Coatings and Treatments for Beam Ends

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By
Villanova University

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16. Abstract

With an aging national transportation infrastructure, many existing bridges require frequent maintenance and repairs. The objective of this project was to conduct an in-depth analysis of new and existing types of beam end coatings and treatments that have been proven to extend the life of new and existing concrete and steel bridge beams. A comprehensive literature review as well as online surveys and phone interviews were conducted to gather information about existing and recently developed technologies. The study revealed that while many promising coatings and treatments are offered on the market, there is a lack of readily available laboratory results that would enable direct comparison of the available methods. This finding applies in terms of the coatings' durability and the potential for extending the service life of existing bridges. Most of the interviewed State DOTs personnel assessed the products listed in respective Qualified Products Lists as performing 'well'. However, there was significant variability between states in the products used, and, of the agencies contacted, none was able to suggest the most promising or advanced products either for concrete or steel bridge beam end treatments. This suggests that comprehensive laboratory evaluation would be needed to select the best available beam end treatments and coatings.

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Coatings and Treatments for Beam Ends

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Executive Summary

In order to evaluate the existing techniques for beam end coatings and treatments, a **comprehensive review of available literature** relevant to the project was performed. Research reports, technical articles, presentations, as well as product specifications and manufacturer data sheets were compiled and reviewed – please refer to ***References*** section for a detailed list of all the documents assessed. With each document analyzed, available preventive maintenance or repair methods were successively recorded in matrix-form file in an Excel spreadsheet. While the electronic file (**LIT.REVIEW.2011.xlsx**) has been attached electronically, a brief summary of the file content has been also listed in Appendix A for readers' reference. Following the addition of names and descriptions of coatings systems and other protection methods, all available information about the system was included in the matrix. Among the parameters considered in this work were constructability, availability of materials, durability under varying environmental conditions, cost history, maintenance needs and timing, and documented results of field trials. Since information was not available for each system in terms of all the parameters listed above, only information provided in the literature was recorded.

Based on the initial literature search findings, **three electronic surveys** were developed to solicit information regarding the performance of available coating systems for steel and concrete beam ends. The three surveys were directed to: 1) concrete coatings manufacturers, 2) steel coatings manufacturers, and 3) agencies and organizations. Each survey consisted of about 35 questions, but the actual number that each respondent was required to answer varied depending on the information provided. All three surveys have been included in this report in ***Appendix B***. The raw results of survey have been combined in Excel spreadsheet: **Raw_Survey_Responses.xlsx**, while the analyzed survey results have been summarized in **Survey.Responses_Analysis.xlsx**. Following the surveys, phone interviews were conducted in order to gain more specific information in regard to products used. The questions asked during the interview were about the specific products in use by the state and new products being tested.

Based on the ***literature review*** related to ***concrete surface treatments***, the following general observations were made:

- Concrete corrosion prevention can be categorized into one of the following: penetrating sealers, surface sealers, coatings, electrochemical methods, corrosion inhibitors, admixtures, patching, reinforcing steel protection, overlays, membranes, and combination systems.
- Most states do not protect concrete beam ends and do not conduct research on coatings and beam end treatments.
- Coatings and combinations systems, which often consist of a penetrating primer with a pore blocker or barrier coating top coat, often provide the longest service life while maintaining a low cost. These systems typically have a recommended preventive maintenance plan ranging between 5 and 10 years.

- While there are benefits related to simple application of coatings and sealers, there are also some restrictions, as sealers, such as silane and siloxane, cannot be applied to elements that have active corrosion or heavy chloride ion contamination. This restricts their application to the shop or well prepared surfaces.
- Cathodic systems provide the greatest protection as per literature data, but are an expensive option due to constant monitoring that is required for the system to be successful.

The ***survey data*** from the ***concrete manufacturers' survey*** suggests that the best corrosion prevention system in terms of service life alone are membranes, which typically are urethanes, epoxies, and acrylics. When a life-cycle cost analysis is considered the best systems are coatings (epoxies, urethanes, polyesters, and acrylics) and penetrating sealers (silane, siloxane, and drying oils). The systems are easy to apply, and typically require a roller or airless spray. They usually are in the range from $14 to $80 per gallon with typical dosage between 50 and 200 ft^2/gal and typically last 11 to 15 years.

The ***literature review*** performed for the ***steel corrosion prevention*** methods revealed different systems that are effective in slowing down the corrosion process. The systems range from one to three different coatings. Among the treatments with the highest expected service life, (mentioned to last a possible 90+ years) is galvanized steel, but it is not applicable to existing bridges and it is also one of the more expensive treatments at $3.82 per square foot. Other treatments that are applicable to both new and existing bridges are inorganic zinc with an epoxy mid coat and urethane top coat, epoxy zinc primer with a high build urethane mid coat, and a high build urethane top coat. These systems have a typical life span of 21 to 31 years.

With the given survey results from the ***steel manufacturers' survey***, the best coating system for new steel is an inorganic steel primer, epoxy/acrylic mid coat, and polyurethane top coat. These coating systems have a life expectancy of 21 to 30 years, and have good durability under various conditions. They are also ranked as generally easy to apply. These same systems are also used on existing bridges, but often are applied after a complete removal of the paint on the bridge, which results in additional cost. A different coating system for existing bridges, which is applied as an over coating of the current paint, is a 3-layer waterborne acrylic latex. This system has an expected service life of 16 to 20 years, has good durability, and is very easy to apply. This type of system is typically priced at $30 to 34/gallon, although this is subject to change depending on project size and location.

It should be noted here, that while steel coatings used on steel bridges are all first approved within NTPEP program and as such, good performance is usually observed, there is a need to develop similar program for concrete coatings to enable laboratory verification of manufacturers specified characteristics.

1. List of Excel Data Files Associated with this Report

Table 1: List of Electronic Files Associated with the Report

File name	File Description
LIT.REVIEW.2011.xlsx	Excel file, summarizing literature review performed within Task 1 of the project. Detailed description of the file can be found in Appendix A.
Survey_contacts_list.xlsx	Excel file, containing list of all contacts that received the electronic surveys.
Raw.Survey.Responses.xlsx	Excel file, containing all responses from the survey (as received).
Survey.Responses.Analysis.xlsx	Excel file, containing analysis of the surveys responses received.
QPL.xlsx	Excel file, with links to 50 State's QPLs and summary of products occurring on states QPLs most often.
Survey.Summary_DOT.xlsx	Detailed Agencies and DOTs survey report from SurveyMonkey® containing statists related to each question.
Survey.Summary_Concrete.xlsx	Detailed concrete manufacturers survey report from SurveyMonkey® containing statists related to each question.
Survey.Summary_Steel.xlsx	Detailed steel manufacturers survey report from SurveyMonkey® containing statists related to each question.
Concrete Product Ranking.xlsx	Ranking of concrete products specified by concrete manufacturers.

2. Existing Products and Systems for Beam End Treatments

2.1 Problem Statement

The condition of the Nation's aging infrastructure has been of heightened concern for many years. The National Academy of Engineering has included the restoration and improvement of urban infrastructure on the list of the 14 Engineering Grand Challenges facing society. The condition of Pennsylvania's infrastructure could be greatly improved if restoration and repairs on the existing infrastructure components, and especially bridges, were implemented. One way to enhance the current condition of bridges in Pennsylvania is to provide coatings or treatments to the existing bridge beam ends (Figure 1). Following this approach would be in line with recent initiatives regarding bridge preservation, as presented at the recent 100 Year Bridge Life Summit. It can also be mentioned here that costs of repairs of existing prestressed concrete I-beams range from 35% to 69% of the cost of a superstructure replacement and, along with replacing the deck joint, it is expected to extend eservice life of a structure at least 30 to 40 years [1].

Figure 1: Examples of concrete beam end deteriorations.

Protection systems are designed to improve the performance of repairs by moderating the underlying causes of concrete deterioration. They should reduce corrosion of metals in concrete and related problems, as well as improve other characteristics of the concrete matrix that cause various types of deterioration [10]. Protection systems should seal the surface of the concrete to prevent ingress of chlorides and modify the concrete to reduce its permeability, increasing the time it takes for the chlorides to reach the reinforcing steel. They should also protect the reinforcing bars to reduce the effects of chlorides when they do reach the steel. For new bridge construction, corrosion protection can be incorporated into the structures by proper design and construction practices, including the use of durable concrete mixtures and an increase in concrete cover thickness [2].

The goal of this project was to provide in-depth research and analysis of new and existing types of beam end coatings or treatments that have been proven to extend the life of new and existing concrete and steel bridge beams. The specific interest of this work included coatings for prestressed concrete beams.

In order to determine the best materials and application methods for coatings and treatments for existing bridge beams in the Commonwealth of Pennsylvania, an extensive study of different materials and techniques for coatings and treatments was conducted. The work proposed in this project looked specifically into:

- Proven and potential materials used for coatings and beam end treatments;
- Proven research results reported through laboratory and field testing;
- Validation of the techniques through field application examples found in the industry and other state departments of transportation.

Scientific and scholar search engines were used to facilitate the literature investigation. The sources used for literature search included, but were not limited to ACI Library, ASCE Library, TRB Publications Index, TRIS Online, ACI Library, ASTM library, AASHTO's NTPEP and more. Based on various selection considerations [21], the results of literature review were compiled in an Excel sheet (LIT.REVIEW.xlsx) described in detail in Appendix A.

2.2 Concrete Products and Systems Reported in the Literature

Currently, there are many different systems available that extend the service life of concrete structures. These include coatings, sealers, overlays, electrochemical methods, corrosion inhibitors, admixtures, patching, reinforcing steel protection, membranes, as well as combination systems. Combination systems consist of more than one coating. In some cases, combination systems can comprise of a penetrating primer as well as an additional coating applied as a topcoat.

Some of the concrete coating systems are divided into different categories based upon application thickness. The ACI Concrete Repair Guide [3] differentiates different systems based the following thickness ranges:

- *Surface sealers* are products of 10 mils (0.25 mm) or less in thickness that generally lay on the surface of the concrete.
- *High-build coatings* consist of materials with a dry thickness greater than 10 mils (0.25 mm) and less than 30 mils (0.75 mm) applied to the surface of the concrete.
- *Membranes* are classified as surface treatments with a thickness greater than 30 mils (0.7 mm) and less than 250 mils (6 mm) applied to the surface of the concrete.
- Overlays are products of 250 mils (6 mm) or greater in thickness that are generally bonded to the surface of the concrete [1].

It should also be mentioned here that coatings systems can be classified and grouped into more than one type of system.

Following PCA's classification [4], four different types of protective treatment for concrete can be specified: (a) hydrophobic (water repelling), (b) sealers, which fill the pores at the surface and can partly be membrane-building, (c) membrane-building coatings, and (d) mortar and concrete coatings (Figure 2).

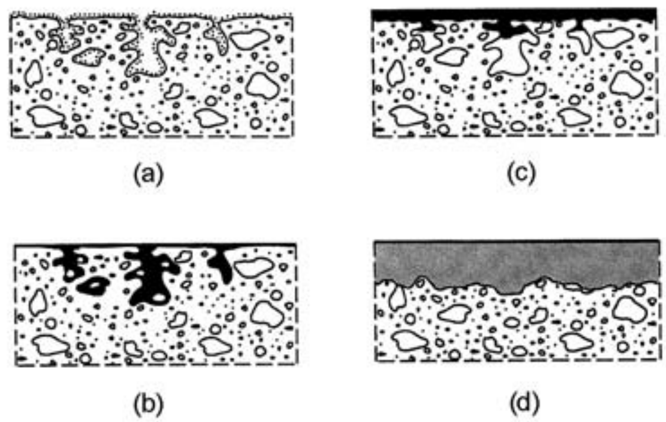


Figure 2: Four different types of protective treatments for concrete: (a) hydrophobic, (b) sealers, (c) membrane-building coatings, and (d) mortar and concrete coatings [4].

In a recent (2005) study conducted by the Wisconsin Highway Research Program [5], an extensive experimental work was performed to compare the effectiveness of four different treatments on prestressed beam ends. The following treatments were tested:

- *Carbon fiber-reinforced polymer wrap*: REPLARK 30 manufactured by Mitsubishi Chemical Corporation. It consisted of the carbon fiber fabric, primer, putty, and resin. Two fabric/resin layers (resin-sheet-resin-sheet) were installed on the beam with fiber orientation in the two layers at 90° with respect to each other.
- *Polymer resin coating*: Two coats of the resin component of the RELPLARK 30 system (no fiber) were applied with a paint roller after application of the primer and putty.
- *Epoxy coating*: Two coats of MASTERSEAL GP Epoxy Sealer, which could be applied with a squeegee, roller, or spray equipment to a clean, dry surface.
- *Sealer*: Two coats of MASTERSEAL SL 40 VOC (solvent based silane penetrating sealer) applied using a roller and paintbrush.

A salt-water distribution system was constructed to subject the beams to controlled salt-water exposure. The beams were subjected to wet/dry cycles, which consisted of four days of exposure to salt water followed by three days dry. The six-month exposure did not result in concrete spalling or significant tendon corrosion, so it was necessary to rapidly induce corrosion in the specimens. This was achieved by subjecting the specimens to cyclic wetting and drying using a 6% sodium chloride solution, and applying a constant voltage to the steel cage. The specimen ends were exposed to four days of salt water drip followed by three days of no water exposure. After exposure to the cyclic wetting and drying, the effectiveness of each treatment was evaluated based on chloride content (measured as percent by weight of concrete), extent of cracking, and extent of observed strand corrosion. The fiber reinforced polymer (FRP) coating and polymer resin were found to be the most effective, followed by the epoxy coating and then silane treatments. It was recommended that polymer resin or epoxy coating be used to protect prestressed concrete beam-ends. Fiber Reinforced Polymer (FRP) wraps did not significantly improve performance over polymer resin coating, and would only add to the cost. More information on strengthening concrete beams with carbon fiber reinforced polymers can be found in [6,7].

The most effective method of preventing beam end corrosion reported in [5] was to apply a polymer resin coating to beam ends before installation out in the field. For repair of existing bridges, researchers recommended applying the protective coatings as soon as possible to bridges that do not yet show significant corrosion damage. When corrosion and damage is advanced, a patch alone would not provide adequate durability. Coating the patch with polymer or epoxy coatings is a viable option. Another conclusion from the study was that surface treatments, while reasonably effective over the short term, have demonstrated limited effectiveness over the long term, unless applied prior to chloride contamination.

It is important to note, however, that the work reported in [5] focused on only four different products/manufacturers, some of which are not available on the market anymore, and as such, the results of this report cannot be treated as representative of general performance of sealers, epoxy and polymer resin coatings.

Concrete surface treatment materials: silanes and siloxanes, were investigated in a study by Ibrahim et al. [8] as a mean of preventing concrete deterioration due to sulfate attack, carbonation, and chloride-induced reinforcement corrosion. The following sealers and coatings were investigated: sodium silicate; silicone resin solution; silane/siloxane; silane/siloxane with an acrylic topcoat; alkyl-alkoxy silane; and a two-component acrylic coating. Silane/siloxane with an acrylic topcoat and a two component acrylic coating were most effective in preventing carbonation of concrete. Silane and silane/siloxane with a topcoat were effective in reducing chloride-induced reinforcement corrosion in in-service structures. Silane/siloxane with an acrylic topcoat was the most effective in minimizing the damage due to sulfate attack. Silane/siloxane with acrylic topcoat and acrylic coating were effective in reducing ingress of CO_2. The aforementioned study [8] on the use of surface treatment materials to improve concrete durability, ranked the investigated treatments in the following order (from best performance to worst performance): Silane/siloxane with an acrylic topcoat, silane, silane/siloxane, silicone resin solution, and sodium silicate [8].

2.2.1 Coatings

Coatings are one or two component organic liquids that are applied to a prepared concrete surface in one or more coats. The primary purpose of coating application is to prevent the ingress of water into the concrete and the diffusion of chloride ions. Different types of coatings include epoxies, acrylics, and urethanes. Epoxies are abrasion resistant and have a high adhesive strength, but are susceptible to degradation by UV light [9]. Acrylics, on the other hand, are brittle and normally have low impact strength. Urethanes have high impact strength and good weathering characteristics, but low abrasion resistance. The service life of coatings depends on the type of coating material applied and the field exposure conditions [9]. Other high-build coatings include acrylics, styrene-butadienes, polyvinyl acetates, chlorinated rubbers, urethanes, polyesters, and epoxies.

In a report from the Kentucky Transportation Center, Palle et al [10] looked into development of KYTC standard specifications and a qualified products list of concrete coatings. Authors stated that there was a need to identify new concrete coatings being successfully used by other transportation entities, investigate other new products that offer improved concrete protection, and take necessary steps to promote the widespread use of those materials. Several questions were posted on the SSPC DOT List Server to be accessed by coatings experts at most DOTs. Main findings of this work can be summarized as follows:

- California DOT (Caltrans) and Indiana DOT (INDOT) have used polyurea based systems, however, there were concerns about UV stability and about repairing existing concrete prior to coating,
- Acrylic concrete coatings were reported as used for protection and aesthetics by Michigan DOT, however concerns were raised with respect to curing compounds, proper surface preparation, and applications in cold weather,
- Ohio DOT was listed as having experience with epoxy – urethane coatings system, but application and mixing problems were reported.

2.2.2 Sealers

Sealers, which are solvent-based liquids applied to a prepared concrete surface to prevent harmful ions entry [11,12] can be divided into penetrating sealers and surface sealers. Penetrating sealers react with the pore structure within hardened concrete to create a nonwettable surface. The wettability of a surface defines how easily a liquid, such as water, will penetrate through the surface and adhere to the substrate. Penetrating sealers prevent liquid water from entering the concrete, but are very permeable to water vapor [13]. Surface sealers block the pores of the concrete and are adequate for application on beams and girders. Several environmental exposure conditions, i.e.: ultraviolet light, moisture, and surface wear may influence the service life of sealers and need to be considered when optimal treatment methods are considered [9]. The top qualities for penetrating water-repellent sealers are: 1) breathability, 2) penetrability, 3) long service life, 4) invisibility, and 5) supportability [14].

Sealers can be especially useful on surfaces exposed to cyclic wetting and drying. In order for the sealer to be effective, the general performance properties, such as damp-proofing ability, breathability, resistance to chemicals, ultraviolet ray penetration and deterioration, low toxicity, resistance to freezing and thawing, and resistance to deicing salt scaling, need to be considered [15]. Concrete sealers can be used to protect all of the exposed concrete surfaces of the structure, including bridge decks, substructure members, and deck undersides. They reduce corrosion of the reinforcement by preventing capillary action at the surface [12], preventing water and chloride ions from penetrating the concrete. Some concrete sealers include linseed oil, epoxies, silanes, siloxanes, siloxane-silane combinations, and methacrylates [17,16].

Linseed oil is discontinued in most states due to environmental concerns. Additionally, engineers feel it does not offer sufficient protection and is not cost effective. It prevents water and chloride ions from penetrating into the concrete, while allowing water vapor to escape. However, the treatment needs to be reapplied every two to five years to maintain its performance [17].

As mentioned before, silane and siloxane react chemically with the concrete to form a hydrophobic layer under the concrete surface that repels water and chloride ions while allowing water vapor to pass through. Prior applications of silane or siloxane sealers do not need to be removed before reapplication of additional coats. They are easy to apply, and can be applied at any time, during or after construction. Disadvantages include surface preparation requirements, material is expensive when ordered in small amounts, and it is also difficult to screen.

Methacrylate, an acrylic resin or plastic made from a derivative of methacrylate acid, is generally applied as a three-component system consisting of a monomer, a promoter, and an activator, mixed together before application. It can be applied as a spray or with a broom or squeegee. Over time, cracks tend to reopen through the polymerized material, decreasing its effectiveness [17].

Penetrating sealers aim to prevent or decrease the penetration of liquid or gaseous media that can enter the pores of the concrete. Ohio DOT suggests the application of a silane or siloxane penetrating sealer on a five-year basis for prestressed concrete I-beams [17]. Penetrating sealers lie within the substrate of the concrete and generally do not degrade due to UV exposure. Abrasion resistance of penetrating sealers can also be classified as generally good. Some penetrating sealers include boiled linseed oil, silanes, siloxanes, corrosion inhibitors, certain epoxies, and high molecular weight methacrylates (HMWM) [12]. High molecular weight methacrylate can be used as a crack sealer in conjunction with the use of silane as a surface sealer. In areas that are not subjected to deicing chemicals, the use of HMWM as a crack sealer can help restore the structural bond strength and the flexural strength, as long as the cracks are narrow and contaminant free [17]. Surface applied penetrating sealers are effective in preventing corrosion as long as they are applied before the onset of significant damage and if they are reapplied periodically. Without reapplication, the sealers are ineffective over the long term [18]. Field performance evaluated over the period of 5 years confirmed effectiveness of concrete surface treatment [19]. While recent laboratory comparisons of different surface treatments are not available, older publications may provide interesting input [20].

Surface sealers limit the amount of moisture, chlorides, or other materials that can enter the pores of the concrete [17]. Surface sealers include epoxies, polyurethanes, methyl methacrylates, moisture-cured urethanes, acrylic resins, certain paints (oil-based and latex) and silicone water-based elastomers [9]. While penetrating sealers have been proven to reduce sulfate attack (silane/siloxanes with acrylic coat), some research shows ineffectiveness of penetrating sealers in preventing carbonation of concrete [8].

Surface coatings can sometimes create a glossy appearance and have limited ability to allow internal concrete moisture to escape, but have relatively good damp-proofing characteristics. As the application rate of these products is increased, the ability to allow moisture to escape is reduced while the damp-proofing performance improves. Some types of surface sealers include acrylics, epoxies, and urethanes [15].

2.2.3 Overlays

Overlays can be formulated to reduce moisture intrusion, to improve durability and corrosion resistance, as well as prevent the intrusion of chlorides. They are used to enhance appearance of the concrete surface and are very effective in masking existing repairs. Some overlays include low slump concrete formulations, polymer concrete, epoxies, certain methyl methacrylates, and polymer-modified concrete [9]. Overlays are not as effective in existing structures because if chloride ions are present, the only protection of the overlay is a decrease in moisture infiltration [17,21].

Polymer concrete (PC) overlays can be installed without the use of heavy equipment. Compared to other overlay systems, PC overlays can be cost effective. Polymer overlays should be applied only to cleaned, dried, and physically sound substrates. All bond surfaces are to be free of loose and unsound materials as well as contaminants and bond breakers such as oils, grease, paints, sealers, curing compounds, water, waxes, dust, solvents, and laitance [22].

Polymer concrete overlays are generally used as a temporary repair method. Polymer concrete overlays are nearly or completely waterproof when they are uncracked. They are used to protect the ingress of water and chloride ions and are relatively expensive and difficult to place. Latex-modified concrete overlays have high material costs and good performance. They are expected to last up to 25 years, after which they typically require replacement. Some problems associated with latex-modified concrete overlays include plastic shrinkage cracks that deepen with age and with scaling in continuously saturated areas [17]. Silica-fume and low slump overlays are typically used in new construction. Low-slump dense concrete overlays prevent chloride ions and moisture from penetrating. These are also expected to last 25 years, but problems have been reported related to difficulties with placement, high cost, and trouble with surface cracking [23]. Silica fume concrete overlays have been reported as effective to reduce the ingress of chloride ions into concrete members that are exposed to salt-water [17].

2.2.4 Membranes

Membranes include urethanes, acrylics, epoxies, neoprenes, cement, polymer concrete, certain methyl methacrylates, and asphaltic products [3]. Waterproof membranes protect against deterioration induced by freeze-thaw cycles and provide a layer to slow down the ingression of chlorides that corrode reinforcement [17]. A relatively smooth surface is required for the application of liquid applied membranes. Membranes and membrane topcoats are usually gray or black, but some manufacturers offer several other colors. However, these colors may have a tendency to fade. The surface of a membrane topcoat is difficult to keep clean. Membranes used to help prevent chloride entry are usually built up in multiple layers and frequently have the ability to bridge cracks in concrete [24].

2.2.5 Corrosion Inhibitors

Corrosion inhibitors are meant to supplement the concretes natural ability to protect the embedded reinforcement by forming a passivating oxide layer on the steel. The most common product contains calcium nitrate. Migrating corrosion inhibitors (MCIs) are also available and are designed to migrate to the embedded reinforcing to protect it against future corrosion [9].

Corrosion inhibitors slow down or prevent corrosion of reinforcing steel in concrete. They are often used in conjunction with other corrosion protection systems, such as epoxy coated steel. They are generally used as admixtures in concrete for new construction, but can also be used for repairs by being admixed into concrete for patches, sprayed, or painted onto the surface of concrete. Organic inhibitors have been shown to limit the number of chloride ions that reach the steel by providing a physical barrier, and the same dosage is recommended regardless of the anticipated maximum chloride concentration in the concrete [17].

2.2.6 Electrochemical Methods

According to NCHRP Synthesis Report 398 [25], cathodic protection is the only technology that can directly stop corrosion in reinforced concrete structures. Patching, replacement of concrete, and encasement and jacketing are relatively ineffective in preventing future corrosion-induced damage. Cathodic protection applies an electric field that favors cathodic and deters anodic reactions. This protection is divided into impressed current and galvanic or sacrificial anode. Impressed current uses an external electrical power source to drive a current through the anode toward the metal to be protected. Galvanic protection is achieved when another metal (anode), which is more electronegative than the metal to be protected, is placed in its vicinity and electrically connected to it [25]. Sacrificial anodes are composed of a consumable metal such as zinc or aluminum and can be installed on the concrete surface or in an internal application without external electrical equipment [17].

These cathodic protection systems are typically reported to have high installation costs, but in contrast also have lower life-cycle costs. The challenge reported is that higher levels of monitoring and maintenance are required. The extension of service life is dependent on the service life of the anode material and the maintenance of system. The performance and durability of anode materials is crucial to the overall success of the system. Failures have been reported in cases of experimenting with new systems, when agencies installed systems without requisite experience and knowledge, systems were not matched to the structure or the environment, improperly designed, or incorrectly installed, and systems were not monitored or maintained appropriately [25].

Agencies that have successfully implemented cathodic protection have experienced reduction in frequency and cost of bridge maintenance, and an increase in service life. In comparison, galvanic protection is more attractive for its lower monitoring and maintenance requirements. No external power source is needed and it is less likely to affect alkali-silica reaction. Galvanic cathodic protection systems are finding application on superstructure elements exposed to deicing salts. Titanium mesh is used most for impressed current protection on beams. Arc sprayed zinc and hockey puck zinc anodes are used most for galvanic protection [25].

Electrochemical chloride extraction is similar to cathodic protection, but the total amount of charge is about 50 to 500 times that used for cathodic protection [9]. This is typically used as a short-term treatment. In this process, chloride ions are pulled out of the contaminated concrete, allowing the concrete to stay in place. Spalls and cracks need to be repaired conventionally or sealed prior to application. It can successfully remove substantial amounts of chloride from contaminated concrete, and lead to an increase in pH of the concrete and repassivation of corroding reinforcing steel [17].

2.2.7 Patching

Patching materials are used to replace localized areas of deteriorated concrete. They usually have short service life because they do not address the cause of the problem (corrosion of the reinforcing bars). The service life depends largely on the corrosivity of the surrounding concrete [9]. Shrinkage cracking and debonding might be a problem as well.

2.2.8 Reinforcing Bar Coatings

Corrosion of reinforcing bars in concrete is initiated and sustained when sufficient amounts of chloride ions, oxygen, and moisture are present at the reinforcing bar surface. Coatings on reinforcing bars are either applied to reinforcing bars prior to installation in a new concrete structure or applied to reinforcing bars for the purpose of corrosion control in damaged concrete structures. Proper surface preparation is essential to achieve maximum adhesion, which is the primary factor governing the performance of any protective coating. When applying the coating to corroded reinforcement bars, the first step is to remove the defective concrete by a suitable method and expose the reinforcing bar both around its full circumference and for a short length beyond the area of corrosion before any surface preparation can be carried out. Several types of commercially available repair coatings include polymer-modified cement slurry, nonpassivating epoxy coatings, passivating epoxy coatings, zinc-rich epoxy coatings, and zinc-rich water-based coatings. A combination of a compatible epoxy coating and a high resistance silica fume patch material was reported to be the most effective in combating corrosion on epoxy-coated rebar concrete elements [9].

2.3 Steel Products and Systems

There are many different options available to prevent steel corrosion, as there are many different combinations of primers, intermediate coats, and top-coats that can be applied to steel surface. Most of the commonly used steel systems currently take advantage of all three layers. Another system that exists to prevent corrosion is using hot-dipped galvanized steel, which may be coated or can be left uncoated.

Currently there are many different coating systems available for steel beam treatments:

- polysiloxane systems which comprise of a zinc based primer and an epoxy siloxane top-coat.
- inorganic zinc primer with an epoxy intermediate coat and a urethane top-coating, considered the “gold standard” according to [26].

One advantage of the organic zinc-rich coatings over the inorganic zinc-rich coatings is that organic zinc has a definable cure period based on external temperature and humidity conditions, which allows application of a top layer with confidence that the primer has fully cured [27]. This makes organic zinc-rich primers easier to apply in the field where the temperature and humidity cannot be regulated. Other coating systems based on a zinc-rich primer use a polyaspartic polyurethane, polyurethane, or polysiloxane top-coat. There are other coating types, which have been used and are moisture cured urethanes, acrylic latexes, and epoxy resins. These coating types may also be zinc-rich.

Published in 2010 MoDOT Report [28] on structural steel coatings for corrosion mitigation mentions that drainage of water from the deck onto the superstructure was the primary factor leading to service failure of the coating. Authors observed that inorganic zinc primers were effective at hindering corrosion, however organic zinc primer had higher adhesive strength. The document also reports that overcoating provides an alternative maintenance option that reduces cost and disruption of the highway system; however, it comes with an increased level of risk of early failure of the newly applied system (versus the full blast and repaint approach). Additionally, polyurea type coatings were reported as very good at producing bond strength, but its salt induced corrosion inhibition was not as strong as the systems with high solid zinc primer. Organic zinc primer was reported as better due to higher adhesive strength and lower probability of peeling-off. Promising application of coating system-micaceous iron oxide zinc primer with aliphatic polyurea polyaspartic topcoat was reported. It had almost equal performance in terms of salt-fog resistance compared to blast cleaning and application of a zinc rich primer, but provided the added feature of superior UV resistance (Excellent) with good (Good) freeze-thaw stability.

Coatings investigated in the report have been shown in Table 2 and Table 3. It should be noted here, that the study does not reveal manufacturers names. The general results of the study conclude that there is not one treatment that can be specified as the best and case-by-case studies are needed to select the best type of coating.

Table 2: Coating systems evaluated in experimental study Phase I [28]

Manufacturers	Coating System in Phase I	Sub Group No.	Brief Coating System Description
G1		**1**	Zinc + Epoxy + Ployurethane
H	**H1**	**1**	Zinc + Polysiloxane
		2	High Solid Epoxy + Polyaspartic
		3	100% solid polyurea + Polyaspartic
		4	High Solid Epoxy + Polyurea A
A	**A1**	**1**	Miozinc+Polyaspartic polyurea
P	**P1**	**1**	Designated primer + Polyurea
N	**N1**	**1**	Zinc Urethane + Epoxy + Ployurethane
		2	Zinc Urethane + Epoxy + Fluoropolymer
I	**I1**	**1**	Urethane primer 1 + Aromatic polyurea +Urethane topcoat
		2	Urethane primer 2 + Aromatic polyurea + Urethane topcoat
		3	Polyamine epoxy + Aromatic polyurea + Urethane topcoat

Table 3: Coating systems evaluated in experimental study Phase II [28]

Manufacturers	Coating System In phase II	Sub Group No.	Brief Coating System Description
CSA		**1**	Calcium sulfonate sealer, primer, topcoat
A	**A2**	**1**	Polyaspartic polyurea topcoat
E	**E2**	**1**	Rust inhibitive primer + intermediate coat+waterborne acrylic topcoat

It can be mentioned here that service life of zinc-rich primer-based coating systems has been reported to last even 30 years [29]. Specification guide for application of coating system with zinc-rich primers to steel bridges is available in the literature [30]. There have also been analytical methods developed to compute reduced capacity of sections with deteriorated steel beams [31].

In order to lower the cost of coatings on new steel bridges, reducing the number of the coats required on the beam has been proposed. Recently published study [32] evaluated performance of eight different one-coat systems and compared it to one three-coat system and one two-coat system. The results showed that although the one-coat systems demonstrated promising performance, they did not perform as well as the three-coat systems under accelerated laboratory and outdoor exposures.

2.4 Causes for Deterioration and Repair Techniques

MDOT report by Ahlborn et al. [17] (published in 2002) presents an excellent review of causes and cures for prestressed concrete I-beam end deterioration, including development of inspection procedures for prestressed concrete I-beams, identification of preventive maintenance strategies to extend the service life of prestressed concrete I-beams ends, and evaluating repair techniques. The reported prestressed concrete crack type and probable causes have been listed in Table 4. The forms of distress frequently observed included concrete spalling, delamination, cracking, and corrosion of reinforcement. The literature review of the study, however, does not analyze in depth specific coatings that extend the life of existing and new beams, rather lists wide range of available products as recommended by PCA [33] and cite some existing data on general performance of 2-part epoxies, siloxanes, silanes, and multi-components (silane, siloxanes, methyl methacrylate) [24,34,35,36].

Table 4: Prestressed Concrete Crack Type and Probable Cause [17]

Location	Crack Type	Potential Cause (per Juntunen, 2000)							
		Loss of Bond	Pre-stressing Cut	Load Hit	Diaph. Bond	Strand Slip	Over-load	Insuff. Reinf.	Reinf. Corr'n
End of Member	Horizontal		✓		✓				
	Diagonal		✓	✓			✓	✓	
	Frown		✓						
	Vertical								✓
	Map							✓	
Remainder of Span	Longitudinal Flange	✓							
	Diagonal			✓		✓			
	Map							✓	

The study indicates that the choice of repair approach depends on the existing condition of beam end, as shown in Table 5. Sealers and coatings are generally recommended for beam ends with low distress levels. The MDOT report does contain experimental component, but it is focused on evaluation of partial depth repair materials (comparison of three different patching materials as a beam end treatment is performed).

Table 5: Preventive Maintenance and Repair Options for Deteriorated Beam-Ends

Low Severity Distress	Moderate Severity Distress	High Severity Distress
Sealers	Partial Depth Repair	Partial Depth Repair
Coatings	Cathodic Protection	Replacement
Do Nothing	Combined Sealers and Coatings	---

Another interesting observation mentioned in MDOT [17] report relates to new approaches to preventive maintenance techniques, where observations are made that modifications to the deck, support member, and primary framing might be an effective way to reduce beam end deterioration. Among possible deck modifications methods, repair or replacement of transverse deck joints, installation of a positive drainage waterproof overlay have been mentioned (Table 6), together with information that there is no evidence in the literature that States are using a joint maintenance approach to prolong prestressed concrete I-beam life. Among the states interviewed, Illinois was the only state indicating documented prestressed concrete beam end maintenance, while Texas was the only state that cited the use of the ACI Concrete Repair Manual and ICRI Repair Guidelines for repairs [40], as opposed to following state DOTs' accepted repair practices. In contrast, experiences from Germany and Netherlands show that care focused on joint quality and preservation much more efficiently limits deterioration issues related to beam ends [37].

Among the states researched, Kentucky Transportation Center distinguishes itself with an active program evaluating protective concrete coatings. Younce et al. [38] evaluated an experimental protective coating that was applied to a concrete median barrier on a section of I-65 in Louisville. This experimental project was the first trial of concrete coatings identified under KYSPR 05-271 Coatings, Sealants and Fillers to Address Bridge Concrete Deterioration and Aesthetics-Phase 1. The coatings systems identified under that study were intended to provide improved protection and aesthetics for reinforced concrete. This project proved that one candidate coatings system could be applied successfully on existing concrete. For another study performed by KTC [10], please refer to section 2.2.1 of this project.

Table 6: Performance Matrix for Preventive Maintenance Techniques [after 17]

Approach	Technical Requiremen	Effectiveness	Durability	Infrastructure	Service Life	Total Score (60 max)
	Weighted Importance	10	7	8	5	
	Impact Definition	0 = Not effective 1 = Inconclusive 2 = Effective	0 = Not durable 1 = Inconclusive 2 = Durable	0 = Required 1 = Inconclusive 2 = Not required	0 = < 4 years 1 = Inconclusive 2 = ≥ 4 years	
Transverse Deck Joint Maintenance	Weighted Importance	20	7	16	10	53
Surface Coatings		10	14	16	10	40
Sacrificial Anode Cathodic Protection		10	7	16	5	38
Surface Applied Corrosion Inhibitors		10	7	16	5	38
Crack Treatment for Beams		10	7	16	5	38
Impressed Current Cathodic Protection		20	0	0	10	30
Penetrating Sealers		0	7	16	5	28
Surface Sealers		0	7	16	5	28

The coatings performance and acceptance testing provided a mechanism for assuring new coatings used on the maintenance painting projects performed successfully. (Note: The list of ASTM standards used to test the sealers is included in Appendix D).

Practices recommended for the inspection, assessment, and repair of deteriorated prestressed concrete bridge beams have been recorded in NCHRP Report 280 [39]. When specifying treatments and repairs, guidelines issued by International Concrete Repair Institute can also be followed. These can be summarized as shown in Figure 3.

In order to enable direct comparison of different beam ends coatings and treatments, the same testing procedures have to be applied to all the testing materials. Ideally, different coatings should be tested under the same environmental exposure, parallel with other treatments. The summary of testing methods that should be considered when performance of coatings and treatments is evaluated [9,40] has been presented in Appendix D.

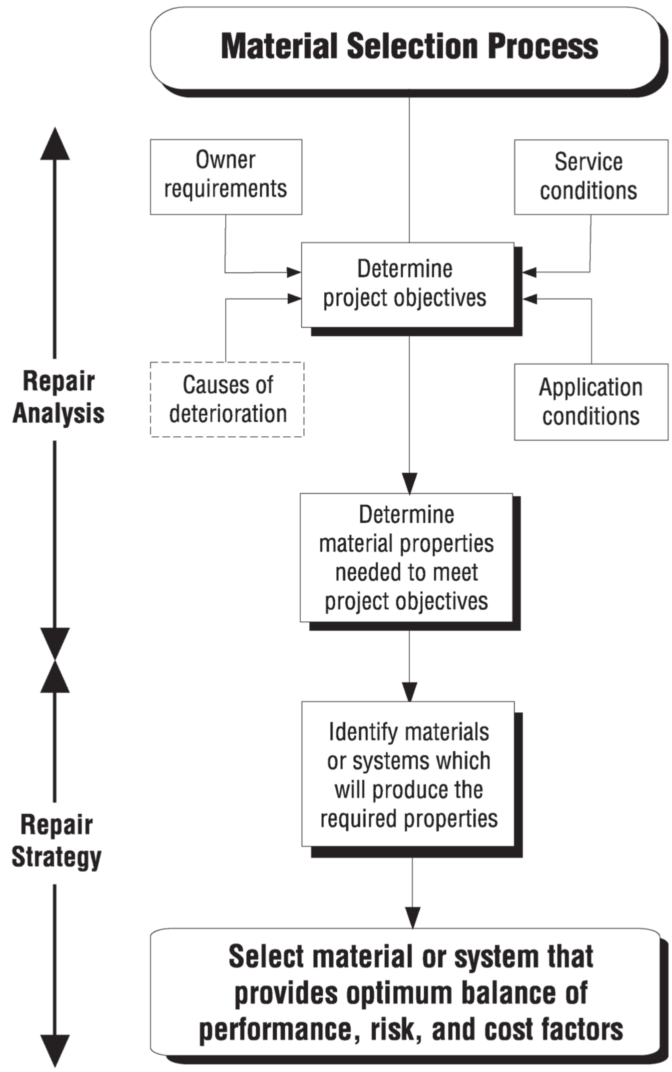


Figure 3: Repair Materials Selection Process [40]

3. Results from On-line Surveys and Phone Interviews

3.1 Survey Development

After reviewing the available literature, three on-line surveys were created to obtain detailed information regarding the treatment of beam ends directly from DOT representatives as well as manufacturers. The information obtained from the literature review was used to form questions that would yield information of interest in correspondence to the goals of the study. A total of three surveys were developed. Two of the surveys were intended for coating manufacturers; one for concrete and one for steel coatings manufacturers. The third survey was intended for state DOTs and other organizations or agencies. Particular attention was placed on agencies and companies that operate in conditions similar to those found in Pennsylvania. While all three surveys are included in Appendix B, Table 7 provides on-line links to the surveys.

Table 7: Three Developed Surveys with on-line links

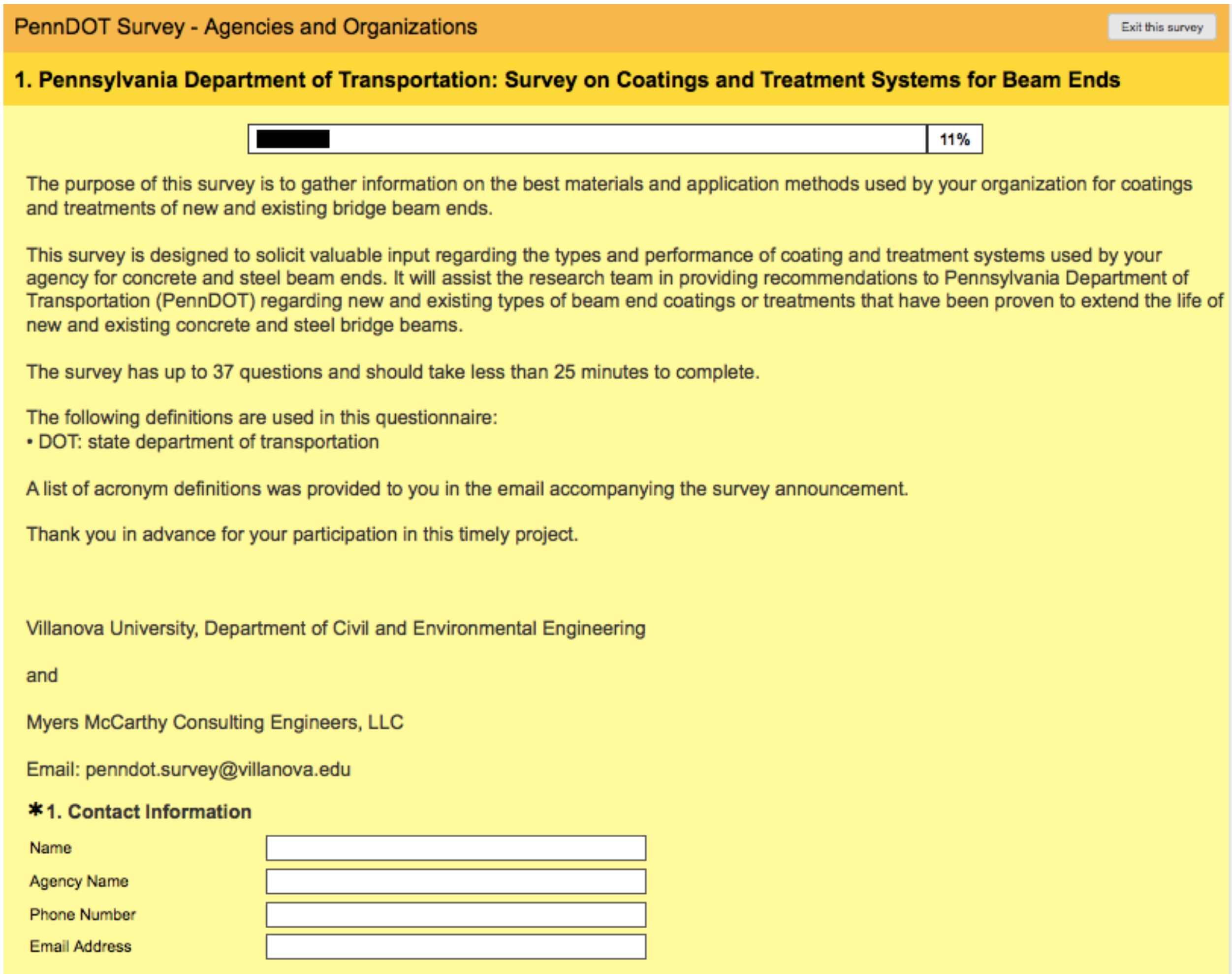
Agency and Organization Survey	https://www.surveymonkey.com/s/PennDOT_Survey_to_Agencies_and_Organizations
Concrete Manufacturer Survey	https://www.surveymonkey.com/s/PennDOT_Survey_to_concrete_coating_manufacturers
Steel Manufacturer Survey	https://www.surveymonkey.com/s/PennDOT_Survey_to_steel_coating_manufacturers

The first page of each survey (Figure 4) served as an introduction to the project topic and explained the purpose of the survey intended to solicit valuable input regarding the performance of coating and treatment systems used for concrete and steel beam ends. In addition, an explanation of the goals of the project was included as:

> *The survey will support PennDOT's overarching goal to investigate new and existing types of beam end coatings or treatments that have been proven to extend the life of new and existing concrete and steel bridge beams.*

The survey design was streamlined and delivered in SurveyMonkey® online format in order to increase the response rate. To enable convenient navigation, the survey contained the following features:

- An introductory page, containing contact information
- A list of the acronyms used in the survey
- A bar displaying percentage of the survey completed
- Pages for response related to coating information
- A section for additional comments



PennDOT Survey - Agencies and Organizations

Exit this survey

1. Pennsylvania Department of Transportation: Survey on Coatings and Treatment Systems for Beam Ends

11%

The purpose of this survey is to gather information on the best materials and application methods used by your organization for coatings and treatments of new and existing bridge beam ends.

This survey is designed to solicit valuable input regarding the types and performance of coating and treatment systems used by your agency for concrete and steel beam ends. It will assist the research team in providing recommendations to Pennsylvania Department of Transportation (PennDOT) regarding new and existing types of beam end coatings or treatments that have been proven to extend the life of new and existing concrete and steel bridge beams.

The survey has up to 37 questions and should take less than 25 minutes to complete.

The following definitions are used in this questionnaire:
• DOT: state department of transportation

A list of acronym definitions was provided to you in the email accompanying the survey announcement.

Thank you in advance for your participation in this timely project.

Villanova University, Department of Civil and Environmental Engineering

and

Myers McCarthy Consulting Engineers, LLC

Email: penndot.survey@villanova.edu

***1. Contact Information**

Name

Agency Name

Phone Number

Email Address

Figure 4: First Page of Survey sent to Agencies and Organizations

A detailed list of all recipients of the surveys have been prepared in Excel format: Survey_contacts_list.xlsx. The file is divided in four tabs listing: 1) Industry contacts, 2) AASHTO Subcommittee on Maintenance recipients, 3) AASHTO Subcommittee on Bridges recipients, and 4) other DOT contacts.

Based on the research findings and thorough analysis of the survey responses, the project team drew conclusions and provided recommendations for the most efficient and cost effective beam end coatings and treatments to be considered by PennDOT.

3.2 Survey Response Rate

The online surveys were active on-line for a period of 8 weeks during the months of July and August 2011. A total number of 190 surveys were sent, including 127 surveys sent to DOT and Agencies, 46 surveys sent to concrete coatings manufacturers, and 17 surveys sent to steel manufacturers (Table 8).

Table 8: Details of the number of surveys sent including response rate.

Survey Recipient	Number of Surveys Sent	Number of Responses	Response Rate
DOT and Agencies	127	33	26%
Concrete Coatings Manufacturers	46	16	35%
Steel Coatings Manufacturers	17	6	35%

As can be seen in Figure 5, an average response rate of 29% was achieved. The lower than expected response rate can be explained by the summer months being a heavy construction season and survey recipients might have not been responding due to heavy work load. The issue was communicated to PennDOT research team and it was concluded that the survey analysis will be performed based on the received responses and additional follow up phone conversations with selected contact people (see section 3.6 for detailed information on all people contacted via phone interviews). While the summary of responses has been presented in Table 8 and Figure 5, detailed information on survey respondents have been presented in Excel file Survey.Responses.Analysis.xlsx. The details on states that responded to the surveys have been shown in Figure 6.

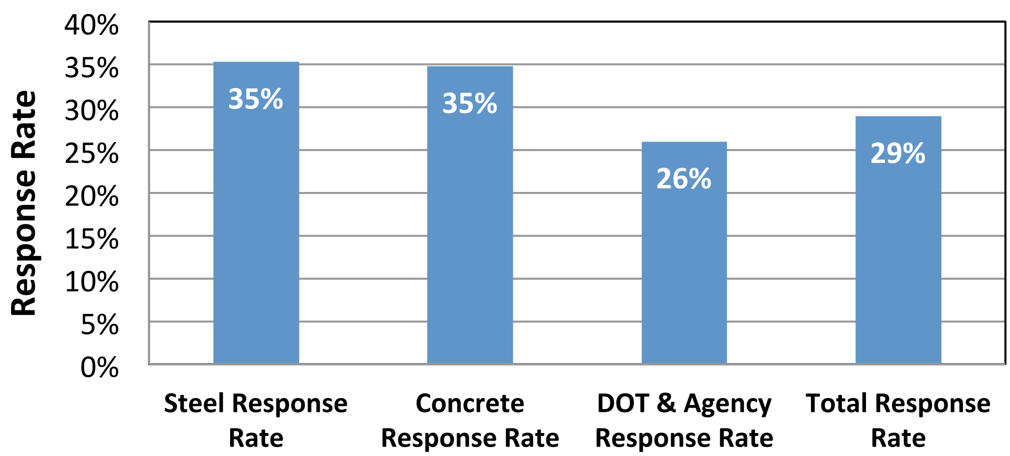


Figure 5: Survey Response Rate

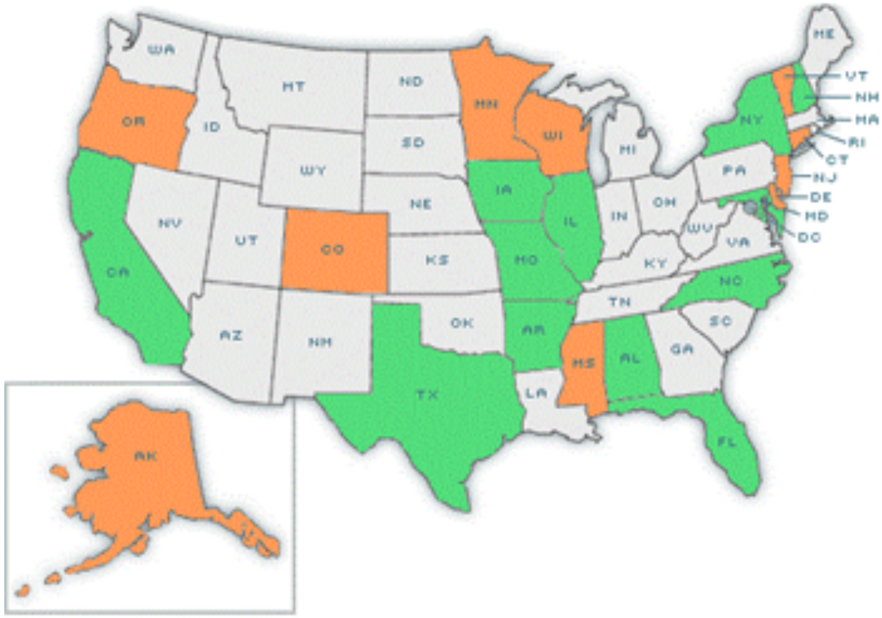


Figure 6: Map of State DOT's that Replied to the Surveys (green –states that replied, orange – states that provided partial response, white – no response received)

3.3 Survey Results for Concrete

A summary of all the responses related to concrete beam end coatings and treatments have been summarized in Figure 7. Among the products recommended by concrete coatings manufacturers, the majority contains an epoxy resin system. Some of the epoxy systems included an additional polyurethane resin component, while other products that were recommended include silanes and silicones.

The feedback regarding concrete coatings from DOTs and other agencies was not as high as expected. However, out of the agencies that responded, a majority replied that they do not coat the ends of concrete beams. Ten out of thirteen responses were either does not coat or rarely coat the beam ends. The other three responses included acrylic, siloxane, and an epoxy resin. It is interesting to note here, that previous survey performed in 2001 [17] also revealed that most states do not repair prestressed I-beams for end deterioration, and if they were to perform one, state DOT specification would be used in the rehabilitation process.

Montana DOT responded that they rarely coat beam ends on concrete. Additionally, Nebraska Department of Roads (NDOR) replied that with new concrete structures, the outside fascia of exterior girders is sealed with a siloxane or an acrylic sealer, but there is no special treatment of girder ends. Some agencies that do use coating systems and provided product descriptions are **Florida DOT**, **Illinois DOT**, and **Iowa DOT (Sikagard 62)**. Protective coatings, concrete sealers, latex acrylic primer, and an epoxy sealer were reported products by agency survey respondents. These systems all require frequent or periodic inspection and are estimated to last 0 to 10 years.

It can be reminded here that the survey sent to DOTs and Agencies was separated into sections on steel beams and concrete beams and responses related to steel coatings are summarized in the following section.

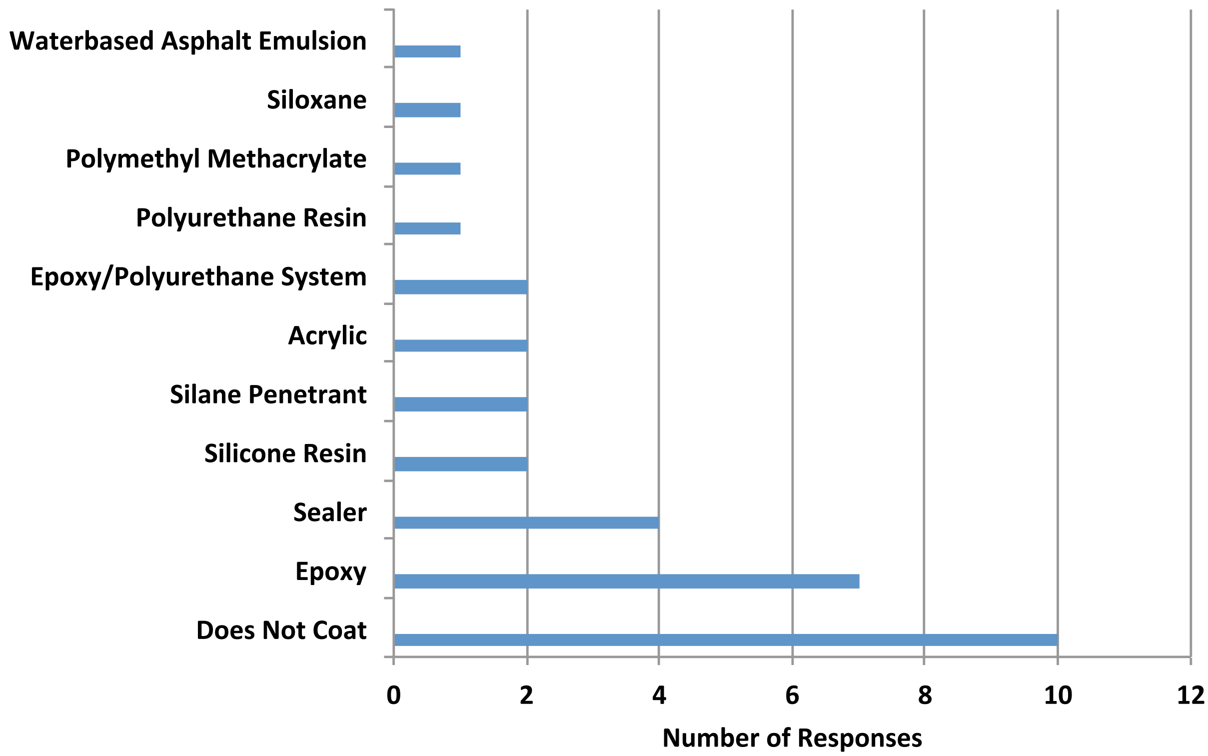


Figure 7: Coating Systems Specified in Concrete Coatings Survey Responses

In the concrete manufacturers survey, the manufacturers were solicited for product names, descriptions, and type of coating for their products recommended for use to protect concrete bridge beam ends. A summary of the results for the specific type of coatings identified can be seen in Table 9 (also available in Survey.Responses.Analysis.xlsx). Some of the products can be classified as more than one type of coating and therefore are counted more than once. Coatings and membranes were reported as the most frequently used treatments, followed by sealers and combination systems.

The concrete manufacturer survey respondents consisted of both companies that were already PennDOT approved and companies that were not currently PennDOT approved, but were interested in acquiring the approval. The concrete manufacturers that were already PennDOT approved for their reported products include:

- Evercrete Corporation,
- Vexcon Chemicals, Incorporated, and
- Klaas Coatings.

There were a number of respondents from companies that were not PennDOT approved for their recommended products but indicated they would like to be. The following concrete coatings manufacturers were interested in PennDOT approval:

- Soprema Incorporated,
- Pruett-Schaffer Chemical Company,
- Textured Coatings of America, Incorporated,
- Pecora Corporation,
- ChemMasters,
- Fox Industries Incorporated,
- Advanced Chemical Technologies Incorporated, and
- Sherwin Williams.

More details of the survey responses have been included in Appendix C.

Table 9: Types of Coating Products Reported in Concrete Manufacturers Survey

Type of Coating	# of Products Reported	Product Names or Description	Manufacturers	Company PennDOT Approved
Coatings	8	TEXCOTE XL 70 BRIDGE COTE	Textured Coatings of America, Inc.	
		TEXCOTE XL 70 BRIDGECOTE W/SILANE	Textured Coatings of America, Inc.	
		Multi laminate epoxy/urethane coating system pecoraDeck P-808 primer Pecoradeck P-806 Top Coat	Pecora Corporation	
		Safe-Cure & Seal EPX Duraguard 310CRU	ChemMasters	
		Epoxykote 100WB	ChemMasters	
		Waterbased Epoxy	Pruett-Schaffer Chemical Co.	
		FX-498 Hydro Ester High Build Coating	Fox Industries Inc.	
		Epoxy: Plymastic 650	Sherwin-Williams	
Membranes	6	Soprema Alsan RS (PMMA waterproofing system)	Soprema Inc.	
		Soprema Alsan Flashing (Asphalt-modified urethane)	Soprema Inc.	
		Multi laminate epoxy/urethane coating system pecoraDeck P-808 primer Pecoradeck P-806 Top Coat	Pecora Corporation	
		Safe-Cure & Seal EPX Duraguard 310CRU	ChemMasters	
		Epoxykote 100WB	ChemMasters	
		Waterbased Asphalt Emulsion	Pruett-Schaffer Chemical Co.	
Penetrating Sealers	4	Evercrete Deep Penetrating Sealer (DPS)	Evercrete Corp.	Yes
		TEXCOTE XL 70 BRIDGECOTE W/SILANE	Textured Coatings of America, Inc.	
		Sil-Act ATS-100LV	Advanced Chemical Technologies Inc.	
		Penetrating Concrete Sealer: SW DOT Concrete Sealer 100	Sherwin-Williams	
Surface Sealers	4	Dynapoxy Low Mod Epoxy - Low Mod 2 component fast curing epoxy based coating	Pecora Corporation	
		Safe-Cure & Seal EPX Duraguard 310CRU	ChemMasters	
		Epoxykote 100WB	ChemMasters	
		Sil-Act EP 700D	Advanced Chemical Technologies Inc.	
Combination Systems	3	Evercrete Top Seal (TS)	Evercrete Corp.	Yes
		Si-Rex03 Silicone Resin Emulsion Paint (SREP)	Klaas Coatings (North America) LLC	Yes
		FX-460 Breathable Masonry Coating System (1 Coat Primer, 1 Coat Top Coat)	Fox Industries Inc.	

Table 9: Types of Coating Products Reported in Concrete Manufacturers Survey (continued)

	0	No products specified for: Electrochemical Methods, Corrosion Inhibitors, Admixtures, Patching, Reinforcing Steel Protection, Overlays		

Table 10: Expected Service Life of Coatings from Concrete Manufacturers Survey

Type of Coating	Expected Service Life (years)							
	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+
Penetrating Sealers	0	**2 products:** • Sil-Act ATS-100LV • SW DOT Concrete Sealer	**1 product:** • TEXCOTE XL 70 BRIDGECOTE W/SILANE	0	0	0	**1 product:** • Evercrete Deep Penetrating Sealer (DPS)	0
Surface Sealer	0	0	**2 products:** • Epoxykote 100WB • Dynapoxy Low Mod Epoxy	**2 products:** • Sil-Act EP 700D • Safe-Cure & Seal EPX Duraguard 310CRU	0	0	0	0
Membranes	0	0	**2 products:** • PecoraDeck P-808 primer Pecoradeck P-806 Top Coat • Epoxykote 100WB	**4 products:** • Soprema Alsan RS • Soprema Alsan Flashing • Safe-Cure & Seal EPX Duraguard 310CRU • Waterbased Asphalt Emulsion	0	0	0	0
Coatings	0	0	**5 products:** • FX-498 HYDRO ESTER HIGH BUILD COATING • Epoxykote 100WB • PecoraDeck P-808 primer Pecoradeck P-806 Top Coat • TEXCOTE XL 70 BRIDGE COTE • TEXCOTE XL 70 BRIDGECOTE W/SILANE	**3 products:** • Epoxy Plymastic 650 • Waterbased Epoxy • Safe-Cure & Seal EPX Duraguard 310CRU	0	0	0	0
Combination Systems	**1 product:** • Evercrete Top Seal (TS)	0	0	**2 products:** • Si-Rex03 Silicone Resin Emulsion Paint (SREP) • FX-460 BREATHABLE MASONRY COATING SYSTEM	0	0	0	0

The service life data of the coating systems obtained from the survey is compiled in Table 10. It can be seen that 84% of respondents reported a service life for their products lasting between 11 and 20 years. One of the more notable responses was the service life reported to be 41 to 50 years for a penetrating sealer with water repellent silicates. This specific product is a deep penetrating sealer called *Evercrete Deep Penetrating Sealer* (DPS) that was reported by the manufacturer (*Evercrete Corporation*) to outlast and outperform every other sealant on the market today. The product penetrates below the surface and chemically reacts with alkali and lime in the concrete, sealing against the ingress of moisture while allowing the concrete to breathe. This sealer protects against rain, salts, oils and chemicals that wear the integrity of the concrete and can be used on most new and old concrete surfaces.

Soprema Incorporated recommends the use of two waterproofing membranes to protect the concrete beam ends that last 16 to 20 years. One of the systems called *Soprema Alsan RS*, which is a rapid set polymethyl methacrylate (PMMA) waterproofing system, utilizes polymethyl methacrylate technology to form a flexible, polyester reinforced cold liquid applied membrane system expected to last 16 to 20 years. This product costs $70 per gallon. The other product reported is *Soprema Alsan Flashing*, an asphalt-modified urethane waterproofing system that costs $50 per gallon. This product is a urethane resin that is UV resistant and alkali resistant and reported to last 16 to 20 years.

Textured Coatings of America, Incorporated has two similar coating systems they recommended for use on bridge beam ends: *TEXCOTE XL 70 BRIDGE COTE* which costs 35 cents per square foot and *TEXCOTE XL 70 BRIDGECOTE with Silane* which costs 40 cents per square foot. Using the recommended application rate of 50 square feet per gallon for both coatings, the cost for the *BRIDGECOTE* and the *BRIDGECOTE with Silane* are $17.50 per gallon and $20 per gallon, respectively. The coatings have the same features except that one coating has the added performance benefits of silane. The products are freeze-thaw, ultraviolet, scaling, and chloride ion intrusion resistant. They require only one coat, can be applied in cold weather, and are suitable for high humidity areas. The coating with the addition of silane has excellent adhesion to concrete and is used for long term performance.

Pecora Corporation offers a fast curing epoxy based surface sealer (*Dynapoxy Low Mod Epoxy* - Low Mod 2 component fast curing epoxy based coating at $30 per gallon) and an epoxy/urethane coating system (Multi laminate epoxy/urethane coating system *pecoraDeck P-808 primer Pecoradeck P-806 Top Coat* at $35 per gallon). The low modulus, low viscosity epoxy surface sealer has excellent bond strength and is reported to be moisture insensitive. The epoxy/urethane coating system provides protection from freeze-thaw damage and chloride induced corrosion with its destructive force on reinforcing steel.

Klaas Coatings has a silicone resin exterior paint combination system called *Si-Rex03 Silicone Resin Emulsion Paint (SREP)* with excellent flexibility and excellent freeze-thaw and salt spray resistance. The combination system includes a penetrating sealer primer with two coats of silicone resin exterior paint.

ChemMasters recommends two epoxy systems (*Safe-Cure & Seal EPX Duraguard 310CRU* at $27.65 to $80 per gallon and *Epoxykote 100WB* at $47.98 per gallon) that provide resistance to chloride ion penetration. Epoxy coatings can be economical and cost effective options that have excellent depth of penetration and excellent adhesion. The water based epoxy *Safe-Cure & Seal EPX Duraguard 310CRU* can be combined with a polyurethane topcoat to improve chemical, UV light, and graffiti resistance. This topcoat also provides excellent abrasion resistance.

Fox Industries has a silicone resin emulsion paint combination system, *FX-460 Breathable Masonry Coating System* (1 Coat Primer, 1 Coat Top Coat), with excellent protection to concrete against attack from water, UV, and chemical attack. This system costs $25 per gallon for the primer and $47.50 per gallon for the top coat. *Fox Industries* also recommended a second coating called *FX-498 Hydro Ester High Build Coating* that costs $45 per gallon. This epoxy resin system is moisture insensitive and corrosion resistant.

Advanced Chemical Technologies recommended a silane based penetrating sealer named *Sil-Act ATS-100LV* which costs $40 per gallon and an epoxy polymer surface sealer named *Sil-Act EP 700D* which costs $50 per gallon. The silane-based product is repellent to water, chloride, ions and waterborne contaminants. It is flexible, easy to store, and easy to apply. The epoxy polymer sealer protects from the intrusion of water, salts, ion and waterborne contaminants.

Sherwin Williams recommended the use of an epoxy ply-mastic coating system (*Epoxy Plymastic 650* at $60 per gallon) and a penetrating concrete sealer (*SW DOT Concrete Sealer 100* at $45 per gallon) to protect the end of bridge beams. The ply-mastic epoxy provides a tough, abrasion and chemical resistant finish. The DOT Bridge and Highway Concrete Sealer that Sherwin Williams recommended is a silicone acrylic sealer that provides outstanding penetration, chloride intrusion protection and color retention.

3.4 Survey Results for Steel

The summary of survey responses has been presented in Figure 8, while specific products have been listed in Table 11. Among DOTs Agencies that replied to the survey, 29% listed using an inorganic zinc primer with an epoxy mid-coat and urethane top-coat. The other systems listed for new steel were inorganic zinc-rich primer with either one or two layers of acrylic latex on top. In one case the DOT replied that it does not regularly coat beam ends on its infrastructure components. The coatings used on existing steel varied more than the coatings for new steel, however 58% of DOTs reported using zinc-rich based systems. The coating systems that were reported being used and were different from the inorganic zinc system include a zinc-rich epoxy primer with an epoxy mid-coat and urethane top-coat. Other systems reported that comprised of three layers include: Three layers of acrylic latex, an organic zinc primer with an epoxy mid-coat and a urethane top-coat, and an aluminum epoxymastic primer with an aluminum epoxymastic mid-coat and an acrylic top-coat. Table 11 summarizes the different products that were reported in the survey.

After analyzing the survey results, it can be seen that there are coating systems that are reported to be used more than other systems. When looking at the coating systems reported to be used for new steel by the different DOT's and Agencies, the following are found to be the most common. These do not include the results from the coating manufacturers contacted.

- Inorganic Zinc Primer/ Epoxy Mid Coat/ Polyurethane Top Coat - 21.05%
- Inorganic Zinc Primer/ Epoxy Mid Coat/ Urethane Top Coat - 15.79%
- Inorganic Zinc Primer/ Acrylic Mid Coat/ Acrylic Top Coat - 15.79%
- Organic Zinc Primer/ Epoxy Mid Coat/ Polyurethane Top Coat - 10.53%

From the results of the survey there were some specific products mentioned as well. Some of these products correlate to the systems that were most frequently reported:

- Inorganic Zinc Primer/ Epoxy Mid Coat/ Polyurethane Top Coat - Carbonzinc 11 HS/ Carboguard 893/ Carbothane 133 HB (This specific set of products was reported twice, once by Oregon DOT and once by New Hampshire DOT)
- Organic Zinc Primer/ Epoxy Mid Coat/ Polyurethane Top Coat - Carbozinc 859/ Carboline 888/ Carboline 133 HB (This specific set of products was reported by New Hampshire DOT)

It is also worth noting that Montana DOT reported that it does not commonly coat beam ends.

The results from the section corresponding to the systems used for existing steel varied more and showed no repetition. It is worth noting though that 77.78% of the systems reported by the different DOT's for existing steel were zinc based primers. The DOT's that reported using zinc based primers were Oregon, Florida, New Hampshire, Alabama, Illinois, and Iowa. One of the two coatings reported by Illinois was not zinc based and the coating reported by California was not zinc based either.

The detailed survey responses are collected in Excel spreadsheet (Survey.Response.Analysis.xlsx), and summarized in Appendix C.

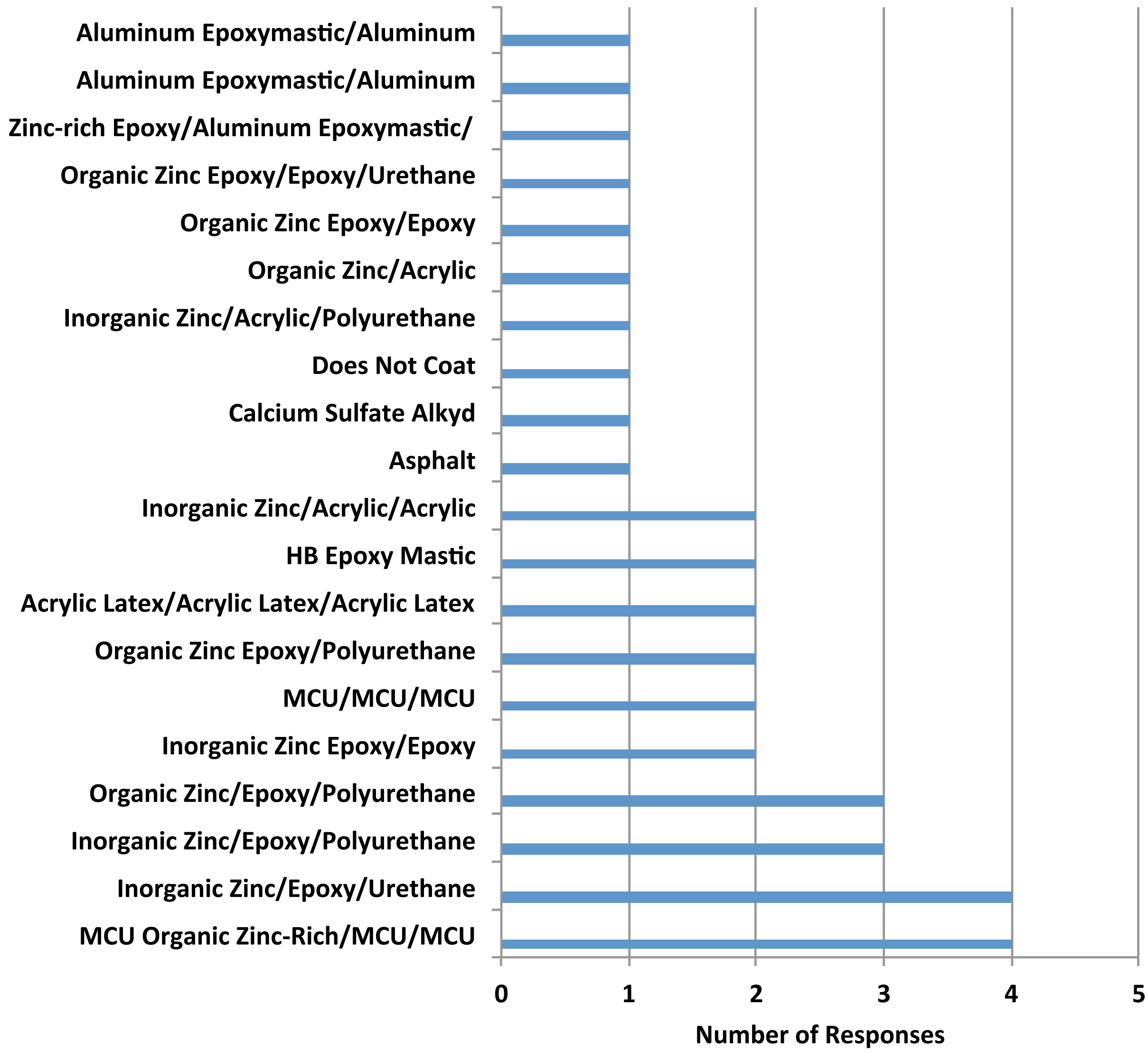


Figure 8: Coating Systems Specified in Steel Coatings Survey Responses

Table 11: Coatings Reported During Survey

System Recommended	Product Names	Manufacturers	Product PennDOT Approved
Organic Zinc Rich Moisture Cured Urethane	Wasser MC Zinc	Wasser	
Moisture Cured Urethane	Ferrox B	Wasser	
Moisture Cured Urethane	Ferrox A	Wasser	
Moisture Cured Urethane - Zinc Rich	Corothane I Galvapac	Sherwin Williams	
Moisture Cured Urethane	Ironox B	Sherwin Williams	
Moisture Cured Urethane	Ironox A	Sherwin Williams	
Solvent Based Inorganic Zinc	Carbozinc II HS	Carboline	Yes
Cycloaliphatic Amine Epoxy	Carboline 893	Carboline	Yes
Aliphatic Acrylic-Polyester Polyurethane	Carboline 133 HB	Carboline	Yes
Organic Zinc Rich Epoxy	Carbozinc 859	Carboline	Yes
Epoxy Polyamide	Carboline 888	Carboline	Yes
Aliphatic Acrylic-Polyester Polyurethane	Caboline 133 HB	Carboline	Yes
Zinc & Micaceous Iron oxide Urethane	Wasser MC-Miozinc	Wasser	
Moisture Cured Urethane	Wasser MC Miomastic	Wasser	
Moisture Cured Urethane	Wasser MC Miomastic	Wasser	
Zinc & Micaceous Iron oxide Urethane	Wasser MC Miozinc	Wasser	
Moisture Cured Urethane	Wasser MC Tar	Wasser	
Moisture Cured Urethane	Wasser MC Tar	Wasser	
Organic Zinc Rich Epoxy	Carbozinc 859	Carboline	Yes
Aliphatic Acrylic-Polyester Polyurethane	Carbothane 133 HB	Carboline	Yes
Organic Zinc Rich Polyamide Epoxy	Zinc Clad III HS	Sherwin Williams	Yes
Acylic Polyurethane	Acrolon 218 HS	Sherwin Williams	
Calcium Sulfonate Alkyd	AS 8301 Series	Watson Coatings Inc.	
Zinc Rich Epoxy	Interzinc 315B	Internation Paints	
Epoxy	Intergard 475 HS	Internation Paints	
Inorganic Zinc Rich Ethyl Silicate	InterZinc 22 HS	Internation Paints	
Epoxy	Intergard 475 HS	Internation Paints	
Organic Zinc Rich Moisture Cured Urethane	MC Zinc 100	Wasser	
Moisture Cured Urethane	MC Miomastic 100	Wasser	
Moisture Cured Urethane	MC Ferrox A	Wasser	
Urethane	MC-Universal Primer DTM	Wasser	
Moisture Cured Urethane	Ferrox B	Wasser	
Moisture Cured Urethane	Ferrox A	Wasser	
High Build Epoxy Mastic	Corlar 2.1 ST	DuPont Industrial Coatings	
Aliphatic Poluyurethane Enamel	Imron 3.5 HG	DuPont Industrial Coatings	
High Build Epoxy Mastic	Corlar 2.1 ST	DuPont Industrial Coatings	
Polyurethane	Imron Industrial Strength	DuPont Industrial Coatings	
Organic Zinc Rich Epoxy	Zinc Clad III HS	Sherwin Williams	Yes
Epoxy	Macropoxy 646 FC	Sherwin Williams	Yes
Acrylic Polyurethane	Acrolon 218 HS	Sherwin Williams	Yes
High Solids Aluminum Filled Polyamine Epoxy	Epoxy Mastic Aluminum II	Sherwin Williams	
High Solids Aluminum Filled Polyamine Epoxy	Epoxy Mastic Aluminum II	Sherwin Williams	
Acrylic Polyurethane	Acrolon 218 HS	Sherwin Williams	Yes

3.5 Existing PennDOT Qualified Product List (QPL) and Practices

PennDOT currently has various coatings and systems in use to help increase the service life of structural concrete. There are a number of systems on PennDOTs qualified product list that fall under boiled linseed oils, fiberglass overlays, and silane/siloxane systems. Some penetrating sealers on the QPL include different silicones and epoxies. Also, under its penetrating sealers to reduce chloride penetration in concrete, it has organo-silicon compounds in water and silicates in water. In addition, PennDOT has many approved waterproofing membranes for various applications on concrete. These systems are applied to both new and existing concrete in order to help extend the service life. A current list of PennDOT approved concrete coatings and protection systems can be seen in Table 12, while steel products have been listed in Table 13.

Table 12: Concrete Coating and Systems in use by PennDOT as of June 2011

Concrete Coatings and Systems		
Company	Product	Product Description
Chem Masters	Anti-Spall 55	Boiled Linseed Oil and Mineral Spirits
Dayton Superior	Day Chem Anti-Spall (J-33)	Boiled Linseed Oil Blend
Degen Oil & Chemical Co.	Boiled Linseed Oil	Boiled Linseed Oil Blend
Euclid Chem. Co.	Euco Linseed Oil Treatment	Boiled Linseed Oil and other Solvents
	Dural 355	Ultra Low Viscosity, Penetrating Epoxy Crack Healer-Sealer
	Baracade WB 244	water based, oligomeric siloxane/silane
Meadows, W.R., of PA	Sealtight Lin-Seal	Boiled linseed oil in mineral spirits anti-spall penetrating sealer
Pruett-Schaffer Chem. Co.	Anti-Spalling Comp.	Boiled Linseed Oil
Vexcon Chemicals, Inc.	Certi-Vex Linseed Anti-Spall	50% boiled linseed and solvents manufactured with special additives
	Powercoat Epoxy Resin (Powercoat Epoxy HD)	Two component clear and colored heavy duty epoxy coating
	Vexcon Powerseal 40 Penetrating Sealer	High performance industrial and commercial grade breathable, efficient waterborne penetrating water repellent sealer that deeply penetrates into new (14 day minimum) or existing concrete and masonry surfaces
Wicktek, Inc.	Densicrete	Sodium Silicate
Zimmerman, E.E., Co.	Anti-Spalling Compound Concrete Sealer	Linseed Oil Based compound
Crafco, Inc.	Geo Tac	Peel-and-stick Waterproofing Membrane
Meadows, W.R., Inc.	Sealtight Mel-Dek	Roll-type waterproofing membrane composed of a nominally 53 mil thick layer of polymeric waterproofing membrane on a shrink-resistant, heavy-duty, 12 mil thick polypropylene woven carrier fabric
	Sealtight Mel-Rol	Roll-type waterproofing membrane. It is composed of a nominally 56 mil thick layer of polymeric waterproofing membrane on a heavy duty, four-mil thick, cross-laminated polyethylene carrier film.
Soprema, Inc.	Antirock	Prefabricated membrane waterproofing material designed with synthetic, non-woven material reinforcements impregnated and coated with SBS modified bitumen.
Polyguard Products, Inc.	Polyguard NW-75	Membrane is comprised of a rubberized asphalt waterproofing sealant adhesive with a non-woven pavement reinforcing grade polypropylene fabric laminated to the outer surface

Table 12: Concrete Coating and Systems in use by PennDOT as of June 2011 (continued)

Royston Labs, Inc. Royston Labs, Inc. (continued)	10AN Easy Pave	Prefabricated reinforced laminate consisting of an impregnated fiberglass, non-woven, high strength inner mat sandwiched between layers of a polymer modified bitumen
	10A-65 Bridge Deck Membrane	Prefabricated reinforced laminate consisting of an impregnated woven fiberglass high strength inner reinforcement sandwiched between two layers of a polymer modified bitumen, with a 1/4-mil Polyester top film
	10A-65 Easy Pave	Prefabricated reinforced laminate consisting of an impregnated woven fiberglass high strength inner mat sandwiched between two layers of a polymer modified bitumen, with a spun bonded polyester top mat
	108-ARN	Prefabricated consisting of a top layer of closely woven, high strength polypropylene fabric, and an adhesive layer of rubber modified bituminous compound reinforced with a non-woven fiberglass fabric
Groco Specialty Coatings	Si-Rex03 Silicone	silicone resin exterior paint
Henry Company	Modac	
PDI, Inc.	Plastic Dip UV 1800	protective coatings resist moisture, acids, abrasion, corrosion, skidding/slipping, and provide a comfortable, controlled grip. It remains flexible, stretchy and will not become brittle or crack in extreme weather conditions
Watson Bowman Acme Corp.	EP Elastic Waterproofing	
Aquron Corporation	Aquron CPT-2000	Sealant solution for new or old concrete installations that includes a highly reactive catalytic agent in waterborne proprietary colloidal silicate base that produces a silica-hydro gel below the surface and inside concrete's matrix that will seal the matrix and significantly preserve its imbedded steel
BASF Construction Chemicals, LLC	Enviroseal 40	Clear, water-based, 40% alkylalkoxysilane penetrating sealer.
Poly-Carb, Inc.	Mark-124	Two-component epoxy penetrating waterproofing sealer
Prosoco, Inc.	Consolideck Saltguard WB	Ready-to-use water-based, VOC compliant silane/siloxane water repellent and "chloride screen" for the protection of concrete and masonry surfaces
Xypex Chemical Corporation	Xypex Concentrate	Xypex is a unique chemical treatment for the water-proofing, protection and repair of concrete. Light grey powder is mixed with water and applied as a cementitious slurry coat as a single coat or as the first coat of a two-coat application.

PennDOT currently uses an inorganic zinc/epoxy/polyurethane system for new structural steel. and an organic zinc-rich epoxy/epoxy/polyurethane system for existing steel. The reason that organic zinc is used on existing steel is that organic zinc does not require as high of a level of cleaning and allows more room for error without having negative results to the coatings service life.

Table 13: Current Structural Steel Coating Systems in use by PennDOT

Structural Steel Coatings				
Company	Primer	Intermediate	Finish	System Description
Carboline Co.	Carbozinc 11 HS	Carboguard 893	Carbothane 133LH	Inorganic Zinc/Cycloaliphatic Amine Epoxy/ Aliphatic Acrylic-Polyester Polyurethane
	Carbozinc 859	Carboguard 888	Carbothane 133 LH	Organic Zinc-Rich Epoxy/ Epoxy Polyamide/ Aliphatic Acrylic-Polyester Polyurethane
Sherwin Williams Co.	ZincClad III HS	Macropoxy 646	Acrolon 218 HS	Organic Zinc-Rich Polyamide Epoxy/ Polyamide Epoxy/ Acrylic Polyurethane

Additionally, all 50 states' QPL were checked for listing of approved product for steel and concrete beam end treatments. While states use different ways to list QPLs and the categories under which the products are listed vary, Table 14 lists the most frequently mentioned companies for steel coatings, while Table 15 provides summary of the most frequently concrete products mentioned.

Table 14: Companies Mentioned in QPLs among Steel Coatings Manufacturers

Occurrence	Manufacturer
28	Carboline Company
26	The Sherwin Williams Company
22	International Paint, Inc.
17	PPG Industries, Inc.
12	ICI Devoe Coatings
10	Wasser Hi-Tech Coatings
5	Ameron Coatings
5	Tnemec
3	Indmar Coatings Corporation
1	Indurall Coatings Iin.
1	TriCom Coatings, Inc.

Table 15: Companies Mentioned in QPLs among Concrete Coatings Manufacturers

Occurrence	Product	Manufacturer
8	Enviroseal 40	BASF Construction Chemicals, LLC
	Tex-Cote 300 Bridge Cote	Textured Coatings of America, Inc.
	Texcote XL-70 Bridge-cote	Textured Coatings of America, Inc.
	Tammscoat	The Euclid Chemical Company
7	Sil-Act ATS-42	Advanced Chemical Technologies
6	Sil-Act ATS-100	Advanced Chemical Technologies
	Weather Worker J29A	Dayton Superior Specialty Chemical
	Powerseal 40	Vexcon Chemicals, Inc.
5	Hydrozo 100	BASF Construction Chemicals, LLC
	Hydrozo Silane 40 VOC	BASF Construction Chemicals, LLC
	DOT Acrylic Texture Coating	The Sherwin Williams Company
4	Permacoat	Dayton Superior Specialty Chemical
	Baracade Silane 40	The Euclid Chemical Company
	TK-590 Tri-Silane	TK Products
3	Aquanil Plus 40	ChemMasters
	TextureDOT	ChemMasters
	Thorocoat DOT	ChemRex, Inc
	Permacoat	Conspec
	Si-Rex03	Klaas Coatings, LLC
	Tammscoat	Tamms Industries
	Concrete Texture Coating	The Sherwin Williams Company
2	Sil-Act Multigard	Advanced Chemical Technologies
	Enviroseal 20	BASF Construction Chemicals, LLC
	Masterseal SL40 VOC	BASF Construction Chemicals, LLC
	Thorocoat	BASF Construction Chemicals, LLC
	Aquanil Plus 55	ChemMasters
	Duraguard System	ChemMasters
	Safe-Cure & Seal EPX	ChemMasters
	Enviroseal 40	ChemRex, Inc
	Deep Penetrating Sealer (DPS)	Evercrete Corporation
	FX-460	Fox Industries, Inc.
	Crete-Shield	Princeton Chemical, Inc.
	SikaPronto 19	Sika Corporation
	Tammoseal	Tamms Industries
	TextureDOT	The Sherwin Williams Company
	TK-290 WB	TK Products
	Powerseal 20	Vexcon Chemicals, Inc.

Table 15: Companies Mentioned in QPLs among Concrete Coatings Manufacturers (continued)

1	Sil-Act ATS-22	Advanced Chemical Technologies
	Sil-Act EP-700D	Advanced Chemical Technologies
	PROTECRETE (CDS)	Applied Concrete Technology, Inc.
	Masterseal CP	BASF Construction Chemicals, LLC
1	Thoroseal	BASF Construction Chemicals, LLC
	Aquanil Plus 100	ChemMasters
	Thorocoat	ChemMasters
	Thoroseal	ChemMasters
	Hydrozo Silane 40 VOC	ChemRex, Inc
	Masterseal SL40 VOC	ChemRex, Inc
	Thoroseal With Acryl 60	ChemRex, Inc
	ChemTec One	ChemTec International
	Conspec Silane 40	Conspec
	Weather Worker S-40	Dayton Superior Specialty Chemical
	Weather Worker WB Heavy Duty (J-27 WB)	Dayton Superior Specialty Chemical
	FX-432	Fox Industries, Inc.
	Enviroseal 40	Harris Specialty Coatings
	Weathguard P40 Sealer	Harris Specialty Coatings
	Dynasylan BH-N	Huls America, Inc.
	Mark-173.5	Poly-Carb Inc.
	Sikagard 550W Elastocolor	Sika Corporation
	Sikagard 62	Sika Corporation
	Sikagard 670W Clear	Sika Corporation
	Sikagard 701W	Sika Corporation
	Baracade 16	Tamms Industries
	Baracade Silane 100	Tamms Industries
	Baracade 16	The Euclid Chemical Company
	Baracade Silane 100	The Euclid Chemical Company
	Baracade WB 244	The Euclid Chemical Company
	CONCRETE FINISHER	The Euclid Chemical Company
	Dural 330	The Euclid Chemical Company
	Dural 335	The Euclid Chemical Company
	TAMMOSEAL SAND FINISH	The Euclid Chemical Company
	SW-244-100VOC	The Sherwin Williams Company
	ULTRACRETE SOLVENT BORNE SMOOTH & TEXTURED MASONRY COATING B46 SERIES	The Sherwin Williams Company
	ULTRACRETE TEXTURED MASONRY TOPCOAT A44W800	The Sherwin Williams Company
	Thoroseal	Thoro Systems
	Certi-Vex Penseal	Vexcon Chemicals, Inc.

3.6 Phone Interviews

In order to obtain more details about the products in use, new product testing and maintenance protocols, multiple series of follow-up interviews were made. During the first round of phone calls the following state departments of transportation and agencies were contacted: Alabama DOT, Arizona DOT, Arkansas DOT, Connecticut DOT, Florida DOT, Illinois DOT, Iowa DOT, Louisiana DOT, Maine DOT, Maryland DOT, Michigan DOT, Minnesota DOT, New York DOT, Oregon DOT, Rhode Island DOT, Wisconsin DOT, as well as KYTC Department of Highways and FHWA Structural Concrete Research Program Manager, together with industry representatives – see Table 16 for the exact list of people contacted.

While the summary of key points mentioned during the interview has been summarized in the following section, the following general comments can be made. None of the contacts that were reached were able to provide specific information on the products that their state uses. Instead, they directed the research team to the qualified products list (QPL) in order to obtain more specific information. All of the contacts mentioned that the products listed on their QPL have performed equally for them. Most of the contacts stated that the state does not coat the end of concrete beams, with exception to **Maryland**, **New York** and **Wisconsin**. The coatings that were stated to be used were an epoxy, an acrylic, or a silane sealant. Each state follows the 2-year inspection plan in accordance with FHWA guideline. Additionally, no state was testing any new products to prevent beam end deterioration.

The results of the phone survey emphasized that none of the respondents was aware of any new research being conducted on new products at this time and that the products currently in use and specified in QPLs are considered to be satisfactory.

Table 16: List of DOT Representative Contacted during the Phone Interviews

State/Company	Interviewee	Phone/Email	Specific Products	Res-ponded
Alabama	George H. Conner, P.E. State Maintenance Engineer	334-242-6272		No
Arizona	Brent Conner, Quality Assurance Engineer	602-712-8206		No
Arkansas	Michael Benson, Division Head	501-569-2185		No
Connecticut	Andrew J. Mroczkowski Product Evaluation Section	860-258-0399		Yes
Florida	Jeffery Gerr			
Illinois	David Lippert	217-782-7200	TK Products	No
Iowa	John Hart, P.E. District 1 Materials Engineer	515-239-1488		No

Table 16: List of DOT Representative Contacted during the Phone Interviews (continued)

Louisiana	Richie Charoenpap, Material Testing & Evaluation Administrator	225-248-4217	Special Surface Finish for concrete, new and existing steel	Yes
Maine	Roland Cote, Maine Department of Transportation Bridge Program	207-624-3490		Yes
Maryland	Charles Brown	410-545-8425		Yes
Michigan	Tim Stallard, Engineer of Materials Technology	517-322-6448		Yes
Minnesota	Jim Kochsiek, Materials Engineer	651-366-5534	TK Products BASF Products	Yes
New York	Pete Weycamp, Bridge Maintenance Group	518-457-8485		Yes
Oregon	Ivan Silbernagel, Coating Specialist	503-986-3018		No
Rhode Island	Michael Sock, Research and Technology	401-222-3030; Ext. 4114		Yes
Wisconsin	James Parry, Quality Assurance Unit Supervisor	608-246-7939		Yes
KYTC Dept. of Highways	Greta Smith	202-624-5815	Progress on NTPEP for Concrete?	
KYTC Dept. of Highways	Derrek Castle	502-564-3160	Progress on NTPEP for Concrete?	
FHWA, Structural Concrete Research Program Manager, Turner-Fairbank Highway Research Center	Benjamin Graybeal			
Carboline	Paul Sallers	302-383-7655		Yes
Sierra Corp, XX DIV	Mark		100% acrylic system used on a bridge in Minnesota 25-28 years ago	Yes
Dow Company				Yes

Summary of key points mentioned during the interviews:

RI DOT –Michael Sock

- RI almost exclusively follows NEPCOAT for steel (inorganic and organic zinc) http://nepcoat.org/qplarchive/abcnepcoat2011a.pdf
- RI uses the same products for new construction and maintenance with concrete
- 4 different concrete sealers, 1 film former and 3 penetrates; among these Crete Shield (water-based epoxy) can be applied after 3 weeks
- Concrete sealer requirements are per spec code 820/M12. RIDOT relies on the manufacturer's recommendation for curing age. RIDOT has their own test method to evaluate concrete coatings: http://www.dot.ri.gov/documents/research/PE/Lab_Test_Proc.pdf. However, they have not had any interest in a while.
- Might have looked at Use Fox industry coating products in the past, but currently use their products only for repairs
- The list of approved products needs updating
- RIDOT does not do their own cost analysis

Maine DOT – **Roland Cote**

- Concrete – Do not coat, mix design includes corrosion preventative chemicals.
    - Concrete deck is water proofed every other year
- Steel – All new steel is weathered (last 10ft is painted) or galvanized if it is over salt water
    - When painted zinc rich coating from NEPCOAT is selected
- A maintenance crew assesses the beams, there is no knowledge of any recoating being done
- NEPCOAT specifications are followed for approval and the names from the NEPCOAT QPL are associated with high quality

Minnesota DOT – **Jim Kochsiek**

- If they use anything for concrete it is an epoxy coat from Sherwin Williams (Listed on QPL)
    - Repair and repainting is done by a contractor
- Steel coatings are listed in the QPL and the contractor chooses which one to use
    - Sherwin Williams is a favored company for coatings
- All new beams are to be coated
- Annual inspections; the lifetime varies but his estimate was approximately 20 years.
- They are looking into a concrete epoxy plug system to prevent corrosion of the torched strands that are on the ends of the beams
- Would be interested in finding out results of the project

Maryland DOT – **Charles Brown**

- When concrete is coated either an epoxy or acrylic is used, these come from either Sherwin Williams or Fox Industries
  - Both were rated as performing the same
  - A contractor is used for maintenance and repairs
- New steel is coated with a zinc rich primer, which varies
  - Depends on the steel producer
- Evaluations and inspections are done every 2 years while recoating varies based upon the conditions of the beams

Michigan DOT – **Tim Stallard** & **Brian Beck**

- No concrete is coated
- Steel uses an Inorganic Zinc/Epoxy/Polyurethane system as seen on QPL
  - They do an accelerated corrosion test all coating perform just about even
  - A contractor is used for maintenance and repairs
- All new beams are coated
- Inspections are done every 2 years as by FHWA standards; beams usually are recoated between 10 to 30 years
- NTPEP is used for coating approvals and testing
- Any names on the QPL are associated with being good quality

Louisiana DOT – **Richie Charoenpap**

- Concrete beam ends are not coated. On the end face of the beam the concrete is ground down and an asphalt material is applied to prevent damage to the beam and help prevent water getting to it
- Steel is coated using a 3 coat zinc system
  - Contractor chooses from their QPL (all generally seem to perform evenly)
  - IOZ performs the best on new steel
  - OZ is the best for the field (has lower cleaning necessary so less chance for a bad bond is lowered)
- DOT maintenance crews are used up to a certain repair size (1 span of the bridge) otherwise it goes to a contractor
- New steel is coated; it is weathering steel and only the ends are coated
- New concrete is coated but only for aesthetics, not to prevent corrosion
- Inspections are done every 2 years
- Follow NTPEP testing standards then perform their own set of tests to verify results & that the particular batch of paint is good quality

New York DOT – **Pete Weycamp**

- Concrete is coated by a silane sealant in the casting yard.
- Steel uses zinc primer systems.
    - Companies he mentioned are Termarust Technologies, Sherwin Williams, and Watson Coatings.
    - For maintenance a high content calcium sulfonate is used, did not know a recoat time, but the originally coating systems last longer.
- Was unable to provide any other answers.

Wisconsin DOT – James Parry

- For concrete there is no set QPL they follow for coatings but they have set characteristics (from NTPEP)
    - Do not test in their own lab
- Steel coatings have a QPL all are equal (could not name anything specific)
- Maintenance is done by a contractor unless it is a minor spot repair then the DOT would take care of it
- All new beams are coated
- Inspections are every 2 years; recoated on a need basis
- Not looking into any new products.

Connecticut DOT – **Andrew Mroczkowski**

- Expected Call from John (call never received)

FHWA, Structural Concrete Research Program Manager, Turner-Fairbank Highway Research Center– **Benjamin Graybeal**

- Not aware of any current FHWA research on this topic.
- Suggested looking into work funded by Michigan DOT at Michigan Tech (Ahlborn) and Wayne State (Aktan) back nearly 10 years ago.

Dow Company

- Contacted to find out the cost of waterborne acrylic latexes, but they just make part of the coating. Research Team was referenced to any of the major distributors in order to find out this information such as Carboline Company or Sherwin Williams.
- Carboline contacted and Research Team was directed to the Pennsylvania representative, Paul Sallers
- Paul Sallers: general price range is $30-34 per gallon, but this can vary with larger projects. Each gallon typically covers 200 sq. ft.

4. Installation & Application Methods of Beam End Treatments

4.1 Concrete System Application Methods

Concrete requires proper surface preparation to ensure the best results from the coatings and systems that are aimed at extending the life of existing surfaces. New concrete requires that sufficient microstructural development has been reached prior to application of the protective system. The coating producer typically determines the necessary degree of hydration for concrete, as it varies with different types of coatings. In the concrete manufacturers survey, respondents were asked to provide necessary hydration times for their products. For example, *Evercrete Corporation* and *Sherwin Williams* replied that an ideal application is 28 days after the concrete pour. *Textured Coatings of America* responded that the necessary hydration is that no liquid water can be present on the surface. The hydration time necessary for *Pecora* products is when the moisture content is below 10%. Similarly, *Klass Coatings* recommended water content below 5%. *Pruett-Schaffer Chemical* products can be applied to damp or green concrete. Lastly, *Advanced Chemical Technolgies* reported a necessary 80% design strength to be reached before application of their products.

For existing concrete, proper surface preparation is required prior to application of any of the systems. Typical surface preparation methods include water-jetting/water-blasting/high water pressure, sandblasting, shot-blasting, scarifiers, grit-blasting, and grinding. Common application methods of the coatings and systems include brush, roller/paint roller, and airless spray. Surface preparation for sealers should remove all surface contaminants, form oils, and loose or incompatible previous coatings [15]. Concrete substrates need to be cured, sound, clean, dry and free from any form of contamination such as laitance, loose particles, oil, grease, curing compounds, shuttering oil and algae growth. This can be achieved by light grit blasting or high pressure water jetting. Water jetting is used to remove dust, friable material, water soluble contaminants, laitance, and efflorescence, and open the concrete with a suitable surface profile. Abrasive sandblasting propels abrasive particles at a high velocity to clean the surface of the concrete.

Surface preparation for patching involves removing the concrete area around the damaged region, typically with a chipping hammer, jackhammer or by water blasting. Any exposed reinforcement is cleaned and possibly treated with a corrosion inhibitor. For application of epoxy and urethane coating systems, ventilation is required and a level surface is typically required.

The surface preparation required for each type of coating reported in the concrete manufacturers survey can be found in Table 17. A large number of products recommended for treatment of concrete beam ends have waterjetting/waterblasting listed as an option for surface preparation of the substrate. Other popular methods reported in the survey were sandblasting and shotblasting. One penetrating sealer, *Sil-Act ATS-100LV*, and one surface sealer, *Sil-Act EP 700D*, reported that no surface preparation was needed. *Evercrete*

Corporation also noted that the surface must be free of dirt, paint, and oil. Other surface preparation methods reported by *Fox Industries* were SSPC-SP1 and ICRI CSP 2-3. SSPC-SP1 is cleaning of the old finish and ICRI CSP 2-3 is an International Concrete Repair Institute surface profile that can be achieved by mechanical means such as shotblasting or hydrodemolition [41,42].

Table 17: Surface Preparation as specified in Concrete Manufacturers Survey

Surface Preparation	Type of Coating				
	Penetrating Sealers	Surface Sealers	Membranes	Coatings	Combin. Systems
Waterjetting/Waterblasting/ High Water Pressure	3	3	4	6	2
Sandblasting	0	3	5	4	0
Shotblasting	0	3	5	3	0
Scarifiers	0	1	3	1	0
Chemical Cleaning	1	0	0	0	1
Gritblasting	0	1	3	1	0
Grinding	0	1	3	1	0
Hydroblasting	0	1	1	1	0
Scabbling	0	1	1	1	0
None	1	1	0	0	0
Other	1*	0	0	1**	1* 1**

* Must be free of dirt, paint, and oil
**SSPC-SP1, ICRI CSP 2-3

Many types of coatings can be placed with more than one type of application method. Surface sealers are applied with brush, roller, squeegee, or spray. High-build coatings are applied with brush, roller, squeegee or spray. Membranes are applied with brush, squeegee, roller, trowel, or spray. Overlays may be placed, troweled, screeded, sprayed, or seeded in one or more layers onto the concrete surface. Latex-modified concrete overlays require a roughened surface prior to installation. Prior to the placement of epoxy overlays, a single prime coat of epoxy should be worked into the cleaned substrate by brushing, troweling, or any other method that will thoroughly wet the substrate [3].

Recommended application methods for coating systems from the literature review and from the concrete manufacturers survey can be seen in Table 18 and Table 19, respectively. The applications methods of coating systems from the literature review indicated the appropriate application options that can be used for each system. The most preferred application method reported in the concrete manufacturers survey was airless spray, which is used for all the types of coatings recorded in the survey. Many respondents also reported roller/paint roller and brush as application method options for different coating systems. Air spray was only reported as an application method for two types of penetrating sealers, *Sil-Act ATS-100LV* (*Advanced Chemical Technologies Inc.*) and Penetrating Concrete Sealer: *SW DOT Concrete Sealer 100* (*Sherwin-Williams*). *Advanced Chemical Technologies* also claimed that their penetrating sealers and surface sealers could be applied with a squeegee or by pouring (*Sil-Act EP 700D* and *Sil-Act ATS-100LV*).

Table 18: Application Methods from Literature Review

Type of Coating	Application Method							
	Spray	Brush	Roller/Paint Roller	Squeegee	Pouring	Trowel	Screeded	Other
Penetrating Sealers								
Surface Sealers	X	X	X	X				
Membranes	X	X	X	X		X		
Coatings	X	X	X	X				
Combination Systems								
Overlays	X	X				X	X	

X - denotes acceptable application methods

Table 19: Application Methods from Concrete Manufacturers Survey

Type of Coating	Application Method						
	Airless Spray	Air Spray	Brush	Roller/Paint Roller	Squeegee	Pouring	Other*
Penetrating Sealers	4	2	1	3	1	1	0
Surface Sealers	2	0	3	3	1	1	0
Membranes	3	0	5	6	0	0	0
Coatings	7	0	5	8	0	0	0
Combination Systems	3	0	1	1	0	0	1

Other* Back roll after spray application

The equipment needed for the application methods above includes spray equipment, mixers, buckets, rollers, brushes, drills with mixing paddles, and squeegees. All of this equipment is not needed for each method, but depends on the application method for each product.

The curing times for each method reported as part of the concrete manufacturer survey is captured in Table 20. The majority of products require 0 to 4 hours to cure. A few of the reported surface sealers, coatings, and membranes require up to 24 hours cure. None of the coating types reported in the survey requires more than a week for curing time.

Table 20: Coating Curing Time from Concrete Manufacturers Survey

Type of Coating	Curing Time (hours)							
	0-4 hours	5-8 hours	12 hours	24 hours	> 24 hours	Days	1 week	> 1 week
Penetrating Sealers	3	0	0	1	0	0	0	0
Surface Sealers	2	0	0	2	0	0	0	0
Membranes	1	3	0	2	0	0	0	0
Coatings	3	1	1	2	0	1	0	0
Combination Systems	2	0	0	0	0	0	1	0

4.2 Steel System Application Methods

Both new and existing steel requires surface preparation prior to application of the system. New steel requires less intense surface preparation than existing steel. The different surface preparations are listed in Table 21 and include SP-2 (Hand Grade Tool Cleaning), SP-3 (Power Tool Cleaning), SP-11 (Power Tool-Bare Steel), SP-7 (Brush-off Blast), SP-6 (Commercial Blast), SP-10 (Near-White Metal Blast), SP-5 (White Metal Blast), and SP-12 (Water Jetting). The surface preparation for a system is often recommended by the manufacturer. SP-10 Near-White Blast was the most commonly recommended surface preparation, recommended by 23% of the steel manufacturers. Application of systems is more complicated because the best application method of the specific layer can change. The common application methods include brush, roller, air spray, and airless spray.

Most zinc-rich coatings are applied by airless spray and require agitation during the application to ensure that an even coating is applied. Even though airless spray is the most common application method, brush, roller, and air spray are also used for application. Each coating is applied to a specified dry film thickness, which is usually recommended by the manufacturers. The dry film thicknesses usually range from 3 mils up to 8 mils per layer for a steel coating. From the survey, most of the steel coating manufacturers recommended SP-10 (Table 21), near-white metal blasting, for the surface preparation of the steel. Curing time of the coatings can vary and are given by the manufacturers, but the most common curing time given from the survey varied from 0 to 8 hours.

Table 21: Surface Preparations for Steel

Surface Preparation Symbol	Surface Preparation Description
SSPC-SP-1	Cleaning of Old Finish
SSPC-SP-2	Hand-tool Cleaning
SSPC-SP-3	Power-tool Cleaning
SSPC-SP-11	Power Tool-Bare Steel
SSPC-SP-7	Brush-blast Cleaning
SSPC-SP-6	Commercial Blast Cleaning
SSPC-SP-10	Near-white Blast Cleaning
SSPC-SP-5	White Blast Cleaning
SSPC-SP-12	Water Jetting

5. Durability Characteristics of Beam End Treatments

5.1 Durability Characteristics of Concrete Systems

The durability of coatings was assessed based on variable temperature exposure, freeze-thaw exposure, direct sunlight, potential loss of color, potential loss of bond to substrate, and resistance to blistering, cracking, and/or chipping.

An analysis of the literature review provided durability characteristics of available coating protection systems. In general, surface sealers are affected by UV exposure and will wear under surface abrasion. Penetrating sealers, on the other hand, generally have good UV resistance and abrasion resistance [3].

According to the survey results obtained from the concrete manufacturers survey, a large number of the respondents claimed that the products had very good durability in all the areas that were included in the survey.

The penetrating sealer with water repellent silicates that was reported to last 41 to 50 years by *Evercrete Corporation* also had very good as the durability rankings in all the variables of interest for the survey. The two waterproofing membranes recommended by *Soprema* also had very good durability rankings to variable temperature exposure, freeze-thaw exposure, direct sunlight, potential loss of color, potential loss of the bond to the substrate, and resistance to blistering, cracking, and/or chipping.

The *Epoxy Plymastic 650* recommended by *Sherwin Williams* was reported to have poor durability in regards to direct sunlight and potential loss of color. *Fox Industries* products were reported to be very poor in the categories of potential loss of bond to substrate and potential loss of color. The Waterbased Epoxy by *Pruett-Schaffer Chemical Company* was given a poor direct sunlight durability ranking and a fair ranking in potential loss of color. *ChemMasters* indicated that their products have poor durability in regards to potential loss of color and potential loss of bond to substrate. In terms of the other durability considerations, including variable temperature exposure, freeze/thaw conditions, and resistance to blistering and cracking, the majority of the recommended products were reported to provide good or very good durability.

5.2 Durability Characteristics of Steel Systems

The durability of coatings was assessed on various factors which included, service life, variable temperature exposure, direct sunlight, potential loss of color, potential loss of bond to substrate, and resistance to blistering, cracking, and/or chipping.

The coating system considered the “golden standard”, an inorganic zinc primer with an epoxy mid-coat and a urethane top-coat, has been listed by many of the DOT’s and agencies on the survey as a coating system they use. They replied to the survey that the inorganic zinc system has a service life of 20 to 30 years. This matches testing that has been done by various organizations which found that the inorganic zinc system had a low amount of rust creepage and had a service life of about 30 years before major touch-up was required [43]. Results from the survey showed that the inorganic zinc system has good durability characteristics and performs well all around. Most notable from the results was that it had very good bond strength and was not very likely to lose bond to the substrate. The other coating systems listed by the DOT's typically had lower rankings in their durability characteristics. Another coating system that ranked similarly to the inorganic systems was an organic zinc system that was mentioned in the surveys.

6. Maintenance of Beam End Treatments

6.1 Concrete System Maintenance

Many coating systems and sealers should be frequently reapplied or repaired to maintain the performance of the system. Some coating treatments do not have specific time periods for reapplication, but rather, are repaired as needed. On the other hand, there are some coatings that need frequent maintenance and reapplication to maintain the performance of the system. While detailed responses are presented in Excel file (Survey.Results.Analysis.xlsx), the recommended maintenance plans from the concrete manufacturers survey for different coating systems are summarized in Table 22.

Table 22: Frequency of Preventive Maintenance Plan from Concrete Manufacturers Survey

Type of Coating	Maintenance Plan						
	None	Every 2 years	Every 3-5 years	Every 6-7 years	Every 8-10 years	Every 10-15 years	Every 15-20 years
Penetrating Sealers	1	0	0	0	2	1	0
Surface Sealers	0	0	0	0	4	0	0
Membranes	1	0	2	1	2	0	0
Coatings	1	0	0	1	4	2	0
Combination Systems	0	1	0	0	0	1	1

The majority of the coating systems require maintenance every 8 to 10 years. There were three products consisting of a penetrating sealer, a coating, and a membrane that did not have any preventive maintenance plan for the system. The coating and membrane were *Pruett-Schaffer Chemical Company* products: Waterbased Epoxy and Waterbased Asphalt Emulsion. The penetrating sealer was a deep penetrating sealer (DPS) manufactured by *Evercrete Corporation*. Combination systems ranged from a maintenance plan of every two years (*Evercrete Top Seal (TS)*) to a plan between 15 and 20 years (Si-Rex03 Silicone Resin Emulsion Paint (SREP)).

6.2 Steel System Maintenance

Steel coatings are maintained by full paint removal and repainting, partial paint removal and repainting, or over coating the current paint. Full paint removal is recommended when there is a large amount of rust covering the beam, exceeding the typical amount of 5% to 10%, which is when maintenance is highly recommended. From the survey results the steel manufacturers recommended doing maintenance work, which could be a simple inspection, on the coating systems every 3 to 8 years in order to help extend the service life, while reducing the cost. If maintenance work is done every 3 to 8 years it would usually consist of spot repairs and over-coating, which requires minimal surface preparation. Due to the minimal surface preparation there would be reduced cost in maintaining the beams. Over-coating is the least expensive method of maintaining the beams, as it requires minimal or no surface preparation and low amounts of paint. This method of maintaining the beams does entail higher labor costs though, due to the more frequent work being done. The other common method of maintaining the beams is to completely remove the coatings applied and reapply a new coating system. This method has higher costs due to the greater volume of paint and greater surface preparation required, but may have lower life-cycle costs because the maintenance does not have to be performed as often.

7. Concluding Remarks

Corrosion damage of beam/girder ends is a major problem and rehabilitation of beam ends has recently become increasingly of interest. One of the leading contributors and reasons for failure is water leaking through faulty expansion joints. This causes spalling of the concrete and ultimately leads to corrosion of the steel reinforcement. As such, joint preservation is an important component of extending the life of beam ends [17,20]. Additionally, beam end protection and treatments need to be applied to increase the life of the beam ends and enhance the infrastructure condition.

The existing data related to concrete beam end coatings and treatments are limited and there is an evident need to conduct a comprehensive laboratory comparison of the existing and newly proposed methods. This need has already been identified in other states, and the Kentucky Transportation Center recently started considering performing a laboratory study on concrete beam end coatings [10,38]. It should be noted here that concrete is a much more complex material than steel and its behavior is more difficult to accurately predict in time. Additionally, the effectiveness of the coating or treatment will also depend on mixture quality and age of concrete it is applied to [44].

Results from the literature review and the survey results indicate that most of the US states do not have beam end maintenance and preservation plans [17], and frequently there is a lack of differentiation between beam protection and beam-ends protection. However, for example, MDOT has a procedure for prestressed concrete I beam end repair with latex modified concrete [45].

The information gathered in this work about different coatings lack common test methods and approval procedures, which makes direct comparison not very applicable. However, based on the received information, the most recommended coating system for **steel beam end coatings** are:

- Inorganic Zinc Primer/Epoxy Mid Coat/ Polyurethane Top Coat
- Inorganic Zinc Primer/ Epoxy Mid Coat/ Urethane Top Coat
- Inorganic Zinc Primer/ Acrylic Mid Coat/ Acrylic Top Coat
- Organic Zinc Primer/ Epoxy Mid Coat/ Polyurethane Top Coat

In terms of **concrete beam end treatments**, the only interviewed DOT that specified a product was Iowa DOT using *Sikagard 62*. To develop a ranking of the products specified by concrete coatings manufacturers, survey questions were used to define ranking categories, as presented in Table 23. Next, the responses were ranked by assigning the highest score for the best performance. It has to be noted here that maximum rating for different categories varied between 3 and 5. Additionally, a raw 'weighted importance' was added allowing differentiating the importance of the rank by assigning different weights. Two case scenarios were considered: in the first one, all categories were considered as equally important resulting in top three products:

- Evercrete Deep Penetrating Sealer (Evercrete Corporation)
- TEXCOTE XL 70 BRIDGE COTE by Textured Coatings of America, Inc.
- TEXCOTE XL 70 BRIDGE COTE W/SILANE by Textured Coatings of America, Inc.

Next, a second scenario was analyzed (Table 24), where more emphasis was placed on time to first application, frequency of inspection, ease of application, service life and cure time (weight = 2) and cost (weight = 3). Based on these criteria, the top three products were:

- Evercrete Deep Penetrating Sealer (Evercrete Corporation)
- Waterbased Asphalt Emulsion (Pruett-Schaffer Chemical Co.)
- TEXCOTE XL 70 BRIDGE COTE by Textured Coatings of America, Inc.

It has to be mentioned here that this ranking was developed solely based on the input from manufacturers and not all the information of interest was available. As such, a comprehensive laboratory evaluation of concrete coatings is suggested, including the top products from concrete coating ratings presented here, but also *Sikagard-62* mentioned by Iowa DOT, as well as products offered by BASF and Euclid company that were most widely cited in the accessed QPLs.

Table 23: Ranking of Concrete Products Specified by Concrete Manufacturers (Scenario I)

Product Name	Manufacturer		History	Time to First Application	Frequency of Inspection	Ease of Application	Cost	Service Life	Cure Time	Durability to Variable Temperature Exposure	Freeze/Thaw Durability	UV Exposure	Loss of Color Durability	Loss of Bond Durability	Resistance to Cracking/ Chipping	Total Score max score: 62
		Performance Measures														
		Weighted Importance	1	1	1	1	1	1	1	1	1	1	1	1	1	
		Ranking	1 = 0 DOTs 2 = 1 - 5 DOTs 3 = 6 - 10 DOTs 4 = >10 DOTs	1 = >21 days 2 = 15 - 21 days 3 = 8 - 14 days 4 = 2 - 7 days 5 = 0 - 1 day	1 = 2 - 5 years 2 = 6 - 10 years 3 = 10-15 years 4 = 15-20 years 5 = None	1 = Professional 2 = Moderate 3 = Novice	1 = > $60/gal. 2 = $46 - $60 3 = $31 - $45 4 = $16 - $30 5 = $0 - $15	1 = 0 - 5 years 2 = 6 - 10 years 3 = 11 - 15 years 4 = 16 - 20 years 5 = >20 years	1 = 1 week 2 = days 3 = 9 - 24 hours 4 = 5 - 8 hours 5 = 0 - 4 hours	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	
Evercrete Deep Penetrating Sealer (DPS)	Evercrete Corporation		2	4	5	3	4	5	5	5	5	5	5	5	5	58
TEXCOTE XL 70 BRIDGE COTE	Textured Coatings of America, Inc.		4	5	3	2	4	3	5	5	5	5	4	5	5	55
TEXCOTE XL 70 BRIDGECOTE W/SILANE	Textured Coatings of America, Inc.		4	5	3	2	4	3	5	5	5	5	4	5	5	55
Waterbased Asphalt Emulsion	Pruett-Schaffer Chemical Co.		1	5	5	3	5	4	4	5	5	3	4	3	4	51
Penetrating Concrete Sealer: SW DOT Concrete Sealer 100	Sherwin-Williams		3	5	2	3	3	2	3	5	5	5	5	5	5	51
Evercrete Top Seal (TS)	Evercrete Corporation		2	4	1	3	4	1	5	5	5	5	5	5	5	50
Soprema Alsan Flashing	Soprema Inc.		1	5	1	3	2	4	4	5	5	5	5	5	5	50
Waterbased Epoxy	Pruett-Schaffer Chemical Co.		1	5	5	3	3	4	5	5	5	2	3	4	5	50
Soprema Alsan RS	Soprema Inc.		1	5	1	2	1	4	5	5	5	5	5	5	5	49
Dynapoxy Low Mod Epoxy	Pecora Corporation		3	3	2	1	4	3	5	5	4	5	4	5	5	49
Si-Rex03 Silicone Resin Emulsion Paint (SREP)	Klaas Coatings (North America) LLC		2	3	4	2	3	4	1	5	5	5	5	5	5	49
pecoraDeck P-808 primer Pecoradeck P-806 Top Coat	Pecora Corporation		3	3	2	1	3	3	4	5	5	5	4	5	5	48
Epoxy : Plymastic 650	Sherwin-Williams		3	4	2	2	2	4	2	5	5	2	2	5	5	43
FX-460 BREATHABLE MASONRY COATING SYSTEM	Fox Industries Inc.		3	2	3	2	1	4	5	5	5	5	1	1	5	42
Sil-Act ATS-100LV	Advanced Chemical Technologies Inc.		4	4	2	3	3	2	5	3	3	3	3	3	3	41
Safe-Cure & Seal EPX Duraguard 310CRU	ChemMasters		2	2	2	2	3	4	3	5	5	5	1	1	4	39
FX-498 HYDRO ESTER HIGH BUILD COATING	Fox Industries Inc.		3	1	2	1	3	3	3	5	5	5	3	1	4	39
Sil-Act EP 700D	Advanced Chemical Technologies Inc.		4	1	2	2	2	4	5	3	3	3	3	3	3	38
Epoxykote 100WB	ChemMasters		2	2	2	2	2	3	3	5	5	3	3	1	4	37

Table 24: Ranking of Concrete Products Specified by Concrete Manufacturers (Scenario II)

Product Name	Manufacturer	Performance Measures	History	Time to First Application	Frequency of Inspection	Ease of Application	Cost	Service Life	Cure Time	Durability to Variable Temperature Exposure	Freeze/Thaw Durability	UV Exposure	Loss of Color Durability	Loss of Bond Durability	Resistance to Cracking/ Chipping	Total Score max score: 62
		Weighted Importance	1	2	2	2	3	2	2	1	1	1	1	1	1	
		Ranking	1 = 0 DOTs 2 = 1 - 5 DOTs 3 = 6 - 10 DOTs 4 = >10 DOTs	1 = >21 days 2 = 15 - 21 days 3 = 8 - 14 days 4 = 2 - 7 days	1 = 2 - 5 years 2 = 6 - 10 years 3 = 10-15 years	1 = Professional 2 = Moderate 3 = Novice	1 = > $60/gal. 2 = $46 - $60 3 = $31 - $45 4 = $16 - $30 5 = $0 - $15	1 = 0 - 5 years 2 = 6 - 10 years 3 = 11 - 15 years	1 = 1 week 2 = days 3 = 9 - 24 hours 4 = 5 - 8 hours	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	1 = very poor 2 = poor 3 = fair 4 = good 5 = very good	
Evercrete Deep Penetrating Sealer (DPS)	Evercrete Corporation		2	4	5	3	4	5	5	5	5	5	5	5	5	88
Waterbased Asphalt Emulsion	Pruett-Schaffer Chemical Co.		1	5	5	3	5	4	4	5	5	3	4	3	4	82
TEXCOTE XL 70 BRIDGE COTE	Textured Coatings of America, Inc.		4	5	3	2	4	3	5	5	5	5	4	5	5	81
TEXCOTE XL 70 BRIDGECOTE W/SILANE	Textured Coatings of America, Inc.		4	5	3	2	4	3	5	5	5	5	4	5	5	81
Waterbased Epoxy	Pruett-Schaffer Chemical Co.		1	5	5	3	3	4	5	5	5	2	3	4	5	78
Evercrete Top Seal (TS)	Evercrete Corporation		2	4	1	3	4	1	5	5	5	5	5	5	5	72
Penetrating Concrete Sealer: SW DOT Concrete Sealer 100	Sherwin-Williams		3	5	2	3	3	2	3	5	5	5	5	5	5	72
Dynapoxy Low Mod Epoxy	Pecora Corporation		3	3	2	1	4	3	5	5	4	5	4	5	5	71
Soprema Alsan Flashing	Soprema Inc.		1	5	1	3	2	4	4	5	5	5	5	5	5	71
Si-Rex03 Silicone Resin Emulsion Paint (SREP)	Klaas Coatings (North America) LLC		2	3	4	2	3	4	1	5	5	5	5	5	5	69
Soprema Alsan RS	Soprema Inc.		1	5	1	2	1	4	5	5	5	5	5	5	5	68
pecoraDeck P-808 primer Pecoradeck P-806 Top Coat	Pecora Corporation		3	3	2	1	3	3	4	5	5	5	4	5	5	67
Sil-Act ATS-100LV	Advanced Chemical Technologies Inc.		4	4	2	3	3	2	5	3	3	3	3	3	3	63
Epoxy : Plymastic 650	Sherwin-Williams		3	4	2	2	2	4	2	5	5	2	2	5	5	61
FX-460 BREATHABLE MASONRY COATING SYSTEM	Fox Industries Inc.		3	2	3	2	1	4	5	5	5	5	1	1	5	60
Safe-Cure & Seal EPX Duraguard 310CRU	ChemMasters		2	2	2	2	3	4	3	5	5	5	1	1	4	58
Sil-Act EP 700D	Advanced Chemical Technologies Inc.		4	1	2	2	2	4	5	3	3	3	3	3	3	56
FX-498 HYDRO ESTER HIGH BUILD COATING	Fox Industries Inc.		3	1	2	1	3	3	3	5	5	5	3	1	4	55
Epoxykote 100WB	ChemMasters		2	2	2	2	2	3	3	5	5	3	3	1	4	53

Red Cells: Data not specified by producer, estimated based on data sheet

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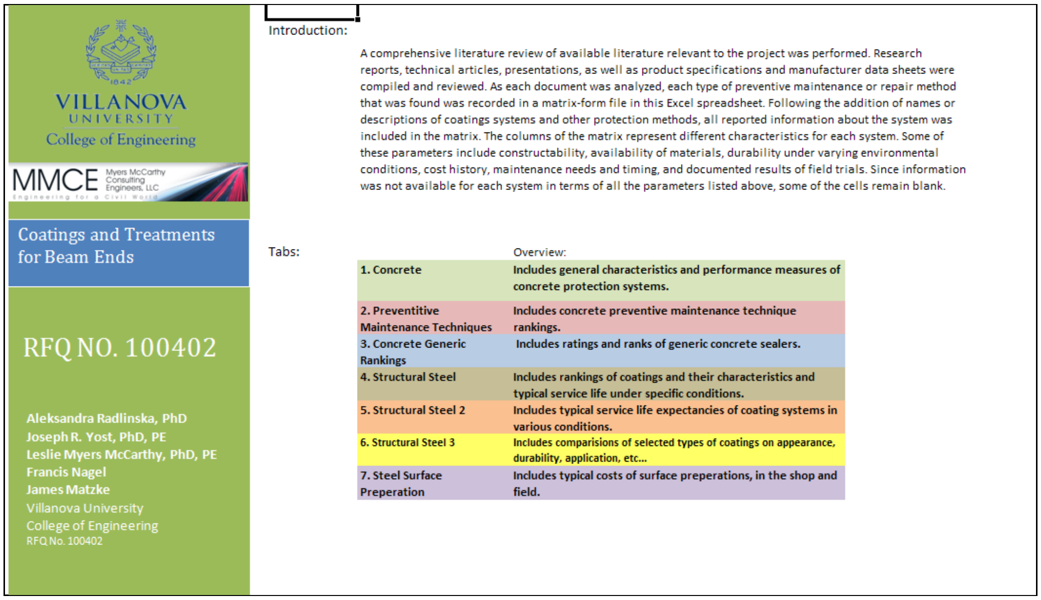
Appendix A: Matrix of Current Practices for Coatings and Paints on Beam Ends

Please note that the following section is intended for brief overview only, as the electronic file (LIT.REVIEW.2011.xlsx) has been attached to the report (Figure A1).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Coatings and Treatments for Beam Ends

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Introduction:

A comprehensive literature review of available literature relevant to the project was performed. Research reports, technical articles, presentations, as well as product specifications and manufacturer data sheets were compiled and reviewed. As each document was analyzed, each type of preventive maintenance or repair method that was found was recorded in a matrix-form file in this Excel spreadsheet. Following the addition of names or descriptions of coatings systems and other protection methods, all reported information about the system was included in the matrix. The columns of the matrix represent different characteristics for each system. Some of these parameters include constructability, availability of materials, durability under varying environmental conditions, cost history, maintenance needs and timing, and documented results of field trials. Since information was not available for each system in terms of all the parameters listed above, some of the cells remain blank.

Tabs:

	Overview:
1. Concrete	Includes general characteristics and performance measures of concrete protection systems.
2. Preventitive Maintenance Techniques	Includes concrete preventive maintenance technique rankings.
3. Concrete Generic Rankings	Includes ratings and ranks of generic concrete sealers.
4. Structural Steel	Includes rankings of coatings and their characteristics and typical service life under specific conditions.
5. Structural Steel 2	Includes typical service life expectancies of coating systems in various conditions.
6. Structural Steel 3	Includes comparisions of selected types of coatings on appearance, durability, application, etc...
7. Steel Surface Preperation	Includes typical costs of surface preperations, in the shop and field.

Figure A1: First Tab of LIT.REVIEW.2011.xlsx File

FILE DESCRIPTION:

Concrete Tab:

The concrete tab of the Excel literature review matrix is an extensive table that includes the general characteristics and performance measures of various coating protection systems. Different types of coatings and treatment techniques comprise the rows of the matrix. These types of protection systems were further subdivided into rows that describe more detailed products and descriptions within each class.

Concrete Generic Rankings:

When considering different types of sealers, there are a number of generic types available for use on bridge beams. The performances of various sealers in both laboratory and field evaluations show high variability not only among, but also within generic sealer groups. Laboratory testing was completed to help develop trends among the existing sealers. The testing methods included in the study were absorption, water vapor transmission, chloride penetration, freezing and thawing/deicer scaling, reinforcement corrosion, accelerated weathering, and carbonation. The sealers were ranked, relative to their performance in each test, and weighted on the basis of the number of products in the generic class and on the number of data sets for the generic class/test method combination. The result is a rating from

0 to 100 in the direction of improving performance. From these ratings, the systems were ranked for each test, with 1 being the top ranking. The last column is a weighted overall rating derived from all of the test methods studied. It is also important to note that the rankings represent average performances of the products and generic types in the various tests and that significant levels of variability are not uncommon. Based on these generic rankings, dual systems have the best ranking overall. Dual systems in this case consist of a penetrating primer with a pore blocker or barrier coating top coat. The most commonly used type of dual system consists of an alkylalkoxy silane primer and a polymethylmethacrylate top coat. In the order of decreasing overall ranking, the generic sealers rank in the following order; dual systems, gum resin, urethane, silane, chlorinated rubber, epoxy, silicone and siloxane, stearate, acrylic, linseed oil, silicate. (NCHRP Synthesis 209)

Preventive Maintenance Techniques:
A matrix was developed by MDOT specifically for distresses attributed to corrosion-induced deterioration from leaking transverse deck joints. The technical requirements selected as the governing criteria have the greatest impact on prestressed concrete I-beams in Michigan. The technical requirements included in this matrix were effectiveness of the approach method, durability, infrastructure requirements, and service life. A description of each technical requirement can be seen in the Preventive Maintenance Techniques Table. In addition to these technical requirements, a weight was assigned to each requirement based on its importance. Effectiveness was given the most weight, followed by infrastructure, durability, and then service life. Although outside the scope of this project, based on the criteria used in this matrix, transverse deck joint maintenance was the best overall approach. The next best overall preventive maintenance approach was surface coatings, which is of particular interest for this research study. However, despite the overall scores for each approach, the best preventive maintenance approaches do not necessarily provide the best performance in each of the technical requirements. Transverse deck joint maintenance and impressed current cathodic protection are the most effective approaches. In terms of durability, surface coatings provide the best performance. All of the approaches do not need infrastructure requirements with the exception of impressed current cathodic protection. Lastly, transverse deck joint maintenance, surface coatings, and impressed current cathodic protection provide the longest service life. (Causes and Cures of Prestressed Concrete I-Beam End Deterioration)

Structural Steel tab:
This portion of the excel file provides various information about coatings for steel. This includes the system description, the system's ability to adhere to old coatings, the service life, and surface preparation requirements. From this tab System 18B provides the best resistances, but not the best service life. The coating system with the highest life expectancy is galvanized steel coated with epoxy and urethane. When compared to other coatings it has a high initial cost, but due to its life time where no maintenance is needed it will have one of the lower life time costs. While galvanized steel may have the best life expectancy, it is not applicable to existing bridges, and therefore a different system must be analyzed for existing bridges. One of the best coatings that can easily be applied to existing structures is system 9, chlorinated rubber zinc/chlorinated rubber high-build/ chlorinated rubber finish.

Structural Steel 2 tab:

This portion of the excel file provides information about various systems that are applied to steel. This information primarily consists of life expectancies in varying conditions and surface preparation requirements. From this tab the system with the highest life expectancy is system 58, Zinc Metallizing/HB Epoxy/HB Epoxy. This system should be able to be applied to existing structures, but it may not be the most cost efficient since costs are not given in this table. Other coatings with similar life expectancy include 31a, 49, 53, 54, 56, 59, 60, 61, 63, 64, 70, 74, 76, and 103. Most of these coatings are able to be applied to both new and existing structures, but a few are only able to be applied to new structures.

Structural Steel 3 tab:

This portion of the excel file includes characteristics of different types of coatings for steel. These characteristics include hardness, flexibility, abrasion resistance, moisture transfer, weatherability, gloss retention, color retention, acid resistance, alkali resistance, solvent resistance, water resistance, temperature resistance, industrial application and maintenance application. It also includes application, appearance, and durability characteristics of some coatings. Finally a table including typical costs of some coatings is included. In this tab characteristics of coatings are displayed. Siliconized polyester, fluorocarbon, urethane-aliphatic two pack, and vinyl lacquer all display excellent characteristics overall, although each is slightly different. Urethane-aliphatic two pack and vinyl lacquer are both recommended for industrial and maintenance application, while siliconized polyester and fluorocarbon are only recommended for industrial application. Overall aliphatic urethane displays the best characteristics of the different coatings compared. Overall aliphatic urethane also has some of the lowest costs when compared to the other coatings shown, making it an excellent choice due to its excellent characteristics and low cost.

Steel Surface Preparation tab:

This portion of the excel file includes cost information of different types of surface preparation methods for steel. These cost tables are broken into sections by region and if the cleaning is taking place in the shop or the field. This tab shows different costs of different surface preparations. When a coating is specified it usually has a recommended surface preparation or multiple recommended surface preparations, but typically the best performance will come from the preparations closer to white blast cleaning.

Appendix B: Original Survey Content

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1. Pennsylvania Department of Transportation: Survey on Coatings and Treatment...

The purpose of this survey is to gather information on the best materials and application methods used by your organization for coatings and treatments of new and existing bridge beam ends.

This survey is designed to solicit valuable input regarding the types and performance of coating and treatment systems used by your agency for concrete and steel beam ends. It will assist the research team in providing recommendations to Pennsylvania Department of Transportation (PennDOT) regarding new and existing types of beam end coatings or treatments that have been proven to extend the life of new and existing concrete and steel bridge beams.

The survey has up to 37 questions and should take less than 25 minutes to complete.

The following definitions are used in this questionnaire:
• DOT: state department of transportation

A list of acronym definitions was provided to you in the email accompanying the survey announcement.

Thank you in advance for your participation in this timely project.

Villanova University, Department of Civil and Environmental Engineering

and

Myers McCarthy Consulting Engineers, LLC

Email: penndot.survey@villanova.edu

*1. Contact Information

Name	
Agency Name	
Phone Number	
Email Address	

2.

2. What type of deicing salt(s) is typically used in your state?

- [ ] Calcium Chloride
- [ ] Magnesium Chloride
- [ ] Potassium Chloride
- [ ] Sodium Chloride

Other

3. Treatment of Beam Ends on New Steel Structures

This section focuses on your agency's experience with coatings and treatment systems in use on New Steel Bridge beams ends.

3. Please list two of your agency's most frequently used coating or protection systems on bridge beam ends for New Steel Structures (System 1; System 2).

Primer:

Mid Coat:

Top Coat:

Other:

4. Please rate the typical durability of the coating products your agency most frequently uses for beam ends on New Steel Structures.

	Variable temperature exposure	Freeze-thaw exposure	Direct sunlight	Potential loss of color or sheen	Potential loss of bond to substrate	Resistance to blistering, cracking, and/or chipping
System 1						
System 2						

5. What is the typical life expectancy (in years) of the two coating systems for beam ends on New Steel Structures most frequently used by your agency?

	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+
System 1	○	○	○	○	○	○	○	○
System 2	○	○	○	○	○	○	○	○

6. What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on New Steel Structures?

System 1

System 2

7. How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on New Steel Structures?

	Very Easy	Easy	Moderate	Difficult	Very Difficult
System 1 (Primer)	○	○	○	○	○
System 2 (Primer)	○	○	○	○	○
System 1 (Mid Coat)	○	○	○	○	○
System 2 (Mid Coat)	○	○	○	○	○
System 1 (Top Coat)	○	○	○	○	○
System 2 (Top Coat)	○	○	○	○	○

8. What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on New Steel structures?

	Never	Not inspected	Periodic (as-needed)	Periodic (scheduled)	Frequent
System 1	◯	◯	◯	◯	◯
System 2	◯	◯	◯	◯	◯

9. Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on New Steel Structures.

System 1 (Primer) ____________________

System 2 (Primer) ____________________

System 1 (Mid Coat) ____________________

System 2 (Mid Coat) ____________________

System 1 (Top Coat) ____________________

System 2 (Top Coat) ____________________

4. Treatment of Beam Ends on Existing Steel Structures

This section focuses on your agency's experience with coatings and treatment systems in use on Existing Steel Bridge beams ends.

10. Does your agency use over-coating systems or paint removal and re-coating systems on Existing Steel bridge beam ends?

- ◯ Over-coating
- ◯ Partial Removal
- ◯ Complete Removal

Other (please specify)

11. Does your agency use the same treatment systems for beam ends on Existing Steel Structures as those you described in the previous section for New Steel Structures?

- ◯ Yes
- ◯ No

5.

12. Please list two of your agency's most frequently used coating or protection systems used on bridge beam ends for Existing Steel Structures (System 1; System 2).

Primer:

Mid Coat:

Top Coat:

Other:

13. Please rate the typical durability of the coating products your agency most frequently uses for beam ends on Existing Steel Structures.

	Variable temperature exposure	Freeze-thaw exposure	Direct sunlight	Potential loss of color or sheen	Potential loss of bond to substrate	Resistance to blistering, cracking, and/or chipping
System 1						
System 2						

14. What is the typical life expectancy (in years) of the two coating systems for beam ends on Existing Steel Structures most frequently used by your agency?

	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+
System 1	◯	◯	◯	◯	◯	◯	◯	◯
System 2	◯	◯	◯	◯	◯	◯	◯	◯

15. What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on Existing Steel Structures?

System 1

System 2

16. How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on Existing Steel Structures?

	Very Easy	Easy	Moderate	Difficult	Very Difficult
System 1 (Primer)	◯	◯	◯	◯	◯
System 2 (Primer)	◯	◯	◯	◯	◯
System 1 (Mid Coat)	◯	◯	◯	◯	◯
System 2 (Mid Coat)	◯	◯	◯	◯	◯
System 1 (Top Coat)	◯	◯	◯	◯	◯
System 2 (Top Coat)	◯	◯	◯	◯	◯

17. What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on Existing Steel structures?

	Never	Not inspected	Periodic (as needed)	Periodic (scheduled)	Frequent
System 1	○	○	○	○	○
System 2	○	○	○	○	○

18. Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on Existing Steel Structures.

System 1 (Primer)

System 2 (Primer)

System 1 (Mid Coat)

System 2 (Mid Coat)

System 1 (Top Coat)

System 2 (Top Coat)

19. Are there any new coatings or systems for Beam Ends on Steel Bridges that are being tested in your materials lab section or on experimental or demonstration projects in the field that are not yet listed on your approved products list? If so how have they been performing?

6. Treatment of Beam Ends on New Concrete Structures

This section focuses on your agency's experience with coatings and treatment systems in use on New Concrete Bridge beams ends.

20. Please list two coating system(s) or protection system(s) used most frequently by your agency on New Concrete Bridge beam ends (System 1; System 2).

Primer

Mid Coat

Top Coat

Other

21. Please rate the typical durability of the coating products your agency most frequently uses for beam ends on New Concrete Structures.

	Variable temperature exposure	Freeze-thaw exposure	Direct sunlight	Potential loss of color or sheen	Potential loss of bond to substrate	Resistance to blistering, cracking, and/or chipping
System 1						
System 2						

22. What is the typical time to the first application of the system?

	System 1	System 2
Hours		
1-7 Days		
8-14 Days		
15-21 Days		
22-28 Days		
29+ Days		

23. How do you determine when the necessary hydration time has been reached?

24. What is the typical life expectancy (in years) of the two coating systems for beam ends on New Concrete Structures most frequently used by your agency?

	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+
System 1								
System 2								

25. What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on New Concrete Structures?

System 1

System 2

26. How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on New Concrete Structures?

	Very Easy	Easy	Moderate	Difficult	Very Difficult
System 1 (Primer)	◯	◯	◯	◯	◯
System 2 (Primer)	◯	◯	◯	◯	◯
System 1 (Mid Coat)	◯	◯	◯	◯	◯
System 2 (Mid Coat)	◯	◯	◯	◯	◯
System 1 (Top Coat)	◯	◯	◯	◯	◯
System 2 (Top Coat)	◯	◯	◯	◯	◯

27. What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on New Concrete Structures?

	Never	Not inspected	Periodic (as needed)	Periodic (scheduled)	Frequent
System 1	◯	◯	◯	◯	◯
System 2	◯	◯	◯	◯	◯

28. Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on New Concrete Structures.

System 1 (Primer)

System 2 (Primer)

System 1 (Mid Coat)

System 2 (Mid Coat)

System 1 (Top Coat)

System 2 (Top Coat)

7. Treatment Systems for Beam Ends on Existing Concrete Structures

This section focuses on your agency's experience with coatings and treatment systems in use on Existing Concrete Bridge beams ends.

29. Does your agency use over-coating systems or paint removal and re-coating systems for beam ends on Existing Concrete Bridges?

- Over-coating
- Partial Removal
- Complete Removal

Other (please specify)

30. Does your agency use the same treatment systems for beam ends on Existing Concrete Structures as those you described in the previous section for New Concrete Structures?

- Yes
- No

8.

31. Please list two coating system(s) or protection system(s) used most frequently by your agency on Existing Concrete Bridge beam ends (System 1; System 2).

Primer

Mid Coat

Top Coat

Other

32. Please rate the typical durability of the coating products your agency most frequently uses for beam ends on Existing Concrete Structures.

	Variable temperature exposure	Freeze-thaw exposure	Direct sunlight	Potential loss of color or sheen	Potential loss of bond to substrate	Resistance to blistering, cracking, and/or chipping
System 1						
System 2						

33. What is the typical life expectancy (in years) of the two coating systems for beam ends on Existing Concrete Structures most frequently used by your agency?

	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+
System 1	○	○	○	○	○	○	○	○
System 2	○	○	○	○	○	○	○	○

34. What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on Existing Concrete Structures?

System 1

System 2

35. How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on Existing Concrete Structures?

	Very Easy	Easy	Moderate	Difficult	Very Difficult
System 1 (Primer)	○	○	○	○	○
System 2 (Primer)	○	○	○	○	○
System 1 (Mid Coat)	○	○	○	○	○
System 2 (Mid Coat)	○	○	○	○	○
System 1 (Top Coat)	○	○	○	○	○
System 2 (Top Coat)	○	○	○	○	○

36. What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on Existing Concrete Structures?

	Never	Not inspected	Periodic (as needed)	Periodic (scheduled)	Frequent
System 1	○	○	○	○	○
System 2	○	○	○	○	○

37. Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on Existing Concrete Structures.

System 1 (Primer)

System 2 (Primer)

System 1 (Mid Coat)

System 2 (Mid Coat)

System 1 (Top Coat)

System 2 (Top Coat)

38. Are there any new coatings or systems for Beam Ends on Concrete Bridges that are being tested in your materials lab section or on experimental or demonstration projects in the field that are not yet listed on your approved products list? If so how have they been performing?

39. Please share any additional comments or suggestions you have regarding PennDOT's efforts on this topic.

9. Survey is now complete

On behalf of the Pennsylvania Department of Transportation, Villanova University and MMCE would like to Thank You for your participation in the survey and your support of the research.

PennDOT - Concrete Manufacturer Survey

1. Pennsylvania Department of Transportation: Coatings and Treatments for Conc...

The purpose of this survey is to gather information on the best materials and application methods for coatings and treatments of new and existing bridge beam ends in the Commonwealth of Pennsylvania.

This survey is designed to assist the research team in recommending the best coating systems for beam ends to Pennsylvania Department of Transportation. It will support PennDOT's overarching goal to investigate new and existing types of beam end coatings or treatments that have been proven to extend the life of new and existing concrete and steel bridge beams.

The survey has 33 questions and should take less than 25 minutes to complete.

The following definitions are used in this questionnaire:
• DOT: state department of transportation

A list of acronym definitions was provided to you in the email accompanying the survey announcement.

Thank you in advance for your participation in this timely project.

Villanova University, Department of Civil and Environmental Engineering

and

Myers McCarthy Consulting Engineers, LLC

Email: penndot.survey@villanova.edu

*1. Contact Information

Name

Company Name

Phone Number

Email Address

2. PennDOT Survey on Coatings and Treatments for Concrete Bridge Beam Ends

The following questions relate to coating systems for new and existing concrete bridge beams. The focus is on beam ends that are often exposed to corrosion due leakage and joint deterioration.

***2. How many products and coating systems do you offer for use on concrete bridge beam ends?**

- ◯ 0-1
- ◯ 2-3
- ◯ 4-5
- ◯ 6-10
- ◯ 11 or more

***3. Are your products PennDOT approved?**

- ◯ Yes.
- ◯ No.

3.

4. Would you be interested in having your product become PennDOT approved? PennDOT APL website:ftp://ftp.dot.state.pa.us/public/pdf/BOCM_MTD_LAB/PUBLICATIONS/PUB_35/CS-4170.pdf

- ◯ Yes.
- ◯ No.

4.

5. What number of State DOTs list your products on their Qualified Products List (QPL)?

- ◯ None
- ◯ 1-5
- ◯ 5-10
- ◯ 10-20
- ◯ 20-30
- ◯ 30-40
- ◯ 40-50
- ◯ All states

6. Select the agencies that have used your product for at least 5 years. <check all that apply>

- [ ] None
- [ ] All state DOTs
- [ ] Alabama
- [ ] Alaska
- [ ] Arizona
- [ ] Arkansas
- [ ] California
- [ ] Colorado
- [ ] Connecticut
- [ ] Delaware
- [ ] District of Columbia
- [ ] Florida
- [ ] Georgia
- [ ] Hawaii
- [ ] Idaho
- [ ] Illinois
- [ ] Indiana
- [ ] Iowa
- [ ] Kansas
- [ ] Kentucky
- [ ] Louisiana
- [ ] Maine
- [ ] Maryland
- [ ] Massachusetts
- [ ] Michigan
- [ ] Minnesota
- [ ] Mississippi
- [ ] Missouri
- [ ] Montana
- [ ] Nebraska
- [ ] Nevada
- [ ] New Hampshire
- [ ]

- [ ] New Jersey
- [ ] New Mexico
- [ ] New York
- [ ] North Carolina
- [ ] North Dakota
- [ ] Ohio
- [ ] Oklahoma
- [ ] Oregon
- [ ] Pennsylvania
- [ ] Puerto Rico
- [ ] Rhode Island
- [ ] South Carolina
- [ ] South Dakota
- [ ] Tennessee
- [ ] Texas
- [ ] Utah
- [ ] Vermont
- [ ] Virginia
- [ ] Washington
- [ ] West Virginia
- [ ] Wisconsin
- [ ] Wyoming
- [ ] Other public transportation agencies (please list):

5. Recommended Coating Systems for use on Concrete Bridge Beam Ends in Pennsyl...

The next series of questions asks you to recommend two coating systems for use on concrete bridge beam ends in Pennsylvania. Some conditions of interest to PennDOT include wet/dry cycles, large amounts of deicing salt, and a variable temperature and humidity range.

You will be asked the same series of questions for Product 1 and Product 2.

7. Name or description of Recommended System 1 (including product name):

8. Name or description of Recommended System 2 (including product name):

9. What is the recommended surface preparation method for the systems?

	System 1	System 2
None	☐	☐
Water-jetting/Waterblasting/High water pressure	☐	☐
Sandblasting	☐	☐
Shotblasting	☐	☐
Hydroblasting	☐	☐
Scabbling	☐	☐
Scarifiers	☐	☐
Compressed air	☐	☐
Wire brushing	☐	☐
Breakers	☐	☐
Gritblasting	☐	☐
Grinding	☐	☐
Chemical cleaning	☐	☐
Chipping hammer	☐	☐
Jackhammer	☐	☐
Acid etching	☐	☐
Other	☐	☐

Other surface prep method recommended (please list):

10. Please provide the recommended application rate (in square-feet/gallon) for:

System 1? ____________

System 2? ____________

11. What is the typical time to first application of the system?

	System 1	System 2
Hours	☐	☐
1 Day	☐	☐
2-7 Days	☐	☐
8-14 Days	☐	☐
15-21 Days	☐	☐
22-28 Days	☐	☐
29+ Days	☐	☐

12. How do you determine when the necessary hydration has been reached?

____

13. What is the recommended application method for the system?

	System 1	System 2
Brush	☐	☐
Squeegee	☐	☐
Roller/paint roller	☐	☐
Trowel	☐	☐
Air Spray	☐	☐
Airless Spray	☐	☐
Flame Spray	☐	☐
Pouring	☐	☐
Other	☐	☐

Other application method recommended (please list):

____

14. What equipment is needed for application of:

System 1? ____________

System 2? ____________

15. What is the frequency of your recommended preventative maintenance plan (e.g. spot repairs, sealant reapplication, etc.)?

	None	Every 2 Years	Every 3-5 Years	Every 6-7 Years	Every 8-10 Years
System 1	○	○	○	○	○
System 2	○	○	○	○	○

Other frequency recommended:

____

16. What type of coating are the two recommended systems (check all that apply)?

	System 1	System 2
Penetrating sealers (silane, siloxane, drying oils, etc.)	☐	☐
Surface sealers (epoxies, acrylics, MMA, etc.)	☐	☐
Coatings (epoxies, urethanes, polyesters, acrylics, etc	☐	☐
Electrochemical methods (surface applied sacrificial anodes, impressed current cathodic protection, electrochemical chloride extraction)	☐	☐
Corrosion inhibitors (organic, inorganic, MCIs, calcium nitrate)	☐	☐
Admixtures (silica fume, fly ash, etc.)	☐	☐
Patching (shotcrete, Portland cement, etc.)	☐	☐
Reinforcing steel protection (zinc-rich paint, epoxy)	☐	☐
Overlays (polymer concrete, latex-modified concrete)	☐	☐
Membranes (urethanes, epoxies, acrylics, neoprenes)	☐	☐
Combination systems	☐	☐

Description of combination system:

17. How would you describe the ease of application for the coating systems?

	Novice	Moderate	Professional
System 1	○	○	○
System 2	○	○	○

Other

18. What is the number of coats required for each recommended system?

	1	2	3	4	5 plus
System 1	○	○	○	○	○
System 2	○	○	○	○	○

19. What is the typical depth of cover on a concrete beam (in inches)?

- ☐ 0.0-0.5
- ☐ 0.6-1.0
- ☐ 1.1-1.5
- ☐ 1.6-2.0
- ☐ 2.1-2.5
- ☐ 2.6-3.0
- ☐ 3.1+

20. What is the typical time to corrosion of the rebar?

21. Please provide the material cost in US$/gallon for:

System 1?

System 2?

22. What is the compatibility of the coating system with new and existing concrete bridges?

	System 1	System 2
Applied to new bridges only	☐	☐
Applied to existing bridges only	☐	☐
Applied to both new and existing bridges	☐	☐

23. What is the expected service life of the coating system (in years)?

	0-5	6-10	11-15	16-20	21-30	31-40	41-50	More than 50
System 1	○	○	○	○	○	○	○	○
System 2	○	○	○	○	○	○	○	○

24. What is the curing time of the coating system?

	System 1	System 2
0-4 hours	☐	☐
5-8 hours	☐	☐
12 hours	☐	☐
24 hours	☐	☐
More than 24 hours	☐	☐
Days	☐	☐
1 week	☐	☐
More than 1 week	☐	☐

25. What is the time to first recoating of the system?

	0-4 hours	5-8 hours	12 hours	24 hours	Weeks	Months	More than 1 year
System 1	○	○	○	○	○	○	○
System 2	○	○	○	○	○	○	○

26. What are the types of Maintenance and Protection of Traffic items needed for installation of the coating system?

	System 1	System 2
Nets to catch coating or treatment debris	☐	☐
Lane closures with detour alignment	☐	☐
Enclosed area of bridge (no special humidity)	☐	☐
Enclosed area of bridge (with humidifier)	☐	☐
Long tapers for lanes drops/transitions	☐	☐
Traffic control devices/pavement markings	☐	☐
Additional roadway illumination	☐	☐
Reflective barricades	☐	☐
Work limited to off-peak times	☐	☐

Other MPT items:

6. Coating Product Durability

The next series of questions relate to describing the durability (e.g., test values, specifications, conditions, etc.) of your two recommended coating products for concrete beam ends.

27. Please rate the typical durability of the coating system regarding the conditions listed below.

	Variable temperature exposure	Freeze-thaw exposure	Direct sunlight	Potential loss of color	Potential loss of bond to substrate	Resistance to blistering, cracking, and/or chipping
System 1						
System 2						

28. What type of deicing salt(s) is your system predominately exposed to?

	System 1	System 2
Calcium Chloride	☐	☐
Magnesium Chloride	☐	☐
Potassium Chloride	☐	☐
Sodium Chloride	☐	☐

Other

29. Which specifications do your coating systems conform to? (ex. AASHTO T-33, ASTM C-1581, Federal Specification, State Specification, etc.)

30. Please provide the dry film thickness of the coating (in units of mils)

System 1

System 2

31. What is the pull-off strength that describes the bonding properties of the coating (based on ASTM D7234-05)?

	Not tested	0-200 psi	200-400 psi	400-600 psi	600-800 psi	800-1000 psi
System 1	○	○	○	○	○	○
System 2	○	○	○	○	○	○

32. What was the type of pull-off failure for the coating system (based on ASTM D7234-05)?

	System 1	System 2
Not tested	☐	☐
Substrate failure (cohesive failure in the substrate)	☐	☐
Adhesive failure between the coating system and the substrate	☐	☐
Adhesive failure between the layers in the coating system	☐	☐
Cohesive failure in the coating system	☐	☐
Adhesive failure of the loading fixture adhesive	☐	☐

Other

33. What is the penetration potential that describes the ingress of chlorides of the coating system (based on ASTM C1152-04)?

	Very Low	Low	Moderate	High	Very High
System 1	○	○	○	○	○
System 2	○	○	○	○	○

PennDOT - Concrete Manufacturer Survey

7. Details or examples of recommended Coating Systems 1 and 2

Please provide any product safety data sheets or product specifications (if available) for the two coating systems recommended in this survey.

Also, we respectfully ask for copies or links to any published research results in journals, conference proceedings, or reports issued by independent laboratories that would support the goals of the PennDOT Coatings and Treatments of Beam Ends project.

34. Please submit any documents you wish to share to: penndot.survey@villanova.edu

35. Please share any additional comments or suggestions you have regarding PennDOT's efforts on this topic.

8. Survey is now Complete

On behalf of Pennsylvania Department of Transportation, Villanova University and MMCE would like to Thank You for your participation in the survey and your support of the research.

PennDOT - Steel Manufacturer Survey

1. Pennsylvania Department of Transportation: Survey on Coatings and Treatment...

The purpose of this survey is to gather information on the best materials and application methods for coatings and treatments of new and existing bridge beam ends in the Commonwealth of Pennsylvania.

This survey is designed to assist the research team in recommending the best coating systems for beam ends to Pennsylvania Department of Transportation. It will support PennDOT's overarching goal to investigate new and existing types of beam end coatings or treatments that have been proven to extend the life of new and existing concrete and steel bridge beams.

The survey has 32 questions and should take less than 25 minutes to complete.

The following definitions are used in this questionnaire:
• DOT: state department of transportation

A list of acronym definitions was provided to you in the email accompanying the survey announcement.

Thank you in advance for your participation in this timely project.

Villanova University, Department of Civil and Environmental Engineering

and

Myers McCarthy Consulting Engineers, LLC

Email: penndot.survey@villanova.edu

*1. Contact Information

Name

Company Name

Phone Number

Email Address

2. PennDOT Survey on Coatings and Treatments for Steel Bridge Beam Ends

The following questions relate to coating systems for new and existing steel bridge beams. The focus is on beam ends that are often exposed to corrosion due to leakage and joint deterioration.

***2. How many products and coating systems do you offer for use on steel bridge beams?**

- ◯ 0-1
- ◯ 2-3
- ◯ 4-5
- ◯ 6-10
- ◯ 11 or more

***3. Are your products PennDOT approved?**

- ◯ Yes.
- ◯ No.

3.

4. Would you be interested in having your product become PennDOT approved? PennDOT APL website:ftp://ftp.dot.state.pa.us/public/pdf/BOCM_MTD_LAB/PUBLICATIONS/PUB_35/CS-4170.pdf

- ◯ Yes.
- ◯ No.

4.

***5. Have the products gone through AASHTO National Transportation Product Evaluation Program (NTPEP) testing and been found compliant?**

- ◯ Yes.
- ◯ No.

5.

6. Have the products gone through AASHTO National Transportation Product Evaluation Program (NTPEP) testing and been found compliant?

- ◯ Yes.
- ◯ No.

6.

7. What number of State DOTs list your products on their Qualified Products List (QPL)?

- ◯ None
- ◯ 1-5
- ◯ 5-10
- ◯ 10-20
- ◯ 20-30
- ◯ 30-40
- ◯ 40-50
- ◯ All states

8. Select the agencies that have used your product for at least 10 years. <check all that apply>

- ☐ None
- ☐ All state DOTs
- ☐ Alabama
- ☐ Alaska
- ☐ Arizona
- ☐ Arkansas
- ☐ California
- ☐ Colorado
- ☐ Connecticut
- ☐ Delaware
- ☐ District of Columbia
- ☐ Florida
- ☐ Georgia
- ☐ Hawaii
- ☐ Idaho
- ☐ Illinois
- ☐ Indiana
- ☐ Iowa
- ☐ Kansas
- ☐ Kentucky
- ☐ Louisiana
- ☐ Maine
- ☐ Maryland
- ☐ Massachusetts
- ☐ Michigan
- ☐ Minnesota
- ☐ Mississippi
- ☐ Missouri
- ☐ Montana
- ☐ Nebraska
- ☐ Nevada
- ☐ New Hampshire
- ☐

- [ ] New Jersey
- [ ] New Mexico
- [ ] New York
- [ ] North Carolina
- [ ] North Dakota
- [ ] Ohio
- [ ] Oklahoma
- [ ] Oregon
- [ ] Pennsylvania
- [ ] Puerto Rico
- [ ] Rhode Island
- [ ] South Carolina
- [ ] South Dakota
- [ ] Tennessee
- [ ] Texas
- [ ] Utah
- [ ] Vermont
- [ ] Virginia
- [ ] Washington
- [ ] West Virginia
- [ ] Wisconsin
- [ ] Wyoming
- [ ] Other public transportation agencies:

9. Are your coating systems for steel bridge beam ends produced and applied within the United States?

- ○ Yes
- ○ No
- ○ Other (please specify)

7. Recommended Coating Systems for use on Steel Bridge Beam Ends in Pennsylvan...

The next series of questions asks you to recommend two coating systems for use on steel bridge beam ends in Pennsylvania. Some conditions of interest to PennDOT include wet/dry cycles, large amounts of deicing salt, and a variable temperature and humidity range.

You will be asked the same series of questions for System 1 and System 2.

10. Name or description of Recommended System 1 (including product name):

11. Name or description of Recommended System 2 (including product name):

12. What is the frequency of your recommended preventative maintenance plan (e.g. spot repairs, sealant reapplication, etc.)?

	None	Every 2 Years	Every 3-5 Years	Every 6-7 Years	Every 8-10 Years
System 1	○	○	○	○	○
System 2	○	○	○	○	○

Other frequency recommended:

13. What is the recommended surface preparation method for the product?

	System 1	System 2
None	☐	☐
SP-2 Hand Grade Tool Cleaning	☐	☐
SP-3 Power Tool Cleaning	☐	☐
SP-11 Power Tool-Bare Steel	☐	☐
SP-7 Brush-off Blast	☐	☐
SP-6 Commercial Blast	☐	☐
SP-10 Near-White Blast	☐	☐
SP-5 White Metal Blast	☐	☐
SP-12 Water Jetting	☐	☐

Other surface prep method recommended:

14. Please provide the recommended application rate (in square ft/gallon) for:

System 1 Primer

System 1 Mid coat

System 1 Top coat

System 2 Primer

System 2 Mid coat

System 2 Top coat

15. What is the recommended application method for the product?

	Brush	Roller	Air Spray	Airless Spray
System 1 Primer	☐	☐	☐	☐
System 1 Mid coat	☐	☐	☐	☐
System 1 Top coat	☐	☐	☐	☐
System 2 Primer	☐	☐	☐	☐
System 2 Mid coat	☐	☐	☐	☐
System 2 Top coat	☐	☐	☐	☐

Other application method recommended:

16. What equipment is needed for application of:

System 1 Primer?

System 1 Mid coat?

System 1 Top coat?

System 2 Primer?

System 2 Mid coat?

System 2 Top coat?

17. How would you describe the ease of application for the coating product?

	Novice	Moderate	Professional
System 1 Primer	○	○	○
System 1 Mid coat	○	○	○
System 1 Top coat	○	○	○
System 2 Primer	○	○	○
System 2 Mid coat	○	○	○
System 2 Top coat	○	○	○

Other

18. Please provide the material cost in US$/gallon for:

System 1?

System 2?

19. What is the compatibility of the coating with new and existing steel bridges?

	System 1	System 2
Applied to new bridges only	☐	☐
Applied to existing bridges only	☐	☐
Applied to both new and existing bridges	☐	☐

20. What is the expected service life of the coating product (in years)?

	0-5	6-10	11-15	16-20	21-30	31-40	41-50	More than 50
System 1	○	○	○	○	○	○	○	○
System 2	○	○	○	○	○	○	○	○

21. What is the curing time of the coating product (in hours)?

	0-4	5-8	12	24	36	48	More than 48
System 1 Primer	○	○	○	○	○	○	○
System 1 Mid coat	○	○	○	○	○	○	○
System 1 Top coat	○	○	○	○	○	○	○
System 2 Primer	○	○	○	○	○	○	○
System 2 Mid coat	○	○	○	○	○	○	○
System 2 Top coat	○	○	○	○	○	○	○

22. What is the time to first recoating of the product?

	0-4 hours	5-8 hours	12 hours	24 hours	Days	Weeks	Months	More than 1 year
System 1 Primer	○	○	○	○	○	○	○	○
System 1 Mid coat	○	○	○	○	○	○	○	○
System 1 Top coat	○	○	○	○	○	○	○	○
System 2 Primer	○	○	○	○	○	○	○	○
System 2 Mid coat	○	○	○	○	○	○	○	○
System 2 Top coat	○	○	○	○	○	○	○	○

23. What are the types of Maintenance and Protection of Traffic items needed for installation of the coating product?

	System 1	System 2
Nets to catch coating or treatment debris	☐	☐
Lane closures with detour alignment	☐	☐
Enclosed area of bridge (no special humidity)	☐	☐
Enclosed area of bridge (with humidifier)	☐	☐
Long tapers for lanes drops/transitions	☐	☐
Traffic control devices/pavement markings	☐	☐
Additional roadway illumination	☐	☐
Reflective barricades	☐	☐
Work limited to off-peak times	☐	☐

Other MPT items:

8. Coating Product Durability

The next series of questions relate to describing the durability (e.g., test values, specifications, conditions, etc.) of your two recommended coating products for steel beam ends.

24. Please rate the typical durability of the coating product regarding the conditions listed below.

	Variable temperature exposure	Freeze-thaw exposure	Direct sunlight	Potential loss of color	Potential loss of bond to substrate	Resistance to deicing chlorides and chemicals	Resistance to blistering, cracking, and/or chipping
System 1							
System 2							

25. What type of deicing salt(s) is your treatment predominately exposed to?

	System 1	System 2
Calcium Chloride	☐	☐
Magnesium Chloride	☐	☐
Potassium Chloride	☐	☐
Sodium Chloride	☐	☐

Other

26. Which specifications do your products conform to? Please list all that apply (Master Painters Institute, AASHTO M-69, ASTM A-703, Federal Specification, SSPC, State Specification, etc.)

27. Is the coating product VOC compliant?

	Yes	No
System 1 Primer	○	○
System 1 Mid coat	○	○
System 1 Top coat	○	○
System 2 Primer	○	○
System 2 Mid coat	○	○
System 2 Top coat	○	○

28. Is the coating product dry fall certified (for windy weather)?

	Yes	No
System 1	○	○
System 2	○	○

29. Please provide the dry film thickness of the coating (in units of mils)

	1-2 mils	3-4 mils	5-6 mils	7-8 mils	9-10 mils	10+ mils
System 1 Primer	◯	◯	◯	◯	◯	◯
System 1 Mid Coat	◯	◯	◯	◯	◯	◯
System 1 Top Coat	◯	◯	◯	◯	◯	◯
System 2 Primer	◯	◯	◯	◯	◯	◯
System 2 Mid Coat	◯	◯	◯	◯	◯	◯
System 2 Top Coat	◯	◯	◯	◯	◯	◯

30. What is the pull-off strength that describes the bonding properties of the coating product (based on ASTM D4541-09)?

	System 1	System 2
Not tested	☐	☐
0-300 psi	☐	☐
300-600 psi	☐	☐
600-900 psi	☐	☐
900-1500 psi	☐	☐
1500-2000 psi	☐	☐
2000-2500 psi	☐	☐
2500-3000 psi	☐	☐

31. What was the type of pull-off failure for the coating product (based on ASTM D4541-09)?

	System 1	System 2
Not tested	☐	☐
Substrate failure (cohesive failure in the substrate)	☐	☐
Adhesive failure between the coating system and the substrate	☐	☐
Adhesive failure between the layers in the coating system	☐	☐
Cohesive failure in the coating system	☐	☐
Adhesive failure of the loading fixture adhesive	☐	☐

Other

____

32. What is the penetration potential that describes the ingress of chlorides of the coating product (based on ASTM C1152-04)?

	Very Low	Low	Moderate	High	Very High
System 1	◯	◯	◯	◯	◯
System 2	◯	◯	◯	◯	◯

9. Details or examples of recommended coating Products 1 and 2

Please provide any product safety data sheets or product specifications (if available) for the two coating products recommended in this survey.

Also, we respectfully ask for copies or links to any published research results in journals, conference proceedings, or reports issued by independent laboratories that would support the goals of the PennDOT Coatings and Treatments of Beam Ends project.

33. Please submit any documents you wish to share to: penndot.survey@villanova.edu

34. Please share any additional comments or suggestions you have regarding PennDOT's efforts on this topic.

10. Survey is now Complete

On behalf of Pennsylvania Department of Transportation, Villanova University and MMCE would like to Thank You for your participation in the survey and your support of the research.

Appendix C: Detailed Results from Surveys Conducted

PennDOT Survey - Agencies and Organizations

Question 1

Contact Information		
Answer Options	**Response Percent**	**Response Count**
Name	100.0%	36
Agency Name	100.0%	36
Phone Number	97.2%	35
Email Address	97.2%	35
	answered question	36
	skipped question	1

Question 2

What type of deicing salt(s) is typically used in your state?		
Answer Options	**Response Percent**	**Response Count**
Calcium Chloride	42.9%	12
Magnesium Chloride	28.6%	8
Potassium Chloride	0.0%	0
Sodium Chloride	78.6%	22
Other		12
	answered question	28
	skipped question	9

Question 3

Please list two of your agency's most frequently used coating or protection systems on bridge beam ends for New Steel Structures (System 1; System 2).		
Answer Options	**Response Percent**	**Response Count**
Primer:	81.0%	17
Mid Coat:	76.2%	16
Top Coat:	81.0%	17
Other:	38.1%	8
	answered question	21
	skipped question	16

Question 4

Please rate the typical durability of the coating products your agency most frequently uses for beam ends on New Steel Structures.

Variable temperature exposure

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	9	4	1	14
System 2	0	1	0	5	3	0	9

Freeze-thaw exposure

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	10	3	0	13
System 2	0	1	0	5	3	0	9

Direct sunlight

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	2	11	0	1	14
System 2	0	1	2	6	0	0	9

Potential loss of color or sheen

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	6	6	2	0	14
System 2	0	0	4	3	2	0	9

Potential loss of bond to substrate

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	5	9	0	14
System 2	0	0	1	5	3	0	9

Resistance to blistering, cracking, and/or chipping

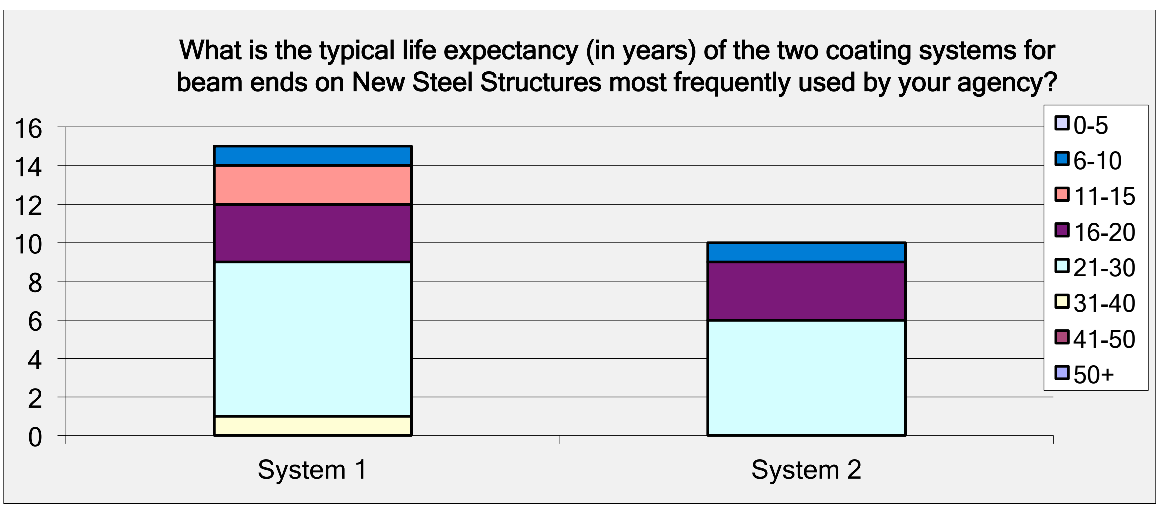
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	10	3	0	14
System 2	0	1	0	6	1	1	9

	Question Totals
answered question	14
skipped question	23

Question 5

What is the typical life expectancy (in years) of the two coating systems for beam ends on New Steel Structures most frequently used by your agency?

Answer Options	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+	Response Count
System 1	0	1	2	3	8	1	0	0	15
System 2	0	1	0	3	6	0	0	0	10
								answered question	16
								skipped question	21

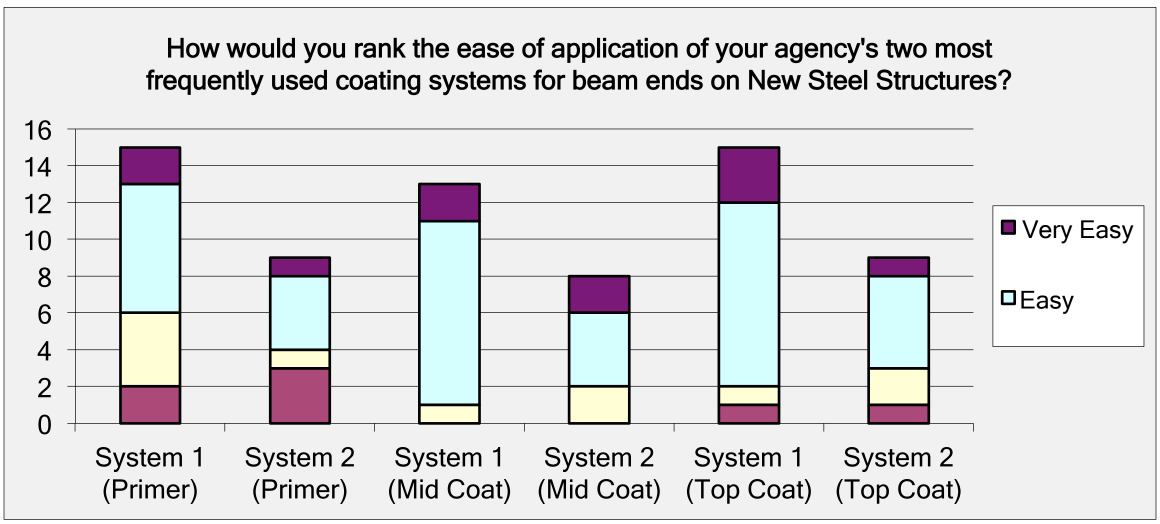


Question 6

What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on New Steel Structures?		
Answer Options	Response Percent	Response Count
System 1	100.0%	11
System 2	63.6%	7
	answered question	11
	skipped question	26

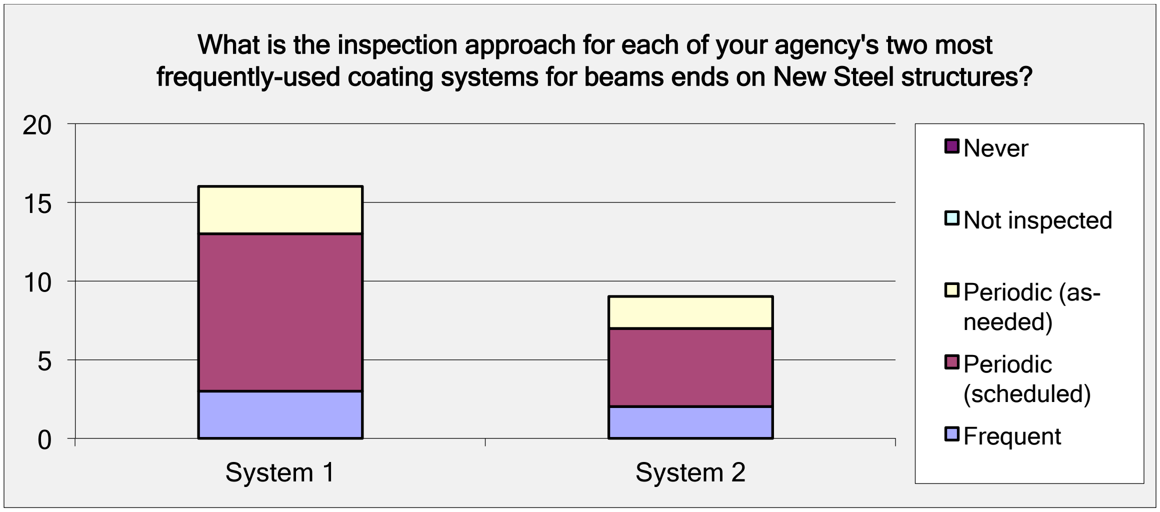
Question 7

How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on New Steel Structures?						
Answer Options	Very Easy	Easy	Moderate	Difficult	Very Difficult	Response Count
System 1 (Primer)	2	7	4	2	0	15
System 2 (Primer)	1	4	1	3	0	9
System 1 (Mid Coat)	2	10	1	0	0	13
System 2 (Mid Coat)	2	4	2	0	0	8
System 1 (Top Coat)	3	10	1	1	0	15
System 2 (Top Coat)	1	5	2	1	0	9
					answered question	15
					skipped question	22



Question 8

What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on New Steel structures?						
Answer Options	Never	Not inspected	Periodic (as-needed)	Periodic (scheduled)	Frequent	Response Count
System 1	0	0	3	10	3	16
System 2	0	0	2	5	2	9
					answered question	16
					skipped question	21



Question 9

Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on New Steel Structures.		
Answer Options	Response Percent	Response Count
System 1 (Primer)	90.9%	10
System 2 (Primer)	63.6%	7
System 1 (Mid Coat)	72.7%	8
System 2 (Mid Coat)	54.5%	6
System 1 (Top Coat)	63.6%	7
System 2 (Top Coat)	54.5%	6
	answered question	11
	skipped question	26

Question 10

Does your agency use over-coating systems or paint removal and re-coating systems on Existing Steel bridge beam ends?		
Answer Options	Response Percent	Response Count
Over-coating	13.3%	2
Partial Removal	6.7%	1
Complete Removal	80.0%	12
Other (please specify)		10
	answered question	15
	skipped question	22

Question 11

Does your agency use the same treatment systems for beam ends on Existing Steel Structures as those you described in the previous section for New Steel Structures?		
Answer Options	Response Percent	Response Count
Yes	43.8%	7
No	56.3%	9
	answered question	16
	skipped question	21

Question 12

Please list two of your agency's most frequently used coating or protection systems used on bridge beam ends for Existing Steel Structures (System 1; System 2).		
Answer Options	Response Percent	Response Count
Primer:	90.9%	10
Mid Coat:	90.9%	10
Top Coat:	90.9%	10
Other:	18.2%	2
	answered question	11
	skipped question	26

Question 13

Please rate the typical durability of the coating products your agency most frequently uses for beam ends on Existing Steel Structures.

Variable temperature exposure

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	6	2	0	8
System 2	0	0	1	3	0	0	4

Freeze-thaw exposure

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	6	1	0	7
System 2	0	0	1	3	0	0	4

Direct sunlight

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	2	4	2	0	8
System 2	0	0	2	2	0	0	4

Potential loss of color or sheen

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	3	4	1	0	8
System 2	0	0	2	2	0	0	4

Potential loss of bond to substrate

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	5	3	0	8
System 2	0	1	1	2	0	0	4

Resistance to blistering, cracking, and/or chipping

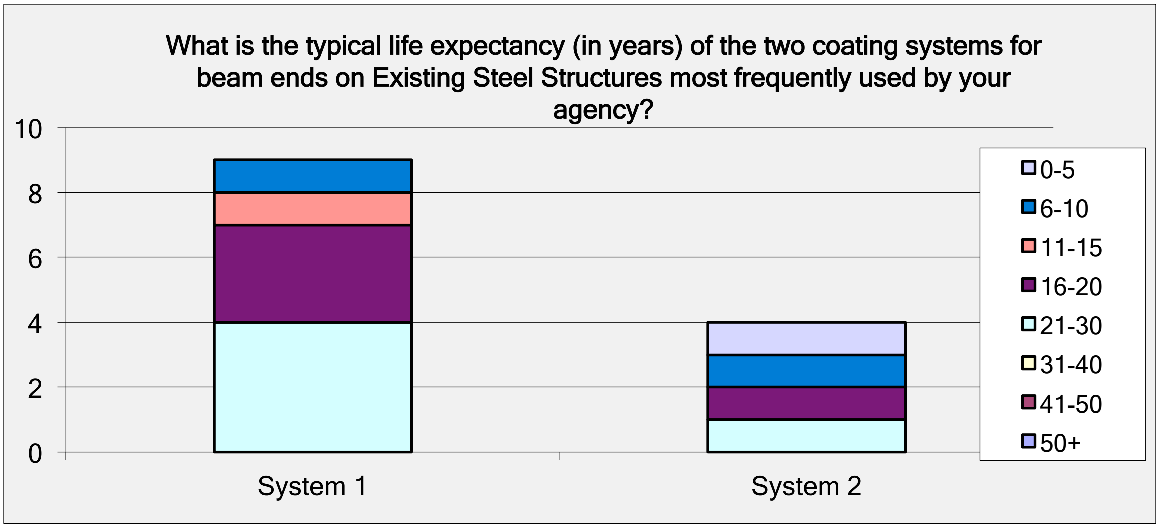
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	6	2	0	8
System 2	0	0	2	2	0	0	4

	Question Totals
answered question	8
skipped question	29

Question 14

What is the typical life expectancy (in years) of the two coating systems for beam ends on Existing Steel Structures most frequently used by your agency?

Answer Options	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+	Response Count
System 1	0	1	1	3	4	0	0	0	9
System 2	1	1	0	1	1	0	0	0	4
								answered question	9
								skipped question	28

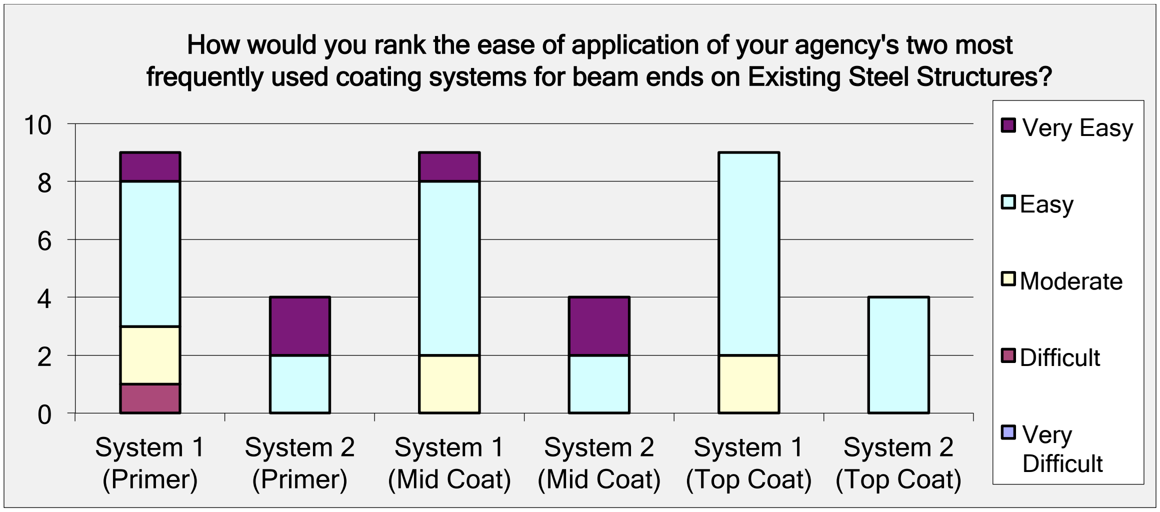


Question 15

What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on Existing Steel Structures?		
Answer Options	Response Percent	Response Count
System 1	100.0%	7
System 2	42.9%	3
	answered question	7
	skipped question	30

Question 16

How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on Existing Steel Structures?						
Answer Options	Very Easy	Easy	Moderate	Difficult	Very Difficult	Response Count
System 1 (Primer)	1	5	2	1	0	9
System 2 (Primer)	2	2	0	0	0	4
System 1 (Mid Coat)	1	6	2	0	0	9
System 2 (Mid Coat)	2	2	0	0	0	4
System 1 (Top Coat)	0	7	2	0	0	9
System 2 (Top Coat)	0	4	0	0	0	4
					answered question	9
					skipped question	28



Question 17

What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on Existing Steel structures?						
Answer Options	Never	Not inspected	Periodic (as needed)	Periodic (scheduled)	Frequent	Response Count
System 1	0	0	0	9	1	10
System 2	0	0	0	5	0	5
					answered question	10
					skipped question	27

Question 18

Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on Existing Steel Structures.		
Answer Options	Response Percent	Response Count
System 1 (Primer)	100.0%	5
System 2 (Primer)	80.0%	4
System 1 (Mid Coat)	60.0%	3
System 2 (Mid Coat)	60.0%	3
System 1 (Top Coat)	60.0%	3
System 2 (Top Coat)	40.0%	2
	answered question	5
	skipped question	32

Question 19

Are there any new coatings or systems for Beam Ends on Steel Bridges that are being tested in your materials lab section or on experimental or demonstration projects in the field that are not yet listed on your approved products list? If so how have they been performing?	
Answer Options	Response Count
	14
answered question	14
skipped question	23

Question 20

Please list two coating system(s) or protection system(s) used most frequently by your agency on New Concrete Bridge beam ends (System 1; System 2).		
Answer Options	**Response Percent**	**Response Count**
Primer	58.8%	10
Mid Coat	17.6%	3
Top Coat	23.5%	4
Other	47.1%	8
	answered question	17
	skipped question	20

Question 21

Please rate the typical durability of the coating products your agency most frequently uses for beam ends on New Concrete Structures.

Variable temperature exposure							
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	3	0	0	4
System 2	0	0	0	1	0	0	1
Freeze-thaw exposure							
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	2	0	0	3
System 2	0	0	0	1	0	0	1
Direct sunlight							
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	2	1	0	4
System 2	0	0	0	1	0	0	1
Potential loss of color or sheen							
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	2	1	0	4
System 2	0	0	0	1	0	0	1
Potential loss of bond to substrate							
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	3	0	0	4
System 2	0	0	0	1	0	0	1
Resistance to blistering, cracking, and/or chipping							
Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	4	0	0	4
System 2	0	0	0	1	0	0	1
							Question Totals
						answered question	4
						skipped question	33

Question 22

What is the typical time to the first application of the system?			
Answer Options	**System 1**	**System 2**	**Response Count**
Hours	0	0	0
1-7 Days	2	0	2
8-14 Days	0	1	1
15-21 Days	0	1	1
22-28 Days	1	0	1
29+ Days	3	0	3
		answered question	6
		skipped question	31

Question 23

How do you determine when the necessary hydration time has been reached?	
Answer Options	Response Count
	4
answered question	4
skipped question	33

Question 24

What is the typical life expectancy (in years) of the two coating systems for beam ends on New Concrete Structures most frequently used by your agency?									
Answer Options	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+	Response Count
System 1	1	3	0	1	0	0	0	0	5
System 2	1	0	0	0	0	0	0	0	1
								answered question	5
								skipped question	32

Question 25

What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on New Concrete Structures?		
Answer Options	Response Percent	Response Count
System 1	100.0%	5
System 2	40.0%	2
	answered question	5
	skipped question	32

Question 26

How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on New Concrete Structures?						
Answer Options	Very Easy	Easy	Moderate	Difficult	Very Difficult	Response Count
System 1 (Primer)	1	2	1	0	0	4
System 2 (Primer)	1	0	0	0	0	1
System 1 (Mid Coat)	0	1	0	0	0	1
System 2 (Mid Coat)	0	0	0	0	0	0
System 1 (Top Coat)	1	1	0	0	0	2
System 2 (Top Coat)	0	0	0	0	0	0
					answered question	5
					skipped question	32

Question 27

What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on New Concrete Structures?						
Answer Options	Never	Not inspected	Periodic (as needed)	Periodic (scheduled)	Frequent	Response Count
System 1	0	0	1	3	2	6
System 2	0	0	0	2	0	2
					answered question	6
					skipped question	31

Question 28

Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on New Concrete Structures.		
Answer Options	Response Percent	Response Count
System 1 (Primer)	100.0%	2
System 2 (Primer)	50.0%	1
System 1 (Mid Coat)	0.0%	0
System 2 (Mid Coat)	0.0%	0
System 1 (Top Coat)	0.0%	0
System 2 (Top Coat)	0.0%	0
	answered question	2
	skipped question	35

Question 29

Does your agency use over-coating systems or paint removal and re-coating systems for beam ends on Existing Concrete Bridges?		
Answer Options	Response Percent	Response Count
Over-coating	0.0%	0
Partial Removal	0.0%	0
Complete Removal	0.0%	0
Other (please specify)		11
	answered question	0
	skipped question	37

Question 30

Does your agency use the same treatment systems for beam ends on Existing Concrete Structures as those you described in the previous section for New Concrete Structures?		
Answer Options	Response Percent	Response Count
Yes	75.0%	6
No	25.0%	2
	answered question	8
	skipped question	29

Question 31

Please list two coating system(s) or protection system(s) used most frequently by your agency on Existing Concrete Bridge beam ends (System 1; System 2).		
Answer Options	Response Percent	Response Count
Primer	33.3%	1
Mid Coat	0.0%	0
Top Coat	0.0%	0
Other	66.7%	2
	answered question	3
	skipped question	34

Question 32

Please rate the typical durability of the coating products your agency most frequently uses for beam ends on Existing Concrete Structures.

Variable temperature exposure

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	0	0	0	1
System 2	0	0	0	1	0	0	1

Freeze-thaw exposure

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	1	0	0	0	1
System 2	0	0	0	1	0	0	1

Direct sunlight

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	1	0	0	1
System 2	0	0	1	0	0	0	1

Potential loss of color or sheen

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	1	0	0	1
System 2	0	0	0	1	0	0	1

Potential loss of bond to substrate

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	1	0	0	1
System 2	0	0	0	0	1	0	1

Resistance to blistering, cracking, and/or chipping

Answer Options	Very Poor	Poor	Fair	Good	Very Good	Excellent	Response Count
System 1	0	0	0	0	1	0	1
System 2	0	0	0	0	1	0	1

	Question Totals
answered question	1
skipped question	36

Question 33

What is the typical life expectancy (in years) of the two coating systems for beam ends on Existing Concrete Structures most frequently used by your agency?

Answer Options	0-5	6-10	11-15	16-20	21-30	31-40	41-50	50+	Response Count
System 1	0	0	0	1	0	0	0	0	1
System 2	0	0	0	1	0	0	0	0	1
								answered question	1
								skipped question	36

Question 34

What is the typical combined cost of the system (includes initial and maintenance) in $/year for beam ends on Existing Concrete Structures?

Answer Options	Response Percent	Response Count
System 1	0.0%	0
System 2	0.0%	0
	answered question	0
	skipped question	37

Question 35

How would you rank the ease of application of your agency's two most frequently used coating systems for beam ends on Existing Concrete Structures?						
Answer Options	Very Easy	Easy	Moderate	Difficult	Very Difficult	Response Count
System 1 (Primer)	1	0	0	0	0	1
System 2 (Primer)	0	1	0	0	0	1
System 1 (Mid	1	0	0	0	0	1
System 2 (Mid	0	0	0	0	0	0
System 1 (Top	0	0	0	0	0	0
System 2 (Top	0	1	0	0	0	1
					answered question	1
					skipped question	36

Question 36

What is the inspection approach for each of your agency's two most frequently-used coating systems for beams ends on Existing Concrete Structures?						
Answer Options	Never	Not inspected	Periodic (as needed)	Periodic (scheduled)	Frequent	Response Count
System 1	0	0	0	0	1	1
System 2	0	0	0	0	1	1
					answered question	1
					skipped question	36

Question 37

Please list any issues or challenges your agency has experienced with each of the coating systems regularly used for beam ends on Existing Concrete Structures.		
Answer Options	Response Percent	Response Count
System 1 (Primer)	0.0%	0
System 2 (Primer)	0.0%	0
System 1 (Mid Coat)	0.0%	0
System 2 (Mid Coat)	0.0%	0
System 1 (Top Coat)	0.0%	0
System 2 (Top Coat)	0.0%	0
	answered question	0
	skipped question	37

Question 38

Are there any new coatings or systems for Beam Ends on Concrete Bridges that are being tested in your materials lab section or on experimental or demonstration projects in the field that are not yet listed on your approved products list? If so how have they been performing?	
Answer Options	Response Count
	9
answered question	9
skipped question	28

Question 39

Please share any additional comments or suggestions you have regarding PennDOT's efforts on this topic.	
Answer Options	Response Count
	6
answered question	6
skipped question	31

Appendix D: Standard and Specifications Related to Evaluating Performance of Beam Ends Coatings and Treatments

ASTM Standards:

ASTM A36/A36M Specification for Carbon Structural Steel

ASTM A490 Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength

ASTM A572 Standard Specification for High-Strength Low-Alloy Columbium- Vanadium Structural Steel

ASTM B117-11 Standard Practice for Operating Salt Spray (Fog) Apparatus

ASTM C39/C39M-11a Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C42/C42M-11 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C67-03a Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile

ASTM C78/C78M-10 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

ASTM C109/C109M-11a Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

ASTM C156 - 11 Standard Test Method for Water Loss [from a Mortar Specimen] Through Liquid Membrane-Forming Curing Compounds for Concrete

ASTM C157/C157M-08 Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete

ASTM C190-85 Method of Test for Tensile Strength of Hydraulic Cement Mortars (Withdrawn 1990)

ASTM C227-10 Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)

ASTM C289-07 Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)

ASTM C295/C295M-11 Standard Guide for Petrographic Examination of Aggregates for Concrete

ASTM C309 - 11 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete

ASTM C348-08 Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars

ASTM C418-05 Standard Test Method for Abrasion Resistance of Concrete by Sandblasting

ASTM C469/C469M-10 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

ASTM C496/C496M-11 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

ASTM C512/C512M-10 Standard Test Method for Creep of Concrete in Compression

ASTM C531-00(2005) Standard Test Method for Linear Shrinkage and Coefficient of Thermal Expansion of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes

ASTM C580-02(2008) Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes

ASTM C642-06 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

ASTM C666/C666M-03(2008) Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

ASTM C672/C672M-03 Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals (Withdrawn 2012)

ASTM C779/C779M-05(2010) Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces

ASTM C793-04 Standard Test Method for Effects of Accelerated Weathering on Elastomeric Joint Sealants

ASTM C882-05 Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear

ASTM C944-99 Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method

ASTM C1012/C1012M-10 Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

ASTM C1042-99 Standard Test Method for Bond Strength of Latex Systems Used With Concrete By Slant Shear (Withdrawn 2008)

ASTM C1138-97 Standard Test Method for Abrasion Resistance of Concrete (Underwater Method)

ASTM C1152/C1152M-04e1 Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

ASTM C1181-00(2005) Standard Test Methods for Compressive Creep of Chemical-Resistant Polymer Machinery Grouts

ASTM C1202-10 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

ASTM C1231/C1231M - 10a Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

ASTM C1581/C1581M-09a Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage

ASTM C1583/C1583M-04e1 Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

ASTM D412-98a Standard Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers-Tension

ASTM D476 Classification for Dry Pigmentary Titanium Dioxide Pigments

ASTM D512 Test Methods for Chloride Ion in Water

ASTM D520 Specification for Zinc Dust Pigment

ASTM D521 Test Methods for Chemical Analysis of Zinc Dust (Metallic Zinc Powder)

ASTM D522-93a(2008) Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings

ASTM D523 Test Method for Specular Gloss

ASTM D562 Test Method for Consistency of Paints Measuring Krebs Unit (KU) Viscosity Using the Stormer-Type Viscometer

ASTM D570-98(2010)e1 Standard Test Method for Water Absorption of Plastics

ASTM D610 Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces

ASTM D638-10 Standard Test Method for Tensile Properties of Plastics

ASTM D696-08 Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C With a Vitreous Silica Dilatometer

ASTM D714 Test Method for Evaluating Degree of Blistering of Paints

ASTM D751-00 Standard Test Methods for Coated Fabrics

ASTM D822-01(2006) Standard Practice for Filtered Open-Flame Carbon-Arc Exposures of Paint and Related Coatings

ASTM D870-97 Standard Practice for Testing Water Resistance of Coatings Using Water Immersion

ASTM D882-10 Standard Test Method for Tensile Properties of Thin Plastic Sheeting

ASTM D968-05(2010) Standard Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive

ASTM D1475-98(2008) Standard Test Method For Density of Liquid Coatings, Inks, and Related Products

ASTM D1640 Test Methods for Drying, Curing, or Film Formation of Organic
Coatings at Room Temperature

ASTM D1652 Test Method for Epoxy Content of Epoxy Resins

ASTM D1653-03(2008) Standard Test Methods for Water Vapor Transmission of Organic Coating Films

ASTM D1654 Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments

ASTM D2073 Test Methods for Total, Primary, Secondary, and Tertiary Amine Values of Fatty Amines, Amidoamines, and Diamines by Referee Potentiometric Method

ASTM D2196 Test Method for Rheological Properties of Non-Newtonian Materials by Rotational (Brookfield-Type) Viscometer

ASTM D2243-95(2008) Standard Test Method for Freeze-Thaw Resistance of Water-Borne Coatings

ASTM D2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates

ASTM D2369-10e1 Standard Test Method for Volatile Content of Coatings

ASTM D2370-98(2010) Standard Test Method for Tensile Properties of Organic Coatings

ASTM D2371 Test Method for Pigment Content of Solvent-Reducible Paints

ASTM D2393-86 Test Method for Viscosity of Epoxy Resins and Related Components

ASTM D2471-99 Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins (Withdrawn 2008)

ASTM D2697-03(2008) Standard Test Method for Volume Nonvolatile Matter in Clear or Pigmented Coatings

ASTM D2698 Test Method for the Determination of the Pigment Content of Solvent-Reducible Paints by High-Speed Centrifuging

ASTM D2794-93(2010) Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)

ASTM D3273-00(2005) Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber

ASTM D3274-09e1 Standard Test Method for Evaluating Degree of Surface Disfigurement of Paint Films by Fungal or Algal Growth, or Soil and Dirt Accumulation

ASTM D3335 Test Method for Low Concentrations of Lead, Cadmium, and Cobalt in Paint by Atomic Absorption Spectroscopy

ASTM D3359-02 Standard Test Methods for Measuring Adhesion by Tape Test
ASTM D3363-05(2011)e1 Standard Test Method for Film Hardness by Pencil Test
ASTM D3718 Test Method for Low Concentrations of Chromium in Paint by Atomic Absorption Spectroscopy
ASTMD3723 Pigment Content of Water-Emulsion Paints by Low Temperature Ashing
ASTM D3960-05 Standard Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings
ASTM D4017-02(2008)e1 Standard Test Method for Water in Paints and Paint Materials by Karl Fischer Method
ASTM D4285 Test Method for Indicating Oil or Water in Compressed Air
ASTM D4400 Test Methods for Sag Resistance of Paints Using a Multinotch Applicator
ASTM D4417 Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel
ASTM D4541-09e1 Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
ASTM D4585-99 Standard Practice for Testing Water Resistance of Coatings Using Controlled Condensation
ASTM D4587-01 Standard Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings
ASTM D4940 Test Method for Conductimetric Analysis of Water-Soluble Ionic Contamination of Blasting Abrasives
ASTM D5095-91(2007) Standard Test Method for Determination of the Nonvolatile Content in Silanes, Siloxanes and Silane-Siloxane Blends Used in Masonry Water Repellent Treatments
ASTM D5860 - 95(2007) Standard Test Method for Evaluation of the Effect of Water Repellent Treatments on Freeze-Thaw Resistance of Hydraulic Cement Mortar Specimens
ASTM D5894-10 Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
ASTM D6133 Standard Test Method for Acetone, p-Chlorobenzotrifluoride, Methyl Acetate, or t-Butyl Acetate Content of Solventborne and Waterborne Paints, Coatings, Resins, and Raw Materials by Direct Injection into a Gas Chromatograph
ASTM D6580 Standard Test Method for the Determination of Metallic Zinc Content in Both Zinc Dust Pigment and in Cured Films of Zinc Dust Pigment and in Cured Films of Zinc-Rich Coatings
ASTM D6904-03(2007) Standard Practice for Resistance to Wind-Driven Rain for Exterior Coatings Applied on Masonry
ASTM D7091 Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals
ASTM D7234-05 Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers
ASTM E11 Specification for Wire-Cloth and Sieves for Testing Purposes
ASTM E96/E96M-10 Standard Test Methods for Water Vapor Transmission of Materials
ASTM E1349 Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional Geometry

ASTM G92 Practice for Characterization of Atmospheric Test Sites
ASTM G140 Standard Method for Determining Atmospheric Chloride Deposition Rate by Wet Candle Method
ASTM G153 - 04(2010) Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
ASTM G154-06 Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials
ASTM G155-04 Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

AASHTO Standards:

AASHTO M 300 Inorganic Zinc-Rich Primer
AASHTO TP 65 Non-Instrumental Determination of Metallic Zinc in Zinc-Rich Primer
AASHTO TP 66 Analysis of Structural Steel Coatings for Hindered Amine Light Stabilizers
AASHTO TP 67 Analysis of Structural Steel Coatings for Isocyanate Content

Federal Standards:

Fed. Std. No. 40 CFR 51.100(s) Volatile Organic Compound Definition
Fed. Std. No. 40 CFR 59.406(a) Volatile Organic Compound Compliance Provision
Fed. Std. No. 40 CFR Part 59, Subpart D, Section 59.400 Through 59.413 National Volatile Organic Compound Emission Standards for Architectural Coatings
Fed. Std. No. 40 CFR 261.24, Table 1 Maximum Concentration of Contaminants for the Toxicity Characteristic
Fed. Std. No. 595 Colors Used in Government Procurement

Other Standards:

ICRI Technical Guideline No. 210.3-2004 (formerly No. 03739), Guide to Using In-Situ Tensile Pull-Off Test to Evaluate Bond of Concrete Surface Materials

EPA Method 24: Determination of Volatile Matter Content, Water Content, Density, Volume Solids, and Weight Solids Of Surface Coatings

List of Abbreviations

AASHTO – American Association of State Highway and Transportation Officials
AASHTO SCOBS – AASHTO Subcommittee on Bridges and Structures
ACI – American Concrete Institute
AISC – American Institute of Steel Construction
APL – Approved Products List
ASTM – American Society for Testing and Materials
DOT – State Department of Transportation (State Highway Agency)
FRP – Fiber Reinforced Polymer
Ft – feet
HB - High Built
HMWM – High Molecular Weight Methacrylates
ICRI – International Concrete Repair Institute
KTC – Kentucky Transportation Center
MCU - Moisture-cured urethane
MMCE – Myers McCarthy Consulting Engineers
MPT – Maintenance and Protection of Traffic
NEPCOAT – Northeast protective Coating Committee
NTPEP – National Transportation Product Evaluation Program
psi – pounds per square inch
QPL – Qualified Products List
PMMA – polymethyl methacrylate
PU - Polyurethane
SSPC – The Society for Protective Coatings
VOC – Volatile Organic Compounds