person, location of the structure and dates of coating application and inspection. (1) New products which do not have a three year field performance history may be accepted under an experimental basis. The coatings manufacturer shall provide a three year performance warranty for the coating material costs for each structure on all coating systems which are accepted on an experimental basis.	4) A one quart sample of the thinner to be used with each coating When the coating has been approved by the Director, further performance testing by the manufacturer will not be required unless the formulation or manufacturing process has been changed, in which case new certified test results will be required.

Appendix D

Factors Affecting Performance and Durability of Overcoating Systems[22]

In the following section we will discuss the factors that affect the success or failure of an overcoating job. The relative importance of the discussed factors is not clearly understood. Furthermore, in many cases the current test methods available do not clearly characterize various factors.

1.Adhesion/cohesion

The use of adhesion tests to rate the ability of an existing paint system to be overcoated and to estimate the durability/compatibility of the repair merit review. Current tests are time consuming to perform, difficult to repeat, and the meaning of the results are subject to individual interpretation. For example large differences have been observed between the test results when different methods are used. Existing paints may be brittle and lack cohesion and intercoat adhesive strength (i.e., typically occurring between an alkyd primer and existing intermediate or top coats of alkyd paints containing aluminum pigments). Knifing adhesion tests such as ASTM D3359-90 ("Measuring Adhesion by Tape Test") typically fracture old alkyd paints causing intracoat (cohesive) failure. The pull-off test ASTM D-4541 ("Standard test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers) measures adhesion between existing coats or between the primer and the substrate, or the cohesive strength of a specific coat depending upon which component fails first. Brittle alkyds may provide only a 1B or 0B rating using the knifing adhesion test. If used on existing paint that contains several overcoated layers, the knifing adhesion test may provide similar values. However, a pull-off adhesion test on the same system may provide readings in excess of 300 psi.

2.Surface Contamination

The presence of soluble salts on existing paint surfaces and in corrosion products pose a distinct threat to repair coating's durability. Soluble salts must be removed in order to provide extended paint durability even though their affects are difficult to assess. They are difficult to detect in the field and their concentration may vary depending on level of de-icing salt application, bridge design, and structural location. Currently, the primary tests for chloride surface contamination are wet chemical tests that are slow to perform and are questionable as to accuracy and precision.