Stainless Steel Prestressing Strands and Bars for Use in Prestressed Concrete Girders and Slabs

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STATE HIGHWAY ADMINISTRATION

Research Report

STAINLESS STEEL PRESTRESSING STRANDS AND BARS FOR USE IN PRESTRESSED CONCRETE GIRDERS AND SLABS

MORGAN STATE UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING

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16. Abstract
Corrosion decay on structures has continued to be a challenge in the scientific and engineering communities, where significant federal and state funds have been spent towards replacement or rehabilitation of bridges that were damaged by corrosion deterioration. In Maryland, a great portion of its yearly bridge funding allocation is spent on performing repairs and rehabilitations on its aging bridge inventory. In an effort to turn this trend around, SHA has tried to monitor problematic design practices and adjust present designs to avoid future maintenance issues. One area that has been particularly problematic for SHA is the deterioration of prestressed steel strands in prestressed concrete beams and girders. In fact, in recent years, SHA has had to perform emergency span replacements on two different bridges because the strands had deteriorated to such an extent that these spans posed serious safety concerns. One tactic SHA has used to remedy this issue has been to increase the concrete cover requirements beyond code requirements to help prevent the onset of deterioration. This will help, but comes at a price. The strands are less effective and more strands are often required. Therefore, this research consists of gathering and synthesizing information on how others have addressed this issue, especially as it relates to the deployment of other materials such as stainless steel prestressing strands that can be used in prestressed concrete girders and slabs given their inherent properties to provide durable corrosion protection and prevention of premature spalling or corrosion-induced cracking. To assess the use of stainless steel and other materials, a survey was conducted and disseminated to contractors, personnel at various departments of transportation, and construction industry personnel. This study presents a summary of various projects that have used corrosion- resistant rebar (CRR), a summary of what other states are doing to address this issue, and results from the survey to address how various states are addressing the issue of corrosion decay on structures.

17. Key Words
Stainless steel; corrosion; concrete structures; life-cycle cost analysis; alternative materials

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Acronyms and Abbreviations

CRR	Corrosion Resistant Rebar
DOT	Department of Transportation
ECR	Epoxy-Coated Rebar
FRP	Fiber Reinforced Polymer
FHWA	Federal Highway Administration
LCCA	Life-Cycle Cost Analysis
MMFX2	Microcomposite Multistructural Formable
SHA	Maryland State Highway Administration

EXECUTIVE SUMMARY

This final report synthesizes critical information about stainless steel and other remedies that have been used to replace corroded prestressing steel strands and bars or prolong the corrosion rate. Various cases studies and applications of these alternate materials to conventional steel are presented and summarized herein. Questions still remain unanswered for the overall long-term durability of these materials although preliminary numbers indicate a potential savings over the life-cycle of a structure if the materials are purchased in large quantities. Moreover, companies that manufacture and sell these materials have been identified in this report.

To assess the current state-of-the-practice and art of using alternate materials (often referred to as corrosion resistant rebar, CRR) and strategies to minimize the issue of corrosion, a survey was created and disseminated to various DOT personnel, precasters and mill representatives. From the survey, several questions needed to be addressed in order to meet the ***main objective*** of determining the feasibility and accessibility of stainless steel prestressing strands and bars as materials to be considered for use in prestressed concrete girders and slabs such as:

- What is the availability of the stainless strands?
- Can they be installed the same way? Same equipment?
- Is the strength and ductility the same?
- Would it make sense from a life-cycle cost perspective?
- Would it reduce current clear cover requirements that exceed AASHTO?
- Could the material be used in combination with regular prestressed strands?
- Is the use of stainless strands more economical than the use of hyper-dense impermeable concrete mixes such as silica fume blends?

The results to these questions are compiled in this final report along with a life-cycle cost analysis studies that have been produced to evaluate the efficacy of using stainless steel materials as viable options to replace conventional steel prestressing strands and bars for use in concrete girders and slabs.

Chapter 1: Introduction

1.1 Problem Statement

Corrosion decay of structures has continued be a challenge in the scientific and engineering communities. In 1997 alone, the Intermodal Surface Transportation Efficiency Act (ISTEA) spent $2.5 billion for the Highway Bridge Replacement Program, where a majority of the funds went towards replacement or rehabilitation of bridge decks that were damaged by corrosion deterioration. Of the estimated 600,000 bridges in the United States, more than 25% are classified as structurally deficient and functionally obsolete. This would require an estimated $9.4 billion a year for 20 years to repair these aging bridges (ASCE, 2005).

Fig. 1: Corrosion of rebar in a bridge deck overhang
Source: http://**www**.empire-solutions.com/bridges.html

The Maryland State Highway Administration (SHA) is not immune to this national crisis. Maryland spends a great portion of its yearly bridge funding allocation on performing repairs and rehabilitations on its aging bridge inventory. In an effort to turn this trend around, SHA has tried to monitor problematic design practices and adjust present designs to avoid future maintenance issues. One area that has been particularly problematic for SHA is deterioration of prestressed steel strands in prestressed concrete beams and girders. Previous studies have shown that inadequate structural details, improper construction practices, and low-quality materials have accounted for the vast majority of poor performance leading to corrosion of prestressed structures. It has been noted that epoxy-coatings may perform less than intended, and can lose adhesion once chlorides reach certain levels of the steel reinforcement (Sagues et al., 1994; Smith and Virmani, 1996; Manning 1996). As such, there is a need to use alternative protective measures like dense concretes, corrosion inhibitors, nonmetallic and steel-alloy corrosion-resistant reinforcement (CTRE, 2006).

SHA has performed emergency span replacements on two different bridges because the stands had deteriorated to such an extent that these spans posed serious safety concerns. What SHA has done to try to address future problems in this area is to increase concrete cover requirements beyond code requirements to help prevent the onset of deterioration. This will help, but comes at a price. The strands are less effective and therefore more strands are often required. Therefore, there exists a need to explore other materials such as stainless steel prestressing strands that can be used in prestressed concrete girders and slabs given their inherent properties to provide durable corrosion protection and prevention of premature spalling or corrosion-induced cracking.

1.2 Approach: Scope of Work and Objectives

This synthesis study was focused on gathering critical information to determine the feasibility and accessibility of stainless steel and other materials to be considered as alternative materials for use in prestressed strands in concrete girders and slabs. The main objectives of this project were to:

(1) Conduct an extensive literature survey of best demonstrated practices for use and availability of stainless steel strands,
(2) Contact manufacturers of stainless steel strands directly to verify research facts and get contacts of clients that have used the material. A survey to manufacturers is also planned to document information and experiences from different manufacturers,
(3) Identify other materials that may achieve similar results and be more advantageous such as carbon fiber strands, and
(4) Synthesize all information obtained and compile a document that evaluates the aforementioned questions, information gathered and lessons learned, including recommendations for future work, if applicable.

1.3 Methodology

This report is divided into five chapters. Chapter 1 presents the problem statement, scope of work and objectives of this study followed by an outline of the report. Chapter 2 provides background information in the form of a literature review on the various types of corrosion resistant rebar. Chapter 3 showcases the data from the survey in addition to the data collected from stainless steel manufacturers. Next, Chapter 4 presents information on life-cycle cost analysis. Lastly, Chapter 5 presents a summary of the work, recommendations, and a discussion of future work.

Chapter 2: Literature Review

2.1 Background on Corrosion Resistant Rebar (CRR)

Given the fact that steel corrodes in the presence of water and oxygen, various corrosion resistant rebar (CRR) are presented and evaluated for consideration as alternatives to conventional steel prestressing strands and bars. Details of the causes and effects of corrosion of prestressing steel can be found in a comprehensive study titled, *Report on Corrosion of Prestressing Steel (ACI 222.2R-14).* Table 1 provides a description of the bars as well as pros/cons reported by Bergmann and Schnell (2007):

1. epoxy-coated rebar,
2. galvanized steel,
3. Zn-ECR,
4. MMFx2 steel,
5. fiber reinforced polymer (FRP) bars,
6. stainless steel clad, and
7. solid stainless steel.

Table 1: Overview of various corrosion resistant rebar (CRR)

Rebar Material	Description	Pros/Cons	Image
Epoxy-coated (ECR)	epoxy-coated strand available in 2 configurations: coated and coated-and -filled	provides longer life than uncoated steel; poor bond with cement paste, fragility and adherence of coating	
Galvanized	protects steel from corrosive chemicals and provides sacrificial anodes	better bond to cement (compared to ECR), less fragile; limited life of coating; cannot be used with uncoated steel because coating will sacrifice itself to protect uncoated steel	
Zn - ECR	rebar is sprayed with molted zinc and epoxy	further tests are being done, very similar to ECR and galvanized; bond and fragility issues may be of concern	
MMFX2 Steel	low carbon chromium proprietary alloy	good bond, no fragility issues, 0.2% deformation yield; poor ductility and higher initial costs than ECR or Galvanized	

Rebar Material	Description	Pros/Cons	Image
FRP	composite materials made of a polymer matrix reinforced with fibers	estimated life expectancy of 65 to 100 years; low elastic modulus	
Stainless Steel Clad	stainless-clad under development but stainless-clad mild reinforcement has been used	need to cap cut ends to avoid corrosion of steel base; stainless-clad prestressed reinforcement remains in the research phase; limited availability in the U.S.	
Solid Stainless Steel	used successfully in corrosive environments	long life (~100 years), corrosion resistant, high strength with good ductility; no fragile coating and no need to cap ends; higher initial cost (2.5-4 x carbon steel)	

2.1.1 Epoxy-coated rebar (ECR) and prestressing bars

Epoxy-coated rebar (ECR) is used to protect conventional black steel from salts and other chemicals that may affect the rebar mats. However, due to its poor adherence, corrosive salts have been known to penetrate through ECR. Because of its thin layer and weaker chemical composition, ECR is only projected to have 5 to 10 years of additional life after the standard of carbon steel given that the epoxy-coating can get either peeled of or nicked due to weathering and/or handling. Sizes for these bars can range from 0.007 to 0.012 inches (ASTM A775/A775M).

Epoxy-coated prestressing bars possess high-strength and have been used for post-tensioning applications. They are coated according to ASTM A775/A775M, which is the same standard for epoxy coating of mild steel reinforcement (ACI 222.2R-14). Epoxy-coated prestressing bars can get damaged during transport and handling just like epoxy-coated rebar although a two-part liquid epoxy can be used on site to repair damaged coating.

2.1.2 Galvanized prestressing steel and strands

Galvanized prestressing steel is similar in function to that of epoxy-coated prestressing steel where it protects the bar from corrosive chemicals but the disadvantages are their limited life of the coating especially on high-strength steel and the reactivity with cement paste in a highly alkaline environment. As such, corrosion rates of zinc can be very high (ACI 222.2R-14).

While the use of galvanized prestressing strand is prohibited by FHWA for use in bridges, they have been used in Europe and Japan (ACI 222.2R-14). It is known that the galvanizing process can affect the material properties of the strand given its cold-drawn process, thereby potentially reducing tensile strengths and degrading relaxation properties. Galvanized seven-wire strands are available in 3/8 to 0.6 in. diameter and in standard grades (ACI 222.2R-14).

2.1.3 Zn-ECR and MMFX2 steel

Zn-ECR differs from ECR in that the rebar is first coated with molten zinc, and then the epoxy (i.e. 2-mil layer of arc-sprayed zinc and then epoxy). Based on a few tests, the molten zinc is suggested to be the only other form of rebar material that could withstand the life expectancy of stainless steel. Microcomposite Multistructural Formable (MMFX2) steel has also been posed as a corrosion resistant bar with a low chromium alloy of 9% with high tensile properties. Even though the lifespan is predicted to be longer than ECR and galvanized steel, and expected to have good bond towards the cement paste, the main drawback of this material is its sole source and poor ductility. Also, there are no actual calculations for the yield strength, yet it has been reported to exhibit high yield deformations on the order of 12%.

2.1.4 Fiber Reinforced Polymer (FRP) bars

FRP bars are also projected to last for 75 years or more. Some disadvantages of FRP (glass, carbon and aramid are common types of FRP) are its low elastic modulus (about 2 to 3 times less than steel) and poor bonding with cement paste. However, the flexible nature of FRP is not a total disadvantage. Full-scale tests of bridge decks tested by Pirayeh Gar et al. (2013) have revealed that prestressed and non-prestressed within a bridge deck can be engineered to satisfy AASHTO LFRD (2012) strength and deflection criteria. Several studies have been performed on the use of FRP bars in bridge decks with promising results (Erki et al., 1993; Balendran, 2002; Kawaguchi, 1993; Dolan, 1990). Of course, higher initial costs can be expected but most experts estimate a life span of 65 to 90 years in service conditions before the loss of strength is unacceptable (CITRE 2006).

2.1.5 Stainless Steel Clad

Researchers have found that stainless steel cladding serves as an excellent corrosion protection for carbon steel bars except at the cut ends where a cap is needed to minimize corrosion of the carbon steel base (Clemena et al., 2004). The results reflect that the clad bars and the stainless steel bars tolerate the same chloride concentrations without corroding. The threshold level of these bars was about 15 times that of the conventional carbon steel bar. The researchers found that stainless steel clad bars are just as corrosion resistant as pure stainless steel bars, which is helpful because it provides a favorable alternative at a lower cost than solid stainless steel (CTRE 2006). However, the use of stainless steel clad is still undergoing more research to validate its performance (ACI 222.2R-14), and there is limited availability of these materials in the United States (CITRE 2006).

2.1.6 Solid Stainless Steel

According to tests conducted by the Federal Highway Administration (1998), stainless steel rebar is expected to last for about 100 years in the northern states of America. The typical types of solid stainless steel are type 304, 316LN and type 2205, which are both very high in tensile strength with excellent fatigue characteristics. Grades 316LN and 2205, respectively, have good low-temperature toughness around -269 degree Celsius, where toughness is measured by impacting a small sample with a swinging hammer, and the distance by which the hammer swings after impact is the actual measure of toughness. The shorter the distance, the tougher the steel as the energy of the hammer is absorbed by the sample (Smith, 2007). Grades 316LN and 2205 have excellent corrosion resistance and can last over 100 years. On the other hand, Grade 304 is less corrosion resistant than the other two grades due to its Pitting Resistance Equivalent Numbers (PRENs).

The PRENs are equal to the percentage of the Chromium (Cr) plus 3.3 % of Molybdenum (Mo) plus 16% Nitrogen (N). Table 2 shows the percentage for each alloy and its known PRENs values. Alloys with higher PRENs have greater resistance to chloride pitting when the risk of the chloride is high on the concrete; in fact, it is better to select a bar material with high PREN for that reason. Note that Grade 316LN has a PREN value of 27 and Grade 2205 has a PREN value of about 34. "Reducing the future maintenance and/or repair costs of reinforced concrete structures thereby increases the life-cycle cost of the bridge and overall project costs, which is one advantage for using stainless steel rebar" (Smith, 2007). In addition, stainless steel rebar is ductile, has the capability of 3 times its diameter for bends, and can be welded together for the commonly used grades. Moreover, solid stainless steel does not need to be coated or covered (Smith, 2007). One disadvantage of the stainless steel rebar compared to other materials such as carbon steel is its cost. The cost of the stainless steel can be around $2.30/lb when installed compared to about $0.50/lb of carbon steel when installed (Schully, 2007). Talley Metals, a Carpenter Technology Corporation Company, has a lower cost stainless steel alloy called EnduraMet®32, which has been used as reinforcement in steel. EuduraMet®32 stainless has far exceeded proposed ASTM corrosion macrocell testing in a simulated pore solution given its 0.015 µm/year average compared to the ASTM requirement of 0.25 µm/year average. In short, prices can change (i.e. lessen) when larger quantities are ordered. For corrosion resistant rebar presented in general, there will be a higher initial cost, but will serve as an investment over the life-cycle cost of the structure.

Table 2: Chemical Composition of Stainless Steel Rebar

Alloy	UNS No.	Cr	Ni	C	Mo	N	PRENs
316LN	S31653	17	12	0.03	2.5	0.13	27
2205	S31803	22	5	0.03	3.0	0.14	34

2.2 Case Studies – Field Application of Stainless Steel

Common practice in construction has been to use conventional carbon steel reinforcement bars and concrete. In more recent years, DOTs have conducted pilot projects to monitor the benefits of using alternative materials such as stainless steel strands and rebar for reinforced concrete. Since a lot of these projects are fairly new, there is not a lot of evidence to support the claim that stainless steel rebar is better than conventional carbon steel. However, from a chemical aspect, there is a lot of evidence that explains how stainless steel rebar is more durable and less susceptible to harsh elements such as deicing salts and other chemically aggressive environments. Therefore, it will not corrode as quickly as carbon steel and this minimizes concrete deterioration.

In order to explore the possibilities of future reinforcing bar applications, experimentation must be conducted to rank the chloride thresholds of different types of steel rebar from most to least corrosion resistant. Researchers predicted that the material with the highest Pitting Resistance Equivalence Number (PREN) would be the material with the highest corrosion resistance (Smith, 2011). Potentiostatic laboratory test methods have been used to try to understand corrosion initiation and propagation stages of the steel rebar, but their hypothesis was disproved (Smith, 2011). Differences in the chloride thresholds did not only depend on material composition. Surface condition and the presence of any microstructural or physical defect can also alter the chloride threshold, which is affected by a variety of physical and environmental factors.

2.2.1 Woodrow Wilson Bridge (MD SHA/Virginia DOT)

The original Woodrow Wilson Bridge (WWB) was constructed in 1961 to carry Interstate 95/495 over the Potomac River and to connect Alexandria, Virginia to Washington, DC. The bridge had 6 lanes with very narrow shoulders and was designed to accommodate 75,000 vehicles daily. By the 1980's, the bridge had nearly twice the accident rate as similar highways in Maryland and Virginia. It was overwhelmed with at least 7 hours of traffic congestion and 200,000 vehicles daily (Ruddell, 2007). The narrow shoulders provided no space for motorists involved in accidents to pull over so there were frequent mile long backups daily. Extreme wear and tear on the almost 40-year-old bridge required the structure to be replaced in the near future. In 1988, the federal government, Maryland, Virginia and the District of Columbia initiated the planning to have the WWB replaced. The new WWB was opened to traffic in July 2006. The new bridge replaced nearly 12 percent of the Capital Beltway (Interstate 495/95) and created four new interchanges, resolving one of the worst bottlenecks on the East Coast. Contractors used about 1100 tons of stainless steel on the bascule spans of the bridge to prevent corrosion of this portion that could be caused by exposure to deicing chemicals and moisture from the river.

2.2.2 US 2 Bridge over Winooski River (Vermont Agency of Transportation)

In March 2009, Vermont Agency of Transportation made stainless steel reinforcing standard for bridge superstructures on high traffic pavements. The Agency classifies Vermont's roads into three levels. Level 1 and 2 includes non-paved roads and roads that are not on the National Highway System and epoxy-coated reinforcement is permitted. The third level is for heavily traveled pavements and stainless steel reinforcement is required. The Agency conducted a demonstration project with the Highways for Life (HFL) program to replace the US 2 Bridge over Winooski River in East Montpelier. This project involved rapidly removing a very narrow, failing, three-span two-lane concrete bridge on a key access route and replacing it with a single span integral abutment bridge. HFL contributed a $568,255 grant to the bridge replacement because of its innovation and reduced construction time. Key innovations include the use of weathering steel girders, a deck of bare High Performance Concrete (HPC) along with stainless steel reinforcement and curbless flush-mounted pedestrian rails. Also, the project was completed in one season instead of two and the traffic was maintained during construction by use of a two-way bypass bridge. This bypass bridge provided increased motorist and worker safety. The simple span design, use of stainless steel reinforcement and HPC provided a maintenance-free structure. This $2.84 million project was slated to save $975,000 in maintenance and replacement costs compared to the $94,500 initial increase in cost.

2.2.3 Missouri DOT

The Missouri DOT constructed its first cast-in-place bridge deck using stainless steel reinforcing bars in 2006 (Wenzlick, 2007). A control bridge was constructed using epoxy-coated rebar. The bridges had identical roadway lengths and girder spacing but different span lengths and skews. They were constructed on the same route, only about 600 feet apart from one another. These factors allowed for good evaluation of the durability and performance of the subject bridge deck in comparison to the conventional deck. Researchers hypothesized that the stainless steel reinforced bridge deck would be longer lasting. Only some preliminary, comparative results like the prices of rebar and the properties of the deck concrete were provided. It was reported that the black steel may have corroded because there was already some level of chloride in the concrete mix. The hypothesis was supported in that the stainless steel rebar was more beneficial to use because it did not corrode with time. However, these conclusions were drawn solely based on a visual inspection because the study did not yield as much data from the instrumentation that was installed as hoped.

2.2.4 Virginia Transportation Research Council (VTRC)

The Virginia Transportation Research Council (VTRC) conducted a project to search for metallic reinforcing bars that were durable and corrosion resistant, but also economical. The corrosion of carbon and epoxy-coated steel reinforcing bars has been the major cause of premature deterioration of many of our nation's concrete bridges (Clemena, 2003). The four alternative corrosion resistant rebar (CRR) types used in this research were (1) stainless steel-clad carbon steel bars, (2) MMFX-2 "microcomposite" steel bars, (3) the new 2101 LDX duplex stainless steel bars, and (4) carbon steel bars coated with a 2-mil layer of arc-sprayed zinc and then epoxy. The researchers embedded these bars into concrete blocks and subjected them to several weeks of ponding with a saturated salt solution and drying. They also did the same testing with two solid stainless steel bars (304 and 316LN) and a carbon steel bar (ASTM A615) for comparison. Researchers found that the presence of a macrocell current between the bars is a definitive indicator of the beginning of corrosion of a steel bar (Clemena, 2003). Researchers developed plots to display the weekly macrocell currents of concrete blocks with the different types of metallic to reflect that the black steel is the least corrosion resistant, of course. ***The pure stainless steel, clad and Zn/EC bars were the most and relatively equally corrosion resistant yet solid stainless steel can deliver optimum structural properties based on studies to date (CTRE 2006).***

2.2.5 New York State DOT

New York State DOT has designed a few bridges with solid stainless steel reinforcing in the deck for various reasons, where they offset some of the additional cost of solid stainless steel (combined with lightweight concrete in one case) by design efficiencies elsewhere in the project (CITRE 2006). The first example is the Alexander Hamilton Bridge, a steel riveted spandrel arch bridge over I-95 across the Harlem River. The project called for deck replacement, widening, steel rehabilitation and seismic upgrades given increased dead load thereby requiring significant reinforcement of the existing riveted steel spandrel arch ribs and spandrel columns. However, solid stainless steel reinforcing was deployed, making the addition of reinforcement unnecessary while reducing overall costs and construction time.

Another stainless steel project was the Undercliff Avenue Bridge, which supports a local street over the eastern approach to the Alexander Hamilton Bridge. The replacement structure needed to span more than 100 feed with welded plate girders that were 32 inches deep with spacing of less than 6 feet. However, the use of stainless steel reinforcement allowed for a 1 inch savings in the deck thickness to be applied to the girder depth, enabling one girder to be totally eliminated and reducing the overall cost of the project.

Similar to the Undercliff Avenue Bridge project, the Major Deegan Expressway Viaduct was in need of deck replacement, widening, steel rehabilitation and seismic upgrades as well. However, stainless steel reinforcing and lightweight concrete in the deck made the need for the estimated 16 new pile-supported foundations to be unnecessary, therefore, reducing the cost of the seismic upgrades.

2.2.6 Summary

In summary, each CRR has its advantages and disadvantages while comparing the benefit to the cost for a specific project. From the literature reviewed for this synthesis study, ***the pure stainless steel, clad and Zn/EC bars were the most and relatively equally corrosion resistant yet solid stainless steel can deliver optimum structural properties based on studies to date (CTRE 2006).*** It is important to note that the corrosion rates in bridge decks have been associated with the amount of cracking (Smith and Virmani, 1996; Fanous et al., 2000). As such, ways to minimize cracking can also be addressed in addition to finding other alternatives than employing CRR, which is addressed in the next chapter that showcases the survey results.

Chapter 3: Survey Assessment and Manufacturer Data

3.1 Survey Overview

A survey was designed to capture expert responses with a purpose to assess the state of practice for methods of corrosion protection of prestressed beams and girders with special emphasis on encounters and best practices of stainless steel rebar and/or strands. This 10-question survey was administered in October 2013 and 33 responses were received. The objective of conducting the survey was to document information and experiences pertaining to the feasibility and accessibility of stainless steel strands. The IRB-approved survey was administered (http://www.surveymonkey.com/s/PJKHRDD) and the results can be viewed online at https://www.surveymonkey.com/results/SM-33L523G/. A copy of the survey can be found in Appendix A of this report.

3.2 Target Audience

The survey was distributed in conjunction with representatives from the Concrete Division and Structural Materials Division of the SHA Office of Materials Technology. The target audience included employees of various DOTs, precast plants, academic institutions and engineering firms. Researchers were particularly interested in the responses rendered from the precasters and mill representatives given their first-hand experience with the cost and effectiveness of the corrosion resistant materials in question. The following is a list of the agencies and precast mills that participated in the survey:

- Connecticut Department of Transportation
- Louisiana Department of Transportation and Development (LA DOTD)
- Slaw Precast
- Arizona Dept. of Transportation (ADOT)
- Caltrans METS
- NDDOT
- Iowa DOT
- ILL Depart of Transportation
- Kansas DOT
- Utah DOT
- State of Maine Department of Transportation
- WVDOH
- Central Atlantic Bridge Associates
- Northeast Prestressed Products
- Washington State DOT
- KY Department of Highways
- Minnesota DOT - Bridge Office
- North Dakota Department of Transportation
- State of Alaska Dept. of Transportation and Public Facilities
- Saskatchewan Highways and Infrastructure
- Nebraska Department of Roads
- PennDOT

From the survey, respondents from 17 states participated in the survey and provided feedback (Fig. 2). It is important to note that the responses were throughout the United States with feedback from states that do experience snow and other freeze-thaw conditions by which salts and other deicing salts are used on roadways and bridge decks that can accelerate corrosion of rebar, and the need to find alternative solutions with corrosion-resistant rebar.

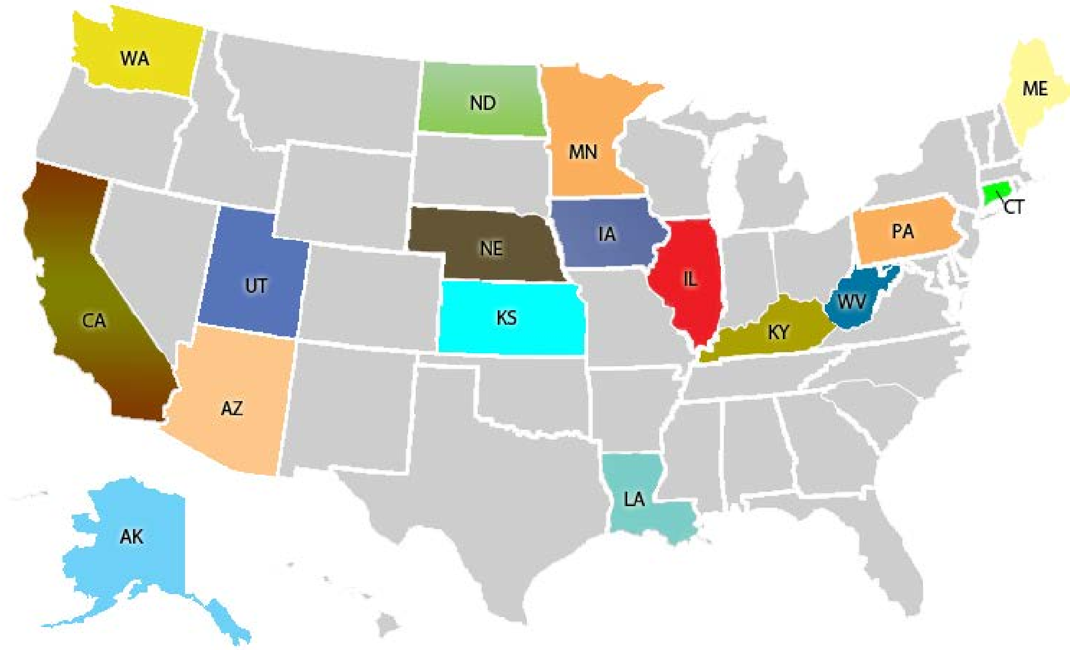

Fig. 2: Representation of survey respondents by state

3.3 Findings: Survey Analysis and Results

Very useful data was extracted from the survey responses. The questions started general inquiries about corrosion protection methods and went on to ask specifically about the respondents' experience with stainless steel rebar. Overall, it seemed that the majority of respondents were either not familiar with and/or did not have much experience with the use of stainless steel rebar, so information was also extracted on alternative strategies besides deployment of CRR to reduce cracking and therefore potential corrosion rates.

The first and last questions asked about the respondents' occupation and contact information so the technical results will come from questions 2-9. Graphical representations of the survey responses can be found in Figures 3-10. The highest recommended strategies to minimize cracking of precast elements are minimizing curing times and using curing methods. Ranking of the effectiveness and financial benefit of these strategies on a scale of 1-8 can be found in Figures 11 and 12 as well as Appendix B for additional graphs of the data collected. The most used or recommended strategies to prevent corrosion of reinforcement in bridge elements was reported to be through using epoxy-coated rebar, lowering permeability concrete and increasing clear cover depth. Some other examples include using High Performance Concrete (HPC or higher strength concrete as indicated in the survey) to reduce cracking of bridge decks by reducing heat of hydration and slowing strength gain. Of course, this results in slower curing times as well as higher initial costs, in general. Ranking of the effectiveness and financial benefit of these strategies on a scale of 1-10 can be found in Figures 13 through 15. ***However, fifty-four percent (54%) of the respondents would not pay to use stainless steel on a project. It was expressed from the survey that stainless steel should only be used for projects that require a larger quantity of reinforcement because of its high price.***

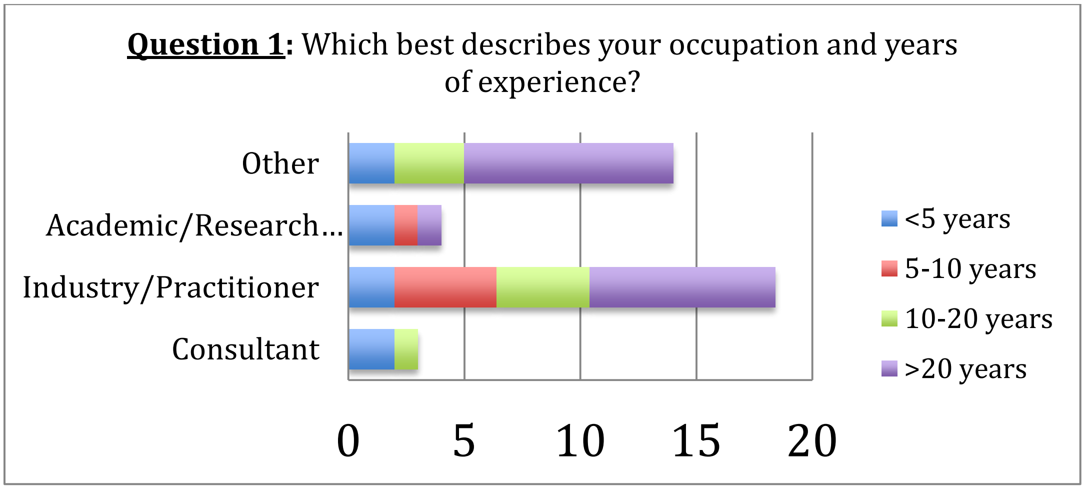

Fig. 3: Survey Question #1

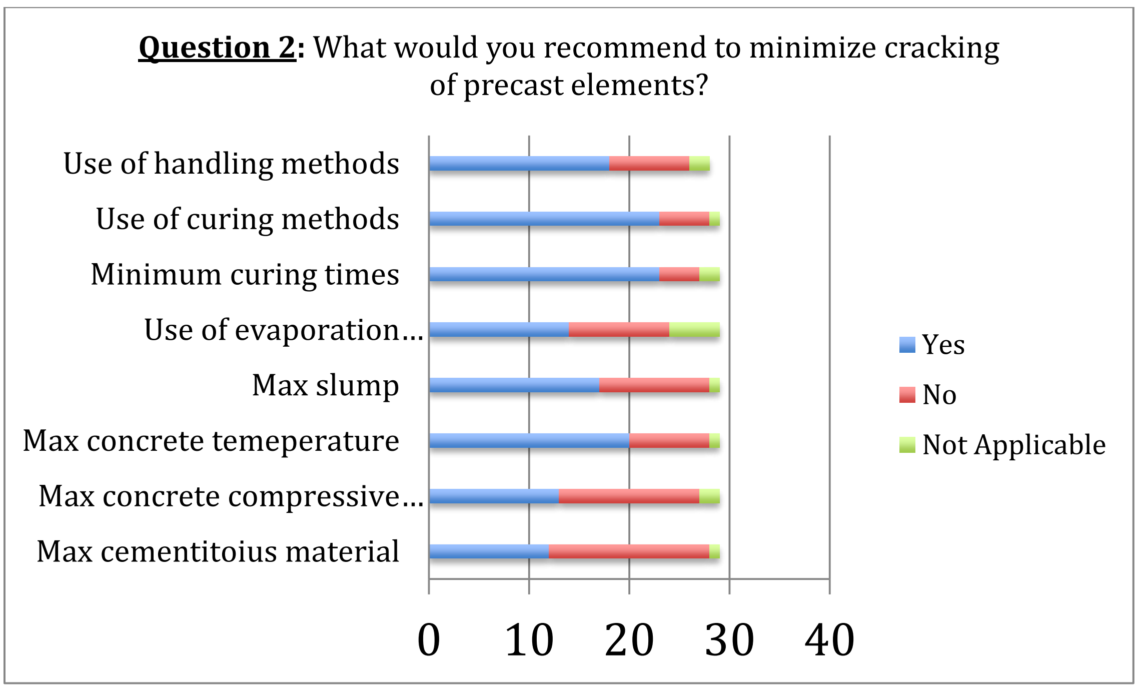

Fig. 4: Survey Question #2

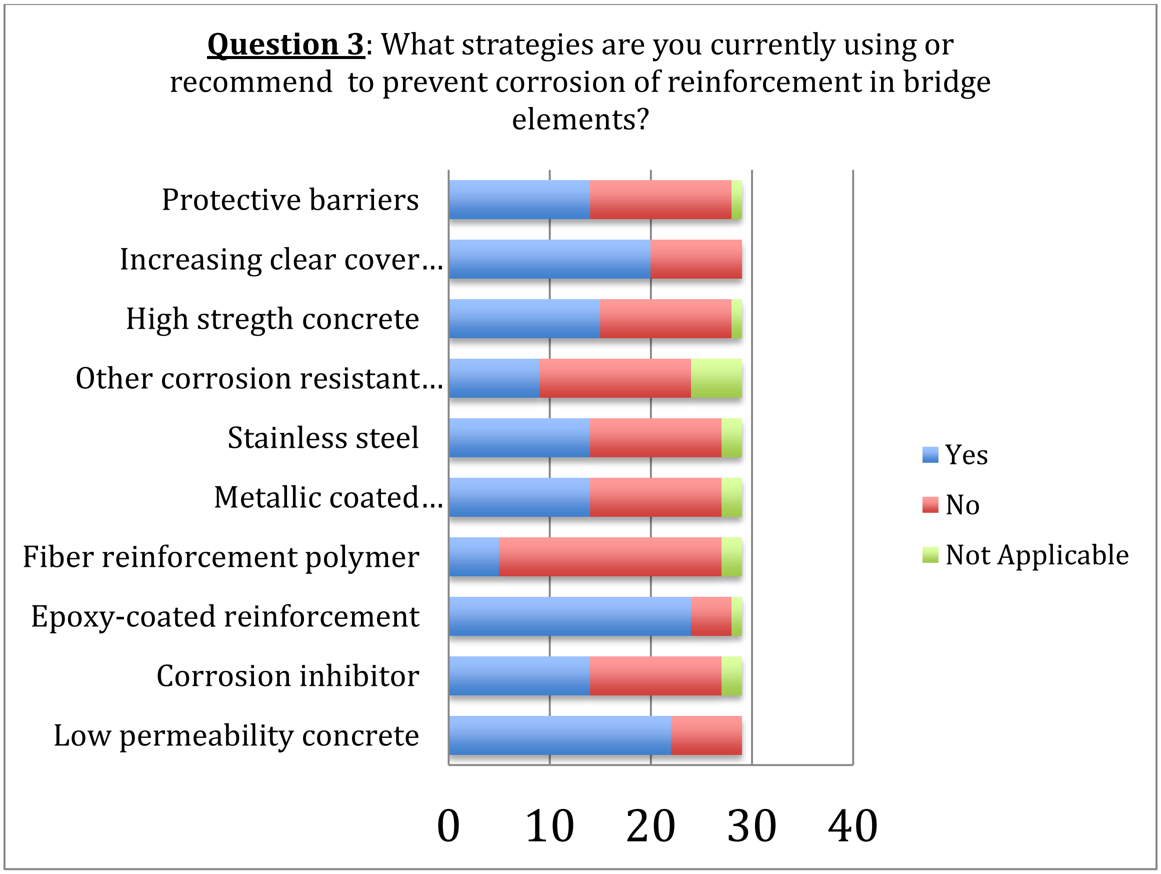

Fig. 5: Survey Question #3

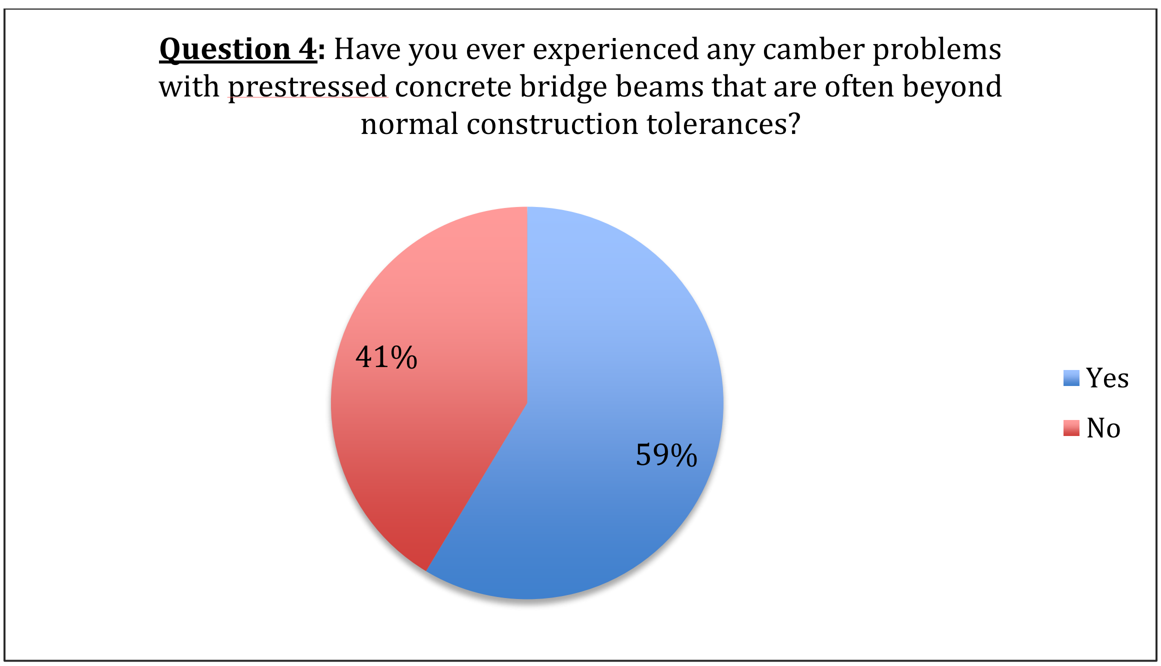

Fig. 6: Survey Question #4

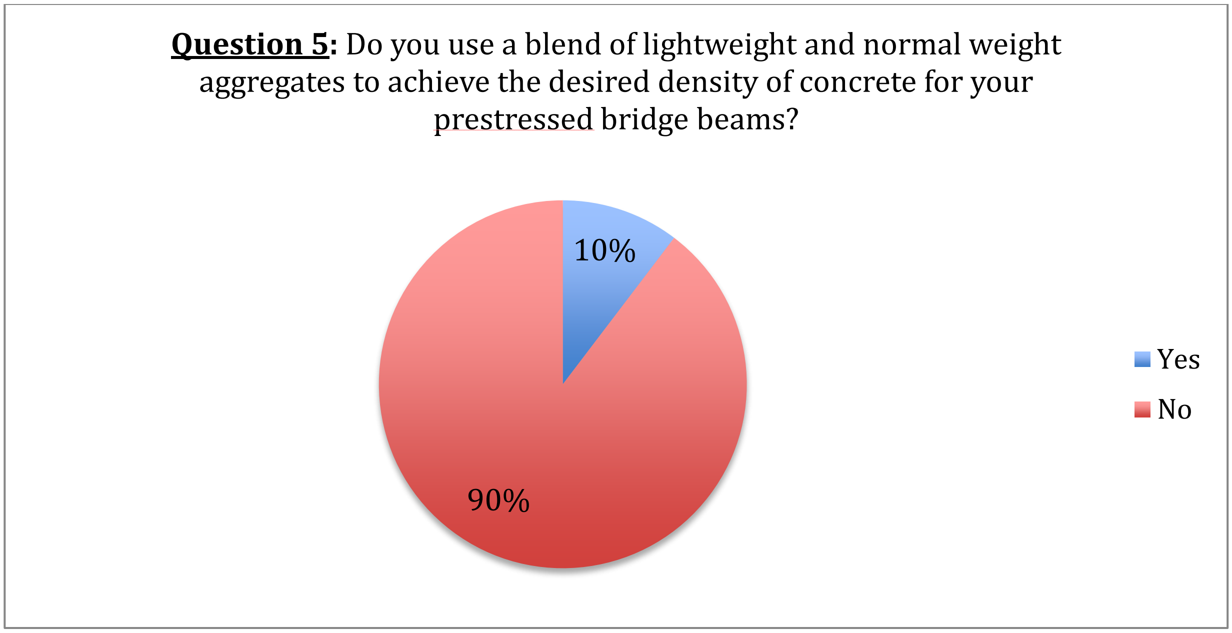

Fig. 7: Survey Question #5

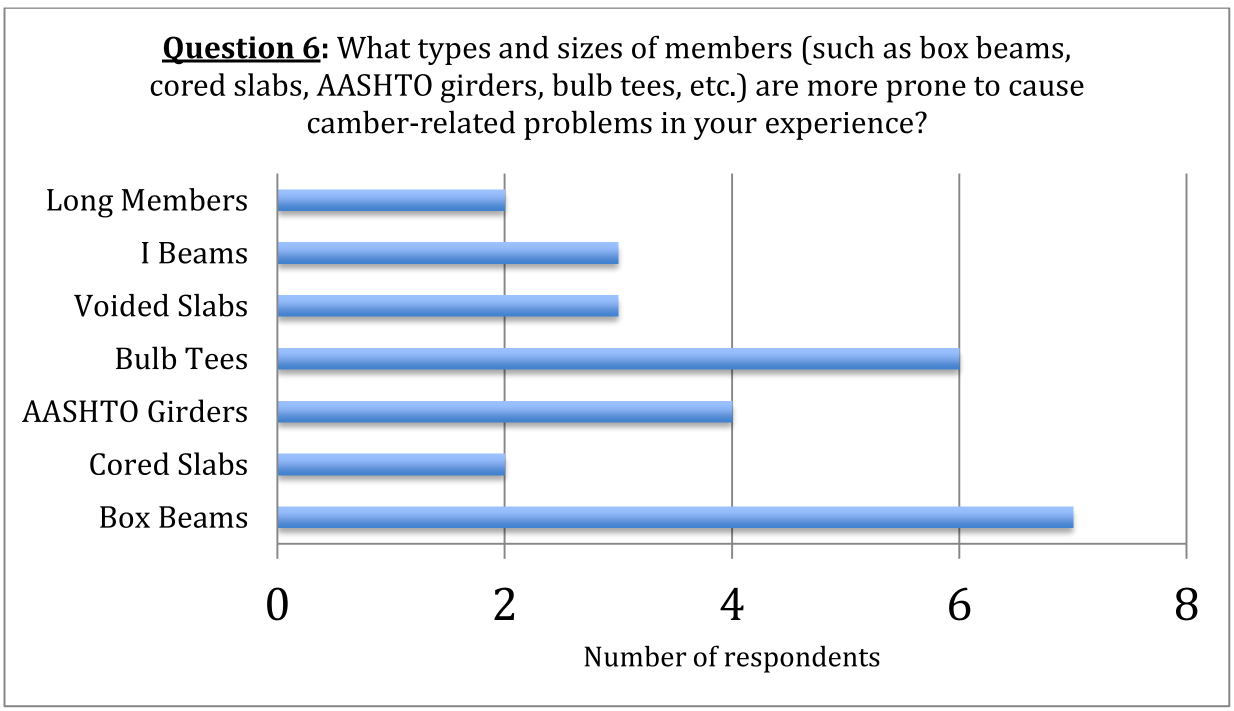

Fig. 8: Survey Question #6

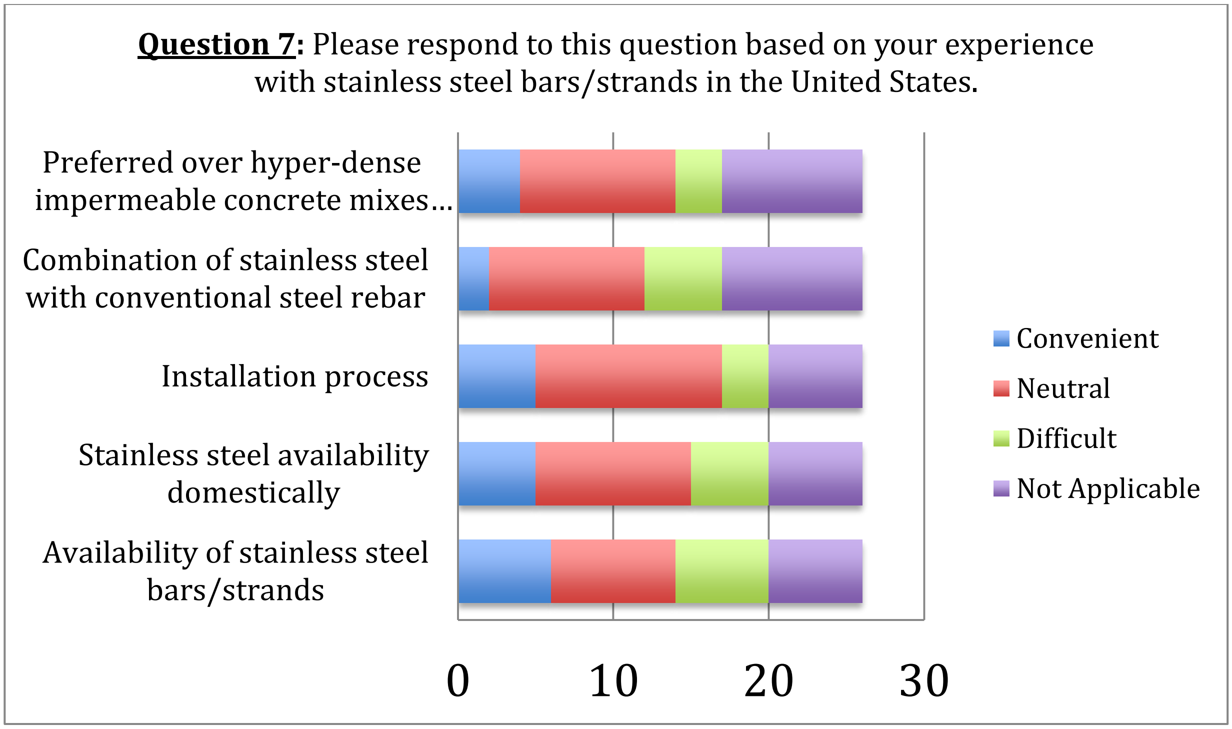

Fig. 9: Survey Question #7

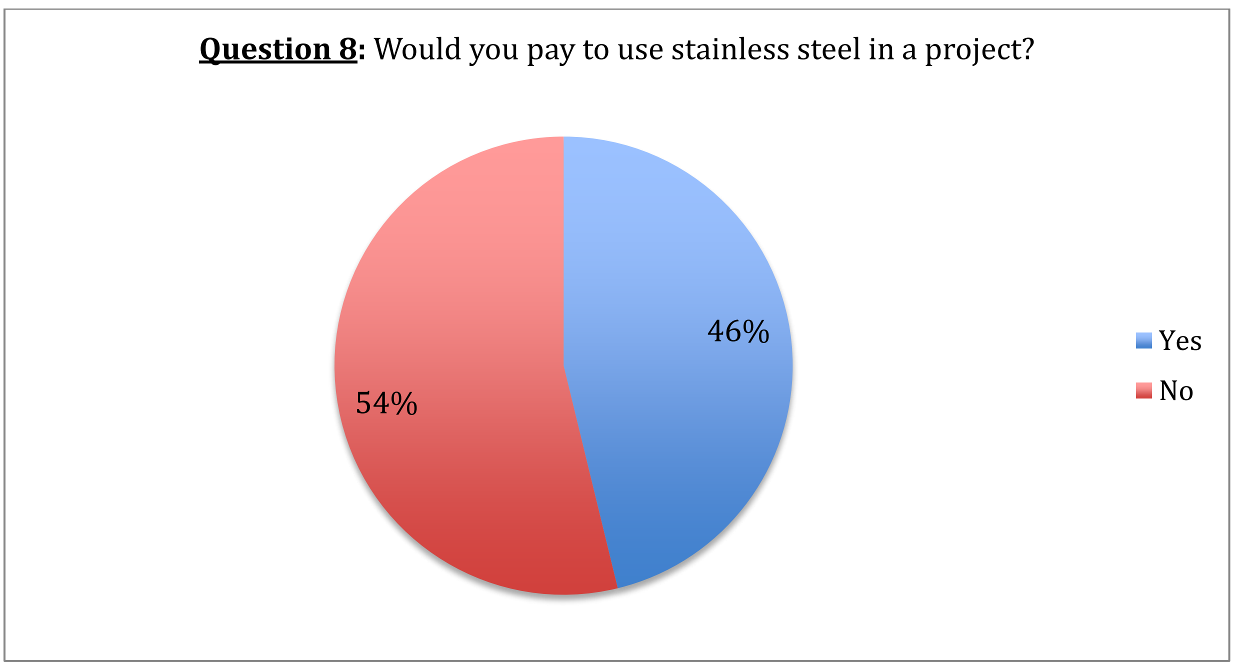

Fig. 10: Survey Question #8

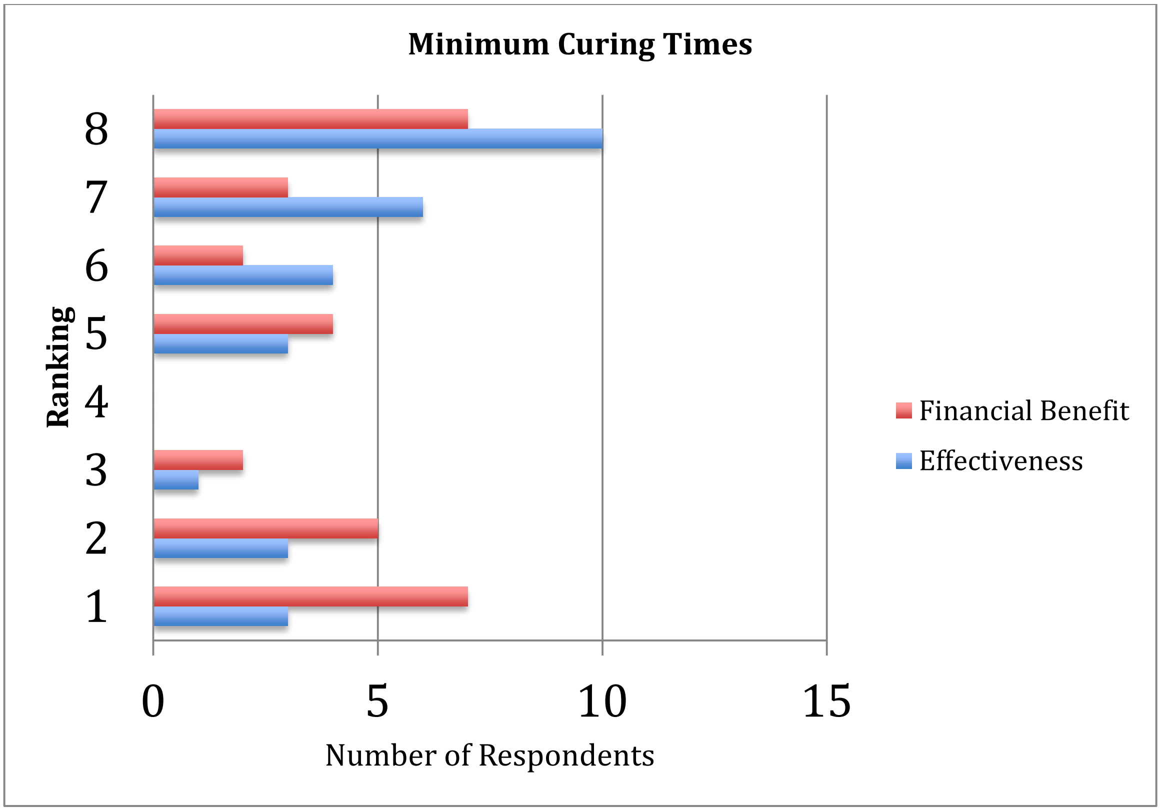

Fig. 11: Survey Question #9

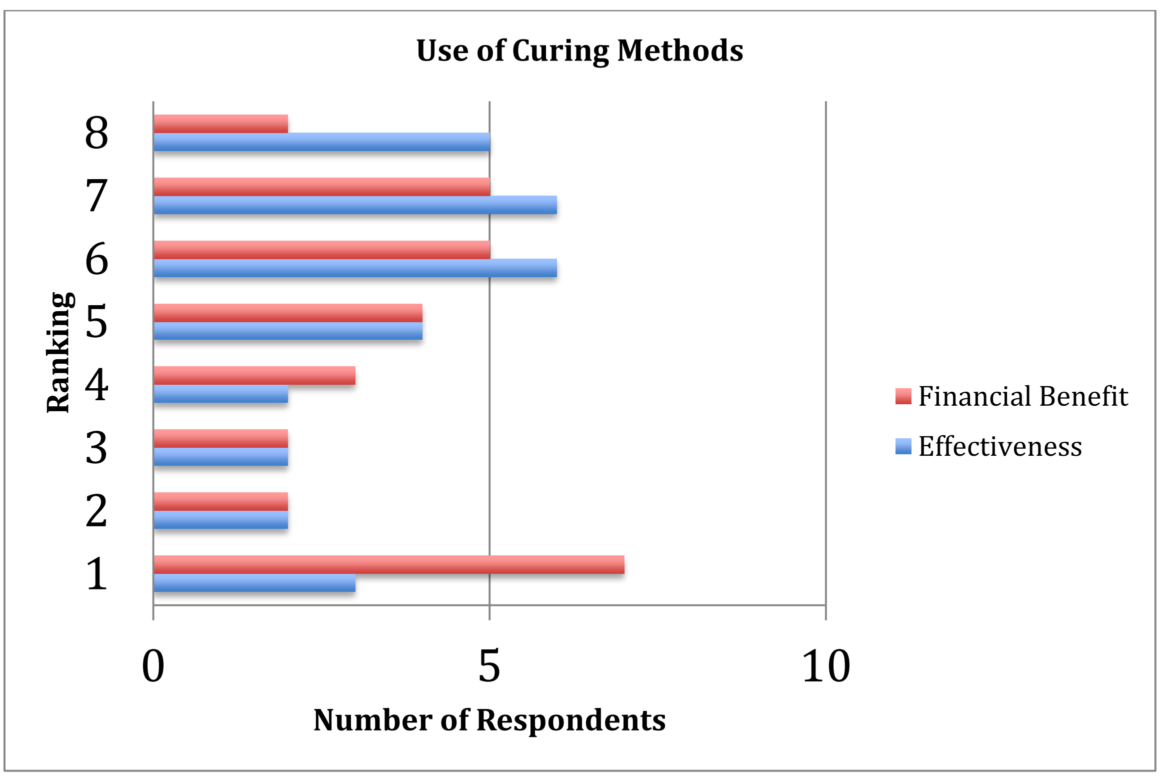

Fig. 12: Survey Question #10

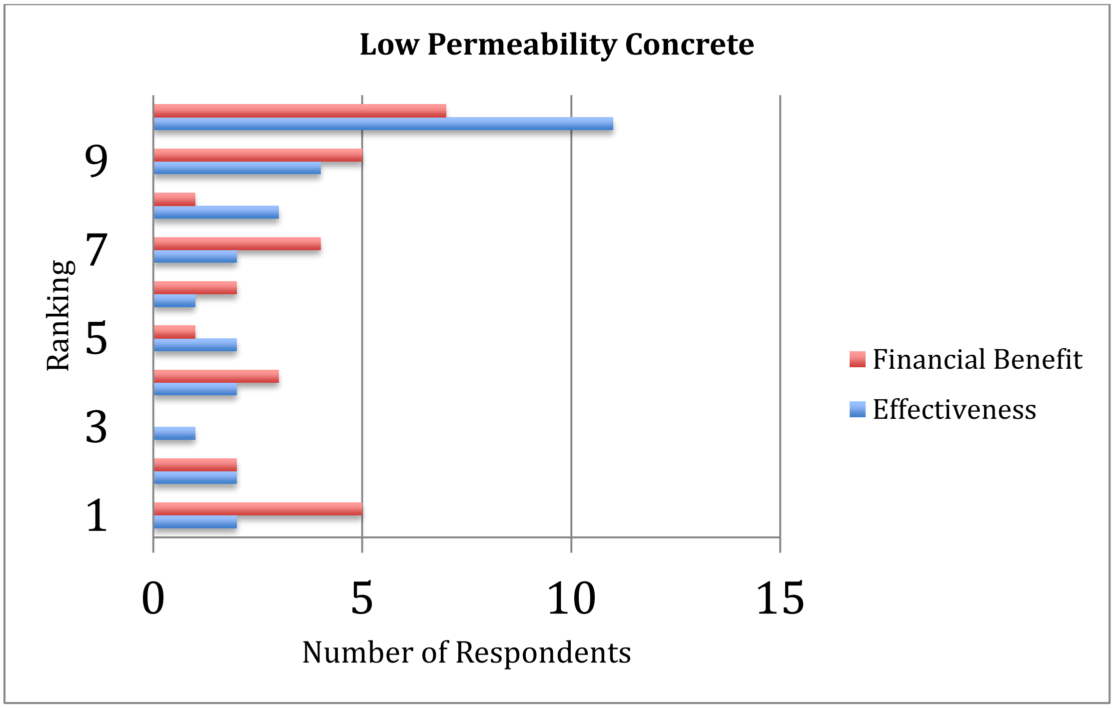

Fig. 13: Survey Question #11

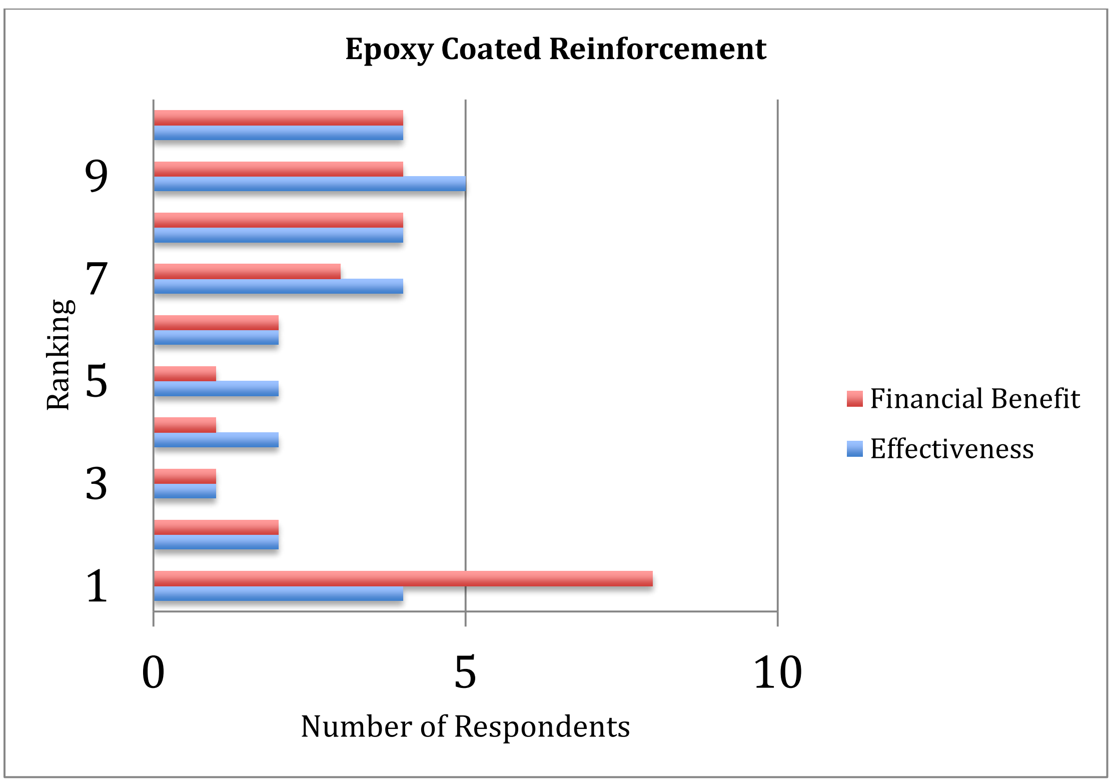

Fig. 14: Survey Question #12

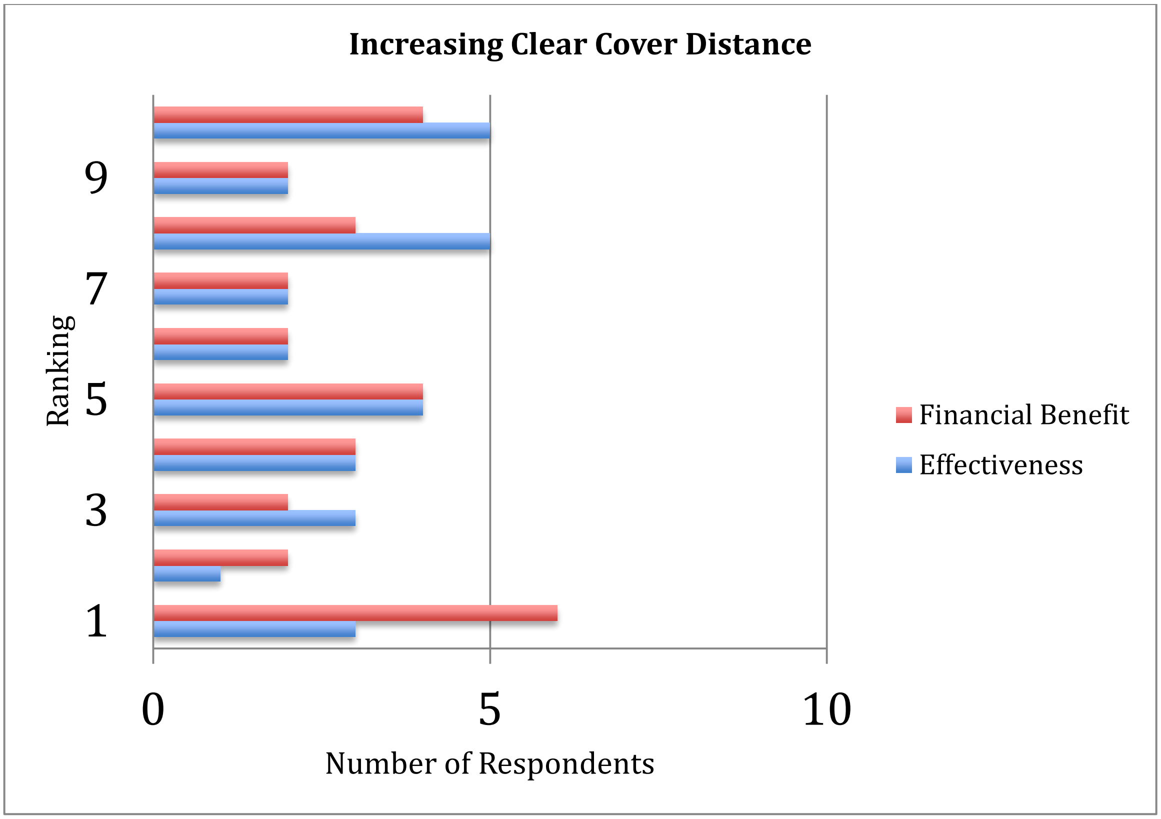

Fig. 15: Survey Question #13

3.4 Data Collected from Stainless Steel Manufacturers

From this study, several questions needed to be addressed in order to meet the ***main objective*** of determining the feasibility and accessibility of stainless steel prestressing strands and bars as materials to be considered for use in prestressed concrete girders and slabs. Table 3 shows a compilation of the responses to these inquiries although mostly information stainless steel rebar and tire wires was available.

Table 3: SHA Questions with Responses Provided by Study

MD SHA Inquiry	Response
What is the availability of stainless steel rebar/strands?	Three companies were found to melt and manufacture in the USA to strict quality standards: 1) North American Stainless in Kentucky (http://www.northamericanstainless.com/), 2) Talley Metals in South Carolina (http://www.talley-metals.com), and 3) Salit Specialty Rebar located in Niagara Falls, New York (http://stainlessrebar.com/). Sumiden Wire Products in Dixon, Tennessee manufactured both 2205 and 2304 strands for a research project funded by the Georgia DOT Research Project Number 10-26 by Lawrence F. Kahn (http://www.concretebridgeviews.com/i74/Article3.php).

MD SHA Inquiry	Response
Are there domestic suppliers? Who are they?	Yes. More details on their product specifications can be found in Appendix C of this report in addition to their individual websites. North American Stainless, 6870 Highway 42 East, Ghent, KY 41015, Phone: (502) 347-6000, FAX: (502) 347-6001, Email: nasinquiries@northamericanstainless.com, Contact: Chris Lyons, Website: http://www.northamericanstainless.com/. Talley Metals, PO Box 2498, Hartsville, SC 29551, Phone: (843) 332-5849 x2121, FAX: (843) 335-5160, Email: sbrunson@cartech.com, Contact: Sharon Brunson, Website: http://cartech.com Salit Specialty Rebar, 3235 Lockport Road, Niagara Falls, NY 14305, Phone: (716) 299-1990, FAX: (716) 299-1993, Email: kcornell@stainlessrebar.com, Contact: Kevin Cornell, Website: http://stainlessrebar.com/.
What is the approximate cost per length?	North American Stainless reported approximately $1.90/ft.
What are the most common/popular types of stainless steel used?	Duplex 2304 was reported to be the most popular for bridge decks as reported by North American Stainless. Talley Metals Technology, Inc., a Carpenter company produces EnduraMet®32, 2205, 316LN, 33, and 2304 in assizes #3 through #38 in lengths up to 40 feet.
What are some sample projects for which these suppliers supported?	Salit Special Rebar has a listing of some of their stainless steel rebar projects throughout North America, Hawaii and the Caribbean, which can be found at: http://stainlessrebar.com/projects/.
Can they be installed the same way? Same equipment?	Stainless steel rebar shall be stored and handled using tools that are not used on carbon steel. Any mechanical connectors should also be stainless. Moreover, the stainless steel reinforcement shall not have direct contact with uncoated steel nor with galvanized reinforcement (exception: stainless steel wires and ties - https://www.dot.ny.gov/portal/pls/portal/mexis_app.pa_ei_eb_admin_app.show_pdf?id=10256). Field bending shall be done by cold methods only.
Are the strength and ductility the same?	Per ASTM A955M, North American Stainless provides three yield strength grades: 300, 420 and 520 MPa. While the typical strength grade for black carbon steel is 420 MPa, previous testing of the Carpenter Alloy 2205 stainless rebar has met the 520 MPa yield strength minimum with superior ductility. As such, these results are about 25% higher than the typical strength required. Two samples of No. 5 solid stainless steel rebar were tested and produced a yield strength of 580 MPa compared to the 520 MPa minimum requirement. The ultimate tensile strength was 790 MPa versus the minimum requirement of 725 MPa. More details can be found in the specifications info sheets in Appendix C.

MD SHA Inquiry	Response
Would it reduce current clear cover requirements that exceed AASHTO?	When stainless steel reinforcing is used, the cover can be reduced, saving costs of concrete and reducing the total weight of the structure.
Is the use of stainless strands more economical than the use of hyper-dense impermeable concrete mixes such as silica fume blends?	Studies by transportation agencies have shown that the use of solid stainless steel reinforcing bar can more than double the life of a bridge deck. It can also increase the cost of the bridge deck by as much as 12% compared to carbon steel reinforcing, but the economic value can outweigh initial costs. In most cases, the additional cost of solid stainless steel reinforcing bar represents approximately 1.5-3% of the total cost of the structure (Tally Metals).
Could the material be used in combination with regular prestressing strands?	Oregon DOT used 2205 stainless steel rebar along with a much large volume of 614,000 kg of grade 60 uncoated carbon steel in a new bridge's substructure elements where corrosion was not a major concern. When used together, the stainless steel rebar was covered with a polyethylene (PE) sleeve where the dissimilar metals intersected to minimize the possibility of galvanic corrosion. An example with stainless steel rebar and prestressing strands was not found by the time of reporting. Conventional steel prestressing strands have been used in conjunction with stainless steel rebar in bridge piles tested by Kahn (2014) and referenced at: http://www.concretebridgeviews.com/i74/Article3.php.

Chapter 4: Life-Cycle Cost Analysis

4.1 Background and Life-Cycle Cost Analysis Case Studies

Life-Cycle Cost (LCC) is the sum of all recurring and one-time costs over the full life span or specified life of a good, service, structure or system. It includes purchase price, installation cost, operating costs, maintenance and upgrade costs, and remaining (residual or salvage) value at the end of ownership or its useful life. The service life of concrete bridges depends on corrosion of the reinforcing steel that is induced by exposure to chloride ions from substances like deicing salts and seawater. A study sponsored by FHWA estimated the annual direct cost of corrosion to be $8.3 billion for highway bridges (Koch et al., 2002).

In efforts to find an alternative for carbon steel rebar, researchers have revealed a way to achieve the durability of stainless steel rebar while maintaining the cost of conventional carbon steel rebar. "Austenitic stainless steel cladding over carbon steel is an attractive alternative to solid stainless steel from both a cost and corrosion mitigation standpoint" (Schully et al., 2007). However, further studies are required to analyze the resulting corrosion behavior when a break in the clad layer occurs, exposing the carbon steel core. There are two very different situations that can cause the exposition of the carbon steel core. Either there is significant localized corrosion through the clad layer or there is some mechanically induced damage.

The Virginia Transportation Research Council (VTRC) conducted a study with the purpose of developing service life estimates of concrete bridge decks and costs for manipulating concrete bridge decks for 100 years (Williamson et. al., 2007). The researchers used a probability based chloride corrosion service life model to estimate the service life of bridge decks built under different concrete and cover depth specifications between 1969-1971 and 1987-1991. They also evaluated the possibilities of using alternative reinforcing materials such as solid stainless steel and stainless steel clad bar as a secondary corrosion protection method. Life cycle costs were estimated for maintaining the bridge decks for 100 years using both present worth and inflated costs. They found that the service life of Virginia's concrete bridges depends on the corrosion of the reinforcing steel that is induced by exposure to chloride ions from substances like deicing salts and seawater. Due to a change in the VDOT specification that dictates a w/c ratio of 0.45 instead of 0.47 and a cover depth of 2.75" instead of 2", all of the bridges tested in this project were not constructed in the same way. The most significant conclusions were that, "The time required for corrosion to induce cracking in the cover concrete can be estimated using existing corrosion-cracking models. An estimated time to corrosion cracking of 6 years for bare steel reinforcement was determined for this study." "The addition of fly ash or slag to the sampled bridge deck concrete mixture appears to dramatically reduce the diffusion rate of chlorides into concrete and have equivalent long term corrosion protection effect" and "the service lives of bridge decks constructed under current specifications (0.45 w/c and 2.75" cover depth) are expected to exceed a design life of 100 years regardless of reinforcement type" (Williamson et. al. 2007). The researchers recommended that newly constructed bridge decks be built under the current specifications with w/c=0.45 and 2.75" cover depth with conventional steel reinforcement. The reason why researchers did not recommend the use of alternative reinforcements over the use of bare steel reinforcements is because of the determination that the service lives of bridge decks constructed under current cover depth and low permeable concrete specifications are expected to exceed 100 years regardless of reinforcement type. So reinforcement types were selected on a first-cost basis.

4.2 Life-Cycle Cost Analysis (LCCA) Estimates from Case Studies

This section focuses on finding an approach to estimate the life-cycle cost of the corrosion resistant rebar (CRR) presented by first analyzing how existing LCCA have been conducted by previous researchers. The Michigan DOT has also conducted estimates for life-cycle cost analysis (LCCA) of stainless and stainless-clad reinforcement for highway bridge use (Kahl 2011). Section 4.2.2 will outline a recommended approach based on all of the information presented. This will aid SHA in identifying the efficacy of selecting one of these materials to replace conventional black steel for one of their projects.

4.2.1 Case Studies

Researchers have found three plausible approaches to determine the LCC of a concrete bridge. Continental Automated Building Association (CABA), National Cooperative Highway Research Program (NCHRP) and Nickel Development Institute (NiDI) developed the three approaches. Equations for these three approaches can be found in Table 4. The factors included in these approaches are First Cost (FC), which includes the costs of design, materials, fabrication and installation, Maintenance Cost (MC), Inspection Cost (IC), Future Rehabilitation Cost (FRC), User Costs (UC), Lost Production Cost (LPC), Material Related Cost (MRC), time period of analysis (t), present worth factor (pwf) and Salvages costs/values (S). In order to determine LCC using the equations developed by CABA and NCHRP, one would have to calculate UC (Table 5). This factor includes the vehicle operating cost, delay of use cost and accident cost. In order to compute these costs, one needs to know the length of the affected roadway, normal traffic speed of the roadway, traffic speed during maintenance activity, and average daily traffic. These figures are going to vary with every LCC calculated. For general research purposes, researchers found the third approach from NiDI to be the most feasible.

Table 4. Three Life-Cycle Cost Analysis (LCCA) Approaches

Agency	Equation
CABA*	$PW = FC + \sum_{t=1}^{t=n} pwf[MC + IC + FRC + UC] + pwf[S]$
NCHRP	$LCC = FC + MC + FRC + UC + S$
NiDI	$LCC = FC + MC + FRC + LPC + MRC$

*CABA calculates LCC in terms of Present Worth (PW)

An economic analysis, using the LCC approach developed by NiDI, was conducted using figures from the replacement of the Schaffhausen Bridge in Switzerland. This bridge was replaced in 1995 and a cost comparison for using carbon steel, epoxy coated steel and stainless steel was conducted at the time. Researchers used inflation rates to project what these costs would be in the present day. Although the material cost of the stainless steel quoted for the Switzerland bridge example was more than ten times that of the carbon steel, the elimination of replacement cost saved more than $2 million from the LCC for the stainless steel bridge. The full economic analysis/LCCA calculation can be found in Table 6.

Table 5. LCCA Equation Factors

LCCA Equation Factors	*FC	MC	IC	FRC	UC	LPC	MRC	t	pwf	S
CABA	✓	✓	✓	✓	✓	–	–	✓	✓	✓
NCHRP	✓	✓		✓	✓	–	–	–	–	–
NiDI	✓	✓	✓	✓	–	✓	✓	–	–	–

*Please note the following designations:

FC= First cost (includes Design, Material, Fabrication & Installation cost)
MC= Maintenance cost
IC= Inspection cost
FRC= Future Rehabilitation/Replacement cost
UC= User cost
LPC= Lost Production cost
MRC= Material Related cost
t= time period of analysis
pwf= Present worth factor
S= Salvage costs/value

Table 6. Economic Analysis of the Schaffhausen Bridge in Switzerland

	Carbon Steel	**Epoxy Coated Steel**	**Stainless Steel**
Material Cost	$8,551	$32,778	$92,477
Fabrication Cost	0	0	0
Installation Cost	$16,285,930	$16,285,930	$16,285,930
First Cost	$16,294,481	$16,318,708	$16,378,407
Maintenance Cost	0	0	0
Replacement Cost	$267,311	$80,193	0
Lost Production Cost	$2,314,388	$2,314,388	0
Material Related Cost	0	0	0
Operating Cost	$2,581,699	$2,394,581	0
Total LCC	$18,876,180	$18,713,289	$16,378,407

4.2.2 Proposed Life-Cycle Cost Analysis (LCCA) Sample Calculation for SHA

Economic comparisons were used in this case study to compare and contrasts the cost relations for each rebar. FHWA uses a life-cycle cost analysis based off the estimated rate of discount of the interest rate minus inflation. According to Schnell et al. (2007), the cost of carbon and stainless steel are undergoing financial growth delay. To provide some analysis for their argument, Bergmann et al. (2007) compares the cost of epoxy-coated reinforcement with stainless steel over the entire bridge deck based on pricing of both materials for use in New York City. If the price of stainless steel in New York was almost three times as large as ECR in bridge decks and the average ECR used in bridge decks is 12%, then stainless steel would illustrate a cost approximately 9 to 15% of the entire deck. For comparison, it was assumed all decks were similar and took into consideration the 10.42% reduction in thickness and the initial cost of the deck will decrease around 1%. Performing both methods showed that the present worth percentage at the end of the life cycle of solid stainless steel was lower than any other material.

Table 7 compares the initial cost of new bridges of different types of deck reinforcement along with the life cycle cost. Bergmann et al. (2007) assumed that the present worth of deck replacement and 100-year life cycle costs 25% for related costs of replacement, and the 100-year life cycle cost assumes replacement with identical deck design at end of each life span and the FRP values assume equivalent linear quantities with all FRP bars one (1) size larger than steel bars (2007). Based on the results, despite the initial cost of solid stainless and EnduraMet®32 stainless steel, both present worth and life-cycle cost of the two materials is lower than every other reinforcement alternatives for the deck.

In conclusion, the use of all three stages illustrates the savings of stainless steel being incorporated later in the funding. There may be an increase in initial costs but the reward would be beneficial to the owner and the company when there are no major replacements needed over a long period of time. The use of this material can be favorable for the economy, society and the environment surrounding it.

Table 7: Initial cost and life-cycle costs of new bridges with various CCR in deck

Reinforcing Type	ECR/ galvanized	MMFX2	FRP	Solid Stainless	EnduraMet®32 Stainless
Initial deck cost	100%	103%	106%	112%	106%
Estimated life (years)	40	50	65	100	100
Presented worth of deck replacement at end of life	26.04%	18.12%	10.35%	2.77%	2.10%
100 year life cycle cost as a percentage of initial cost of ECR deck	130.22%	121.12%	115.21%	114.77%	108.62%

Chapter 5: Conclusion, Recommendations and Future Work

This report provides critical information on the current state-of-the-practice and art of using alternate materials (often referred to as corrosion resistant rebar, CRR) and strategies to minimize the issue of corrosion. The main focus of the study was to explore the efficacy of stainless steel rebar such that SHA can have enough information to make a decision as to whether or not they would be interested in changing from traditional strands to stainless steel rebar and/or strands for various projects. A national survey with 1 international respondent was created and disseminated to various DOT personnel, precasters and mill representatives to gain information on various practices for addressing cracking and corrosion as a result of cracking in addition to familiarity of stainless steel in various projects. This synthesis study provides background information on various case studies for which stainless steel was used, general information about alternative materials with particular focus on the availability of stainless steel, and detailed information from stainless steel manufacturers to assist the decision-making process for SHA regarding this matter. Life-cycle cost analysis (LCCA) case studies are presented as examples for SHA to ascertain the feasibility of deploying stainless steel in a project. Moreover, companies that specifically melt and manufacture stainless steel in the United States have been identified in this report.

One way to address corrosion is to first address the issue of cracking, especially in prestressed structures. From the survey results, it was determined that the highest recommended strategies to minimize cracking of prestressed, precast elements were to minimize curing times and use curing methods. The most used or recommended strategies to prevent corrosion of reinforcement in bridge elements was reported to be through using epoxy-coated rebar, lowering permeability concrete and increasing clear cover depth. Some other examples include using High Performance Concrete (HPC or higher strength concrete as indicated in the survey) to reduce cracking of bridge decks by reducing heat of hydration and slowing strength gain. However, fifty-four percent (54%) of the respondents would not pay to use stainless steel on a project. It was expressed from the survey that stainless steel should only be used for projects that require a larger quantity of reinforcement because of its high price. Nevertheless, the overall investment in stainless steel specifically over the other CRR for its life-cycle performance can outweigh the higher initial costs as presented by the life-cycle cost analysis (LCCA) example estimates presented. The Appendices include supplemental information gathered from the survey and manufacturers' information.

Future work includes supporting experimental testing of rebar to validate data provided by the stainless steel suppliers should SHA want to conduct their own tests, especially as it relates to assessing ductility and ultimate strengths. Parametric studies can also be conducted to look at the optimal stainless steel rebar sizes and design options that can be used on a particular project.

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Appendices

Appendix A: Survey

Performance Evaluation Survey For Quality Control And Quality Assurance (QA/QC)

SECTION A - PBES PRODUCTION PRACTICES

2 / 3 67%

***1. Which best describes your occupation and years of experience?**

	<5 years	5-10 years	10-20 years	>20 years
Consultant				
Industry/Practitioner				
Academic/Research Engineer				
Other				

Which state do you currently work (e.g. Maryland)?

***2. What would you recommend to minimize cracking of precast elements? Rank your top 8 choices (Scale: 1=low and 8=high).**

	Strategy Recommended	Rank Effectiveness (Scale 1-8)	Rank Financial Benefit (Scale 1-8)
a. Specify maximum cementitious material content			
b. Specify maximum concrete compressive strength			
c. Specify maximum concrete temperature			
d. Specify maximum slump			
e. Use evaporation retardants			
f. Specify minimum curing times			

g. Use of curing method			
h. Use of handling methods			

i. In addition, what do you see as the biggest barrier or problem with QA/QC of PBES?

***3. What strategies are you currently using or recommend to prevent corrosion of reinforcement in bridge elements? Rank your top 10 choices (Scale: 1=low and 10=high).**

	Strategy Used or Recommended	Rank Effectiveness (Scale 1-10)	Rank Financial Benefit (Scale 1-10)
a. Low-permeability concrete			
b. Corrosion inhibitor			
c. Epoxy-coated reinforcement			
d. Fiber-reinforced polymer			
e. Metallic-coated reinforcement			
f. Stainless steel			
g. Other corrosion-resistant			
h. High strength concrete			
I. Increasing clear cover distance			
j. Protective barriers			

k. Please describe the specific problem and the solution was to overcome the problem.

✱4. Have you ever experienced any camber problems with prestressed concrete bridge beams that are often beyond normal construction tolerances?

YES NO

State the typical construction tolerances used and could strand arrangement resulting in problems. Specifically, if two beams have identical number of strands and center of gravity of strands, can the placement of strands within the unit resulting in camber issues?

✱5. Do you use a blend of lightweight and normal weight aggregates to achieve the desired density of concrete for your prestressed bridge beams?

YES NO

If so, do you experience more severe camber problems than using normal weight concrete?

✱6. What types and sizes of members (such as box beams, cored slabs, AASHTO girders, bulb tees, etc.) are more prone to cause camber-related problems in your experience?

Prev Next

Performance Evaluation Survey For Quality Control And Quality Assurance (QA/QC)

SECTION B - MATERIALS

3 / 3 100%

7. Please respond to this question based on your experience with stainless steel bars/strands in the United States?

	Convenient	Neutral	Difficult	Not Applicable
a (i). Availability of stainless steel bars/strands				
ii) Stainless steel availability domestically				
b. Installation process				
c. Combination of stainless steel with conventional steel rebar				
d. Preferred over hyper-dense impermeable concrete mixes such as silica fume blends				

e. Please describe the specific problem and what the solution was to overcome the problem.

8. Would you pay to use stainless steel in a project?

YES NO

Do you feel that the benefits of using stainless steel overshadows the cost? What kind of cost differential has been experienced?

9. If you have used or know someone who has used either stainless steel rebar or strands, then list the company for which the materials were procured and your familiarity with the product. Feel free to also elaborate on any other issues or challenges experienced when using this material.

10. Please enter your contact information. Thank you.

E-mail address

Phone (mobile)

Phone (work)

Name of company

Prev Submit

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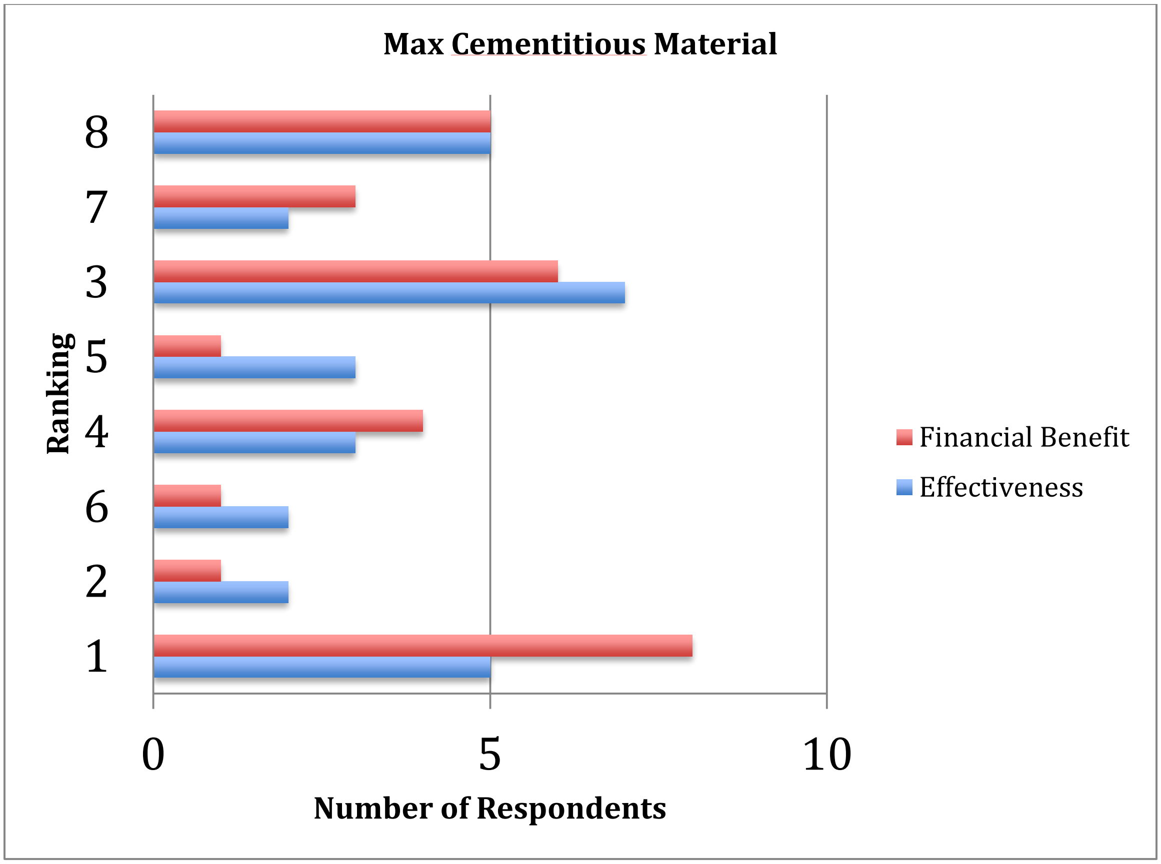
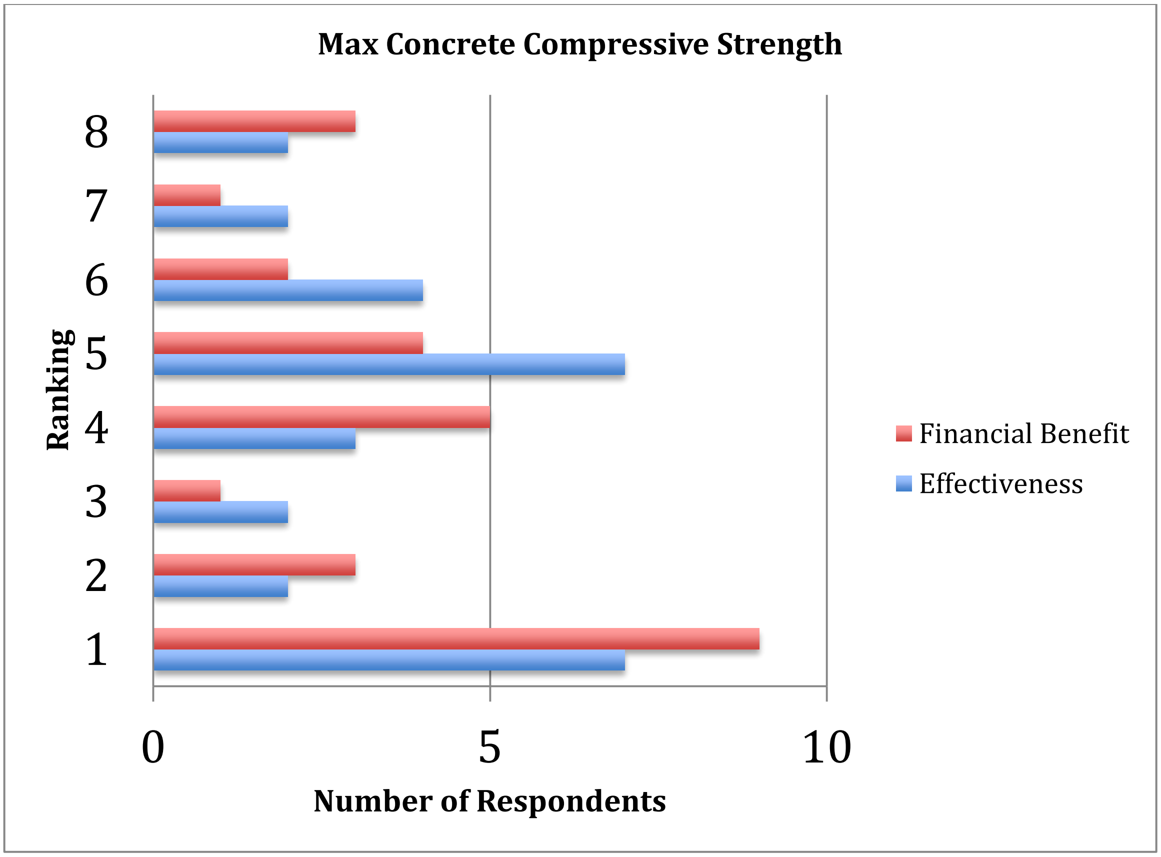
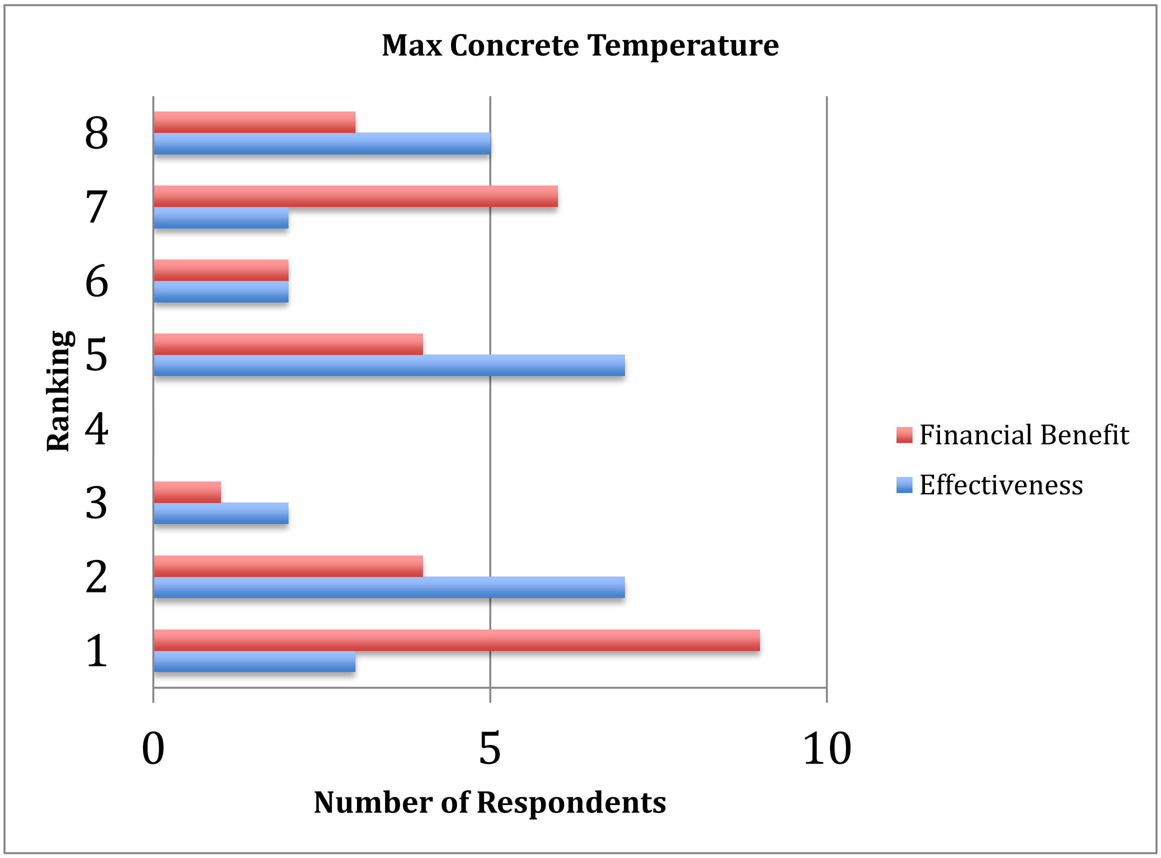
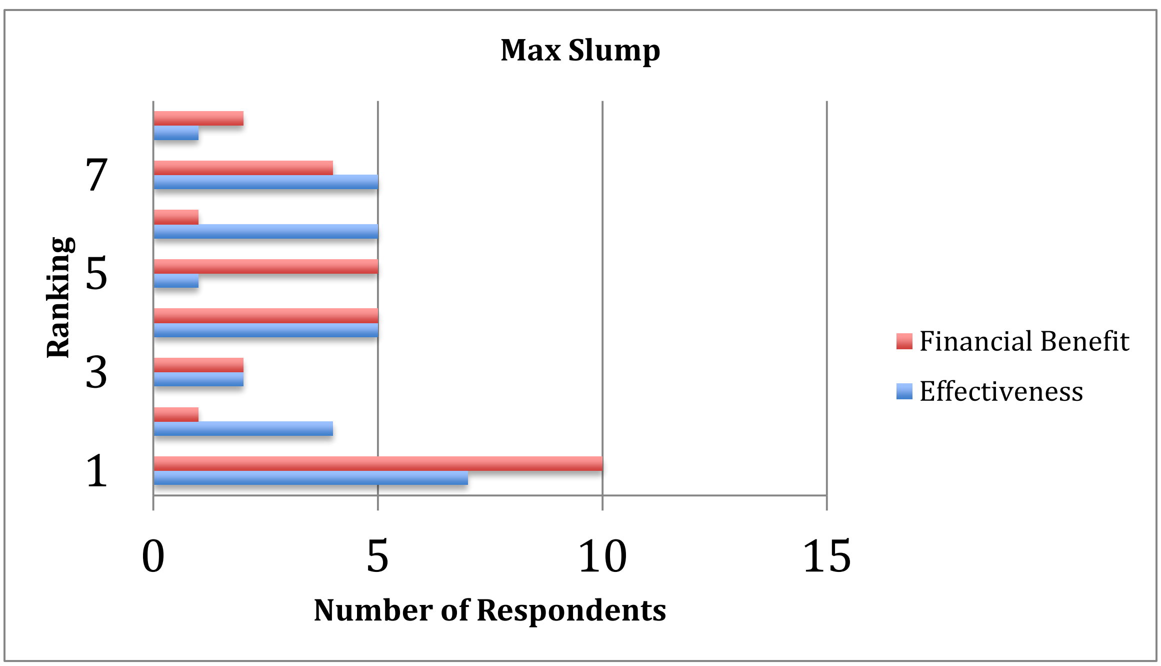
Appendix B: Additional Survey Data

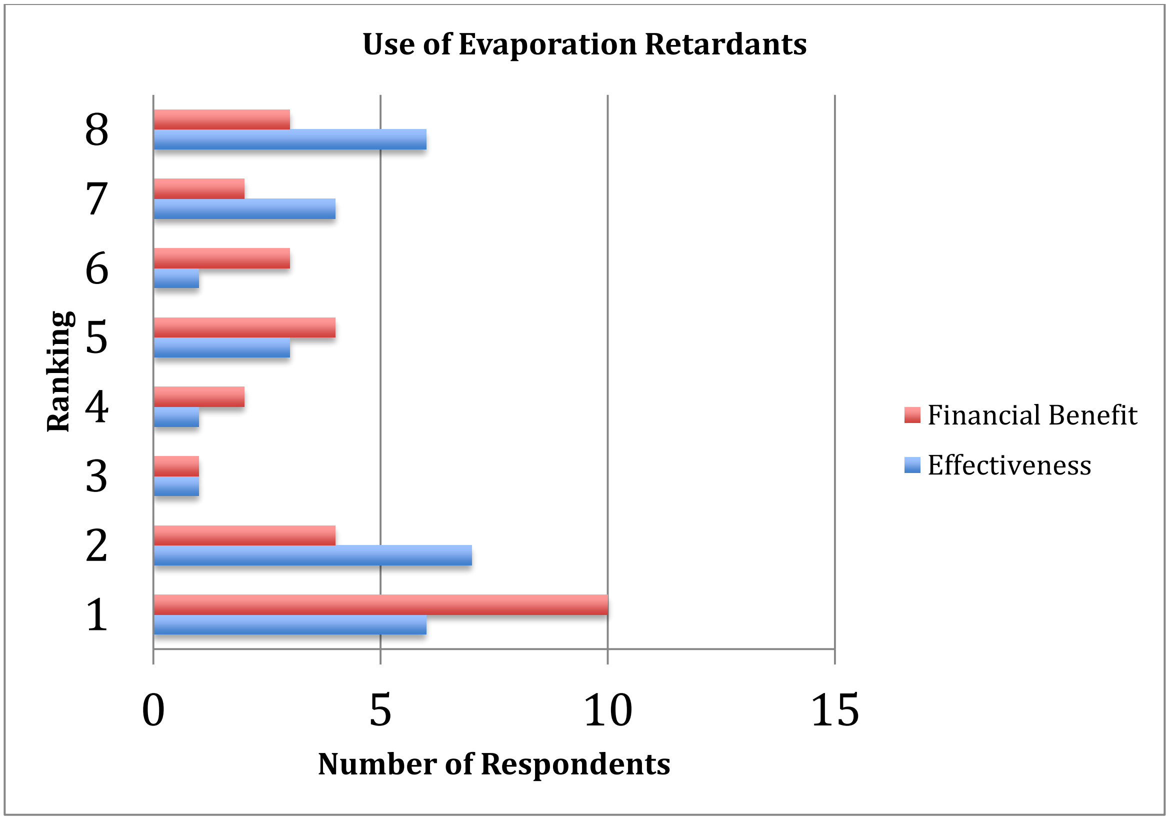
Question 2 Rankings

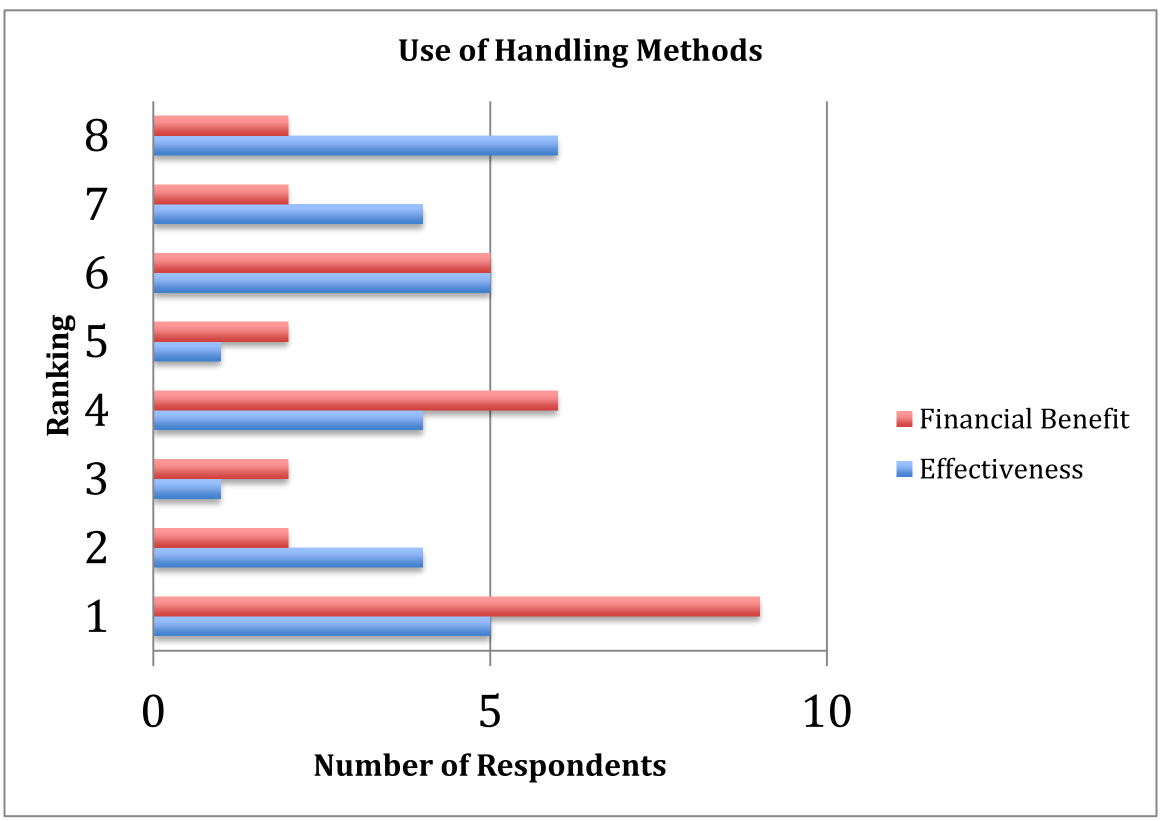



Max Concrete Compressive Strength
Ranking
8
7
6
5
4
3
2
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness

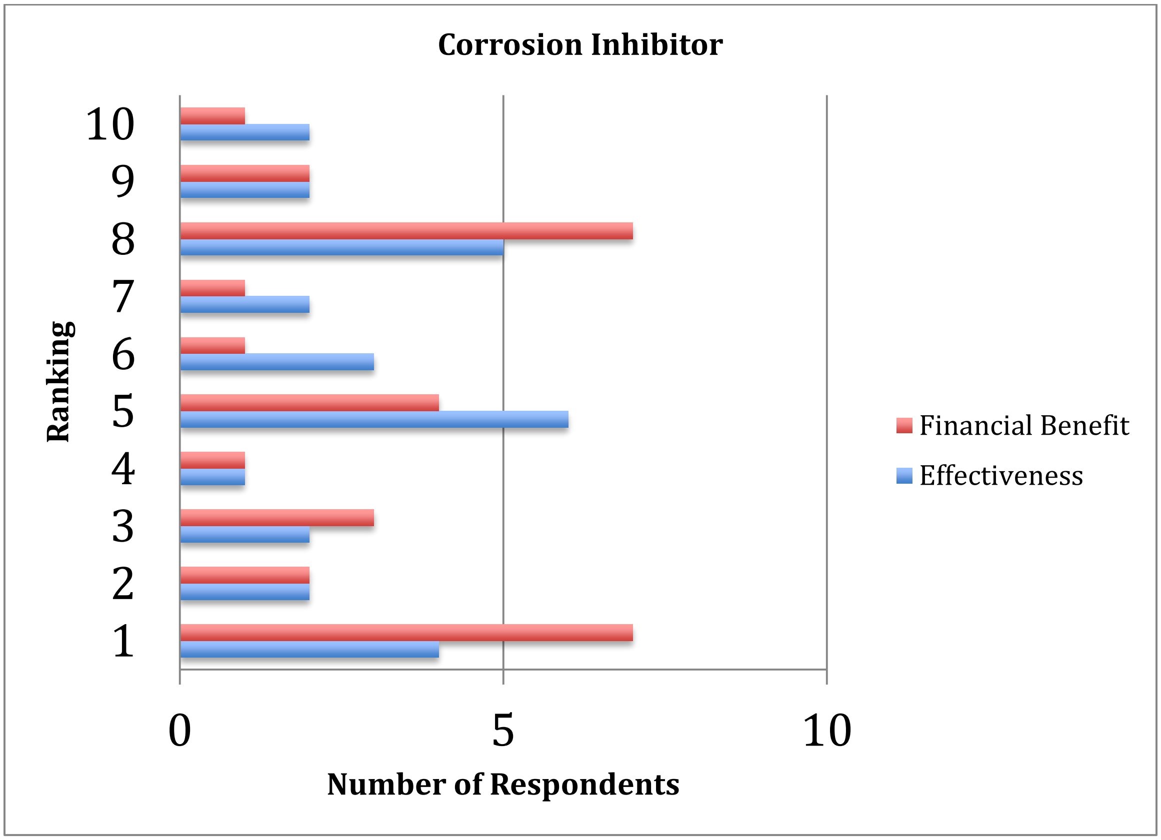

Max Concrete Temperature
8
7
6
5
4
3
2
1
Ranking
0
5
10
Number of Respondents
Financial Benefit
Effectiveness

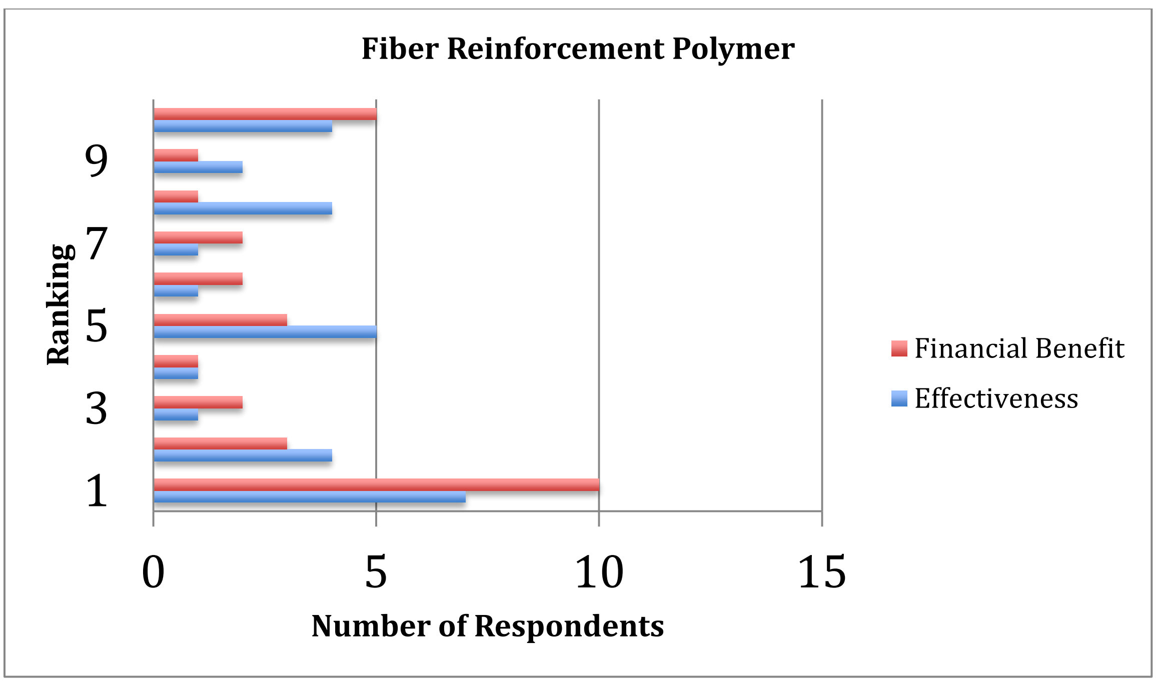

Max Slump
7
5
3
1
Ranking
0
5
10
15
Number of Respondents
Financial Benefit
Effectiveness

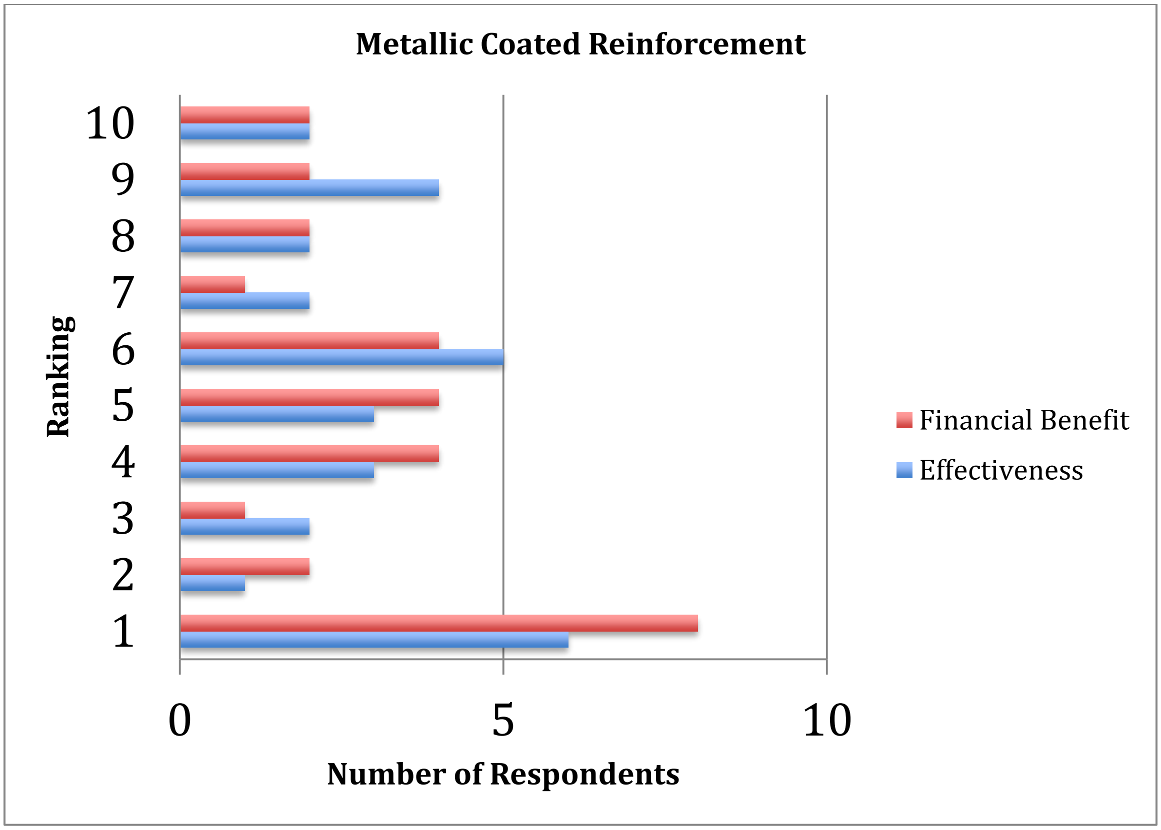

Use of Evaporation Retardants
Ranking
8
7
6
5
4
3
2
1
0
5
10
15
Number of Respondents
Financial Benefit
Effectiveness

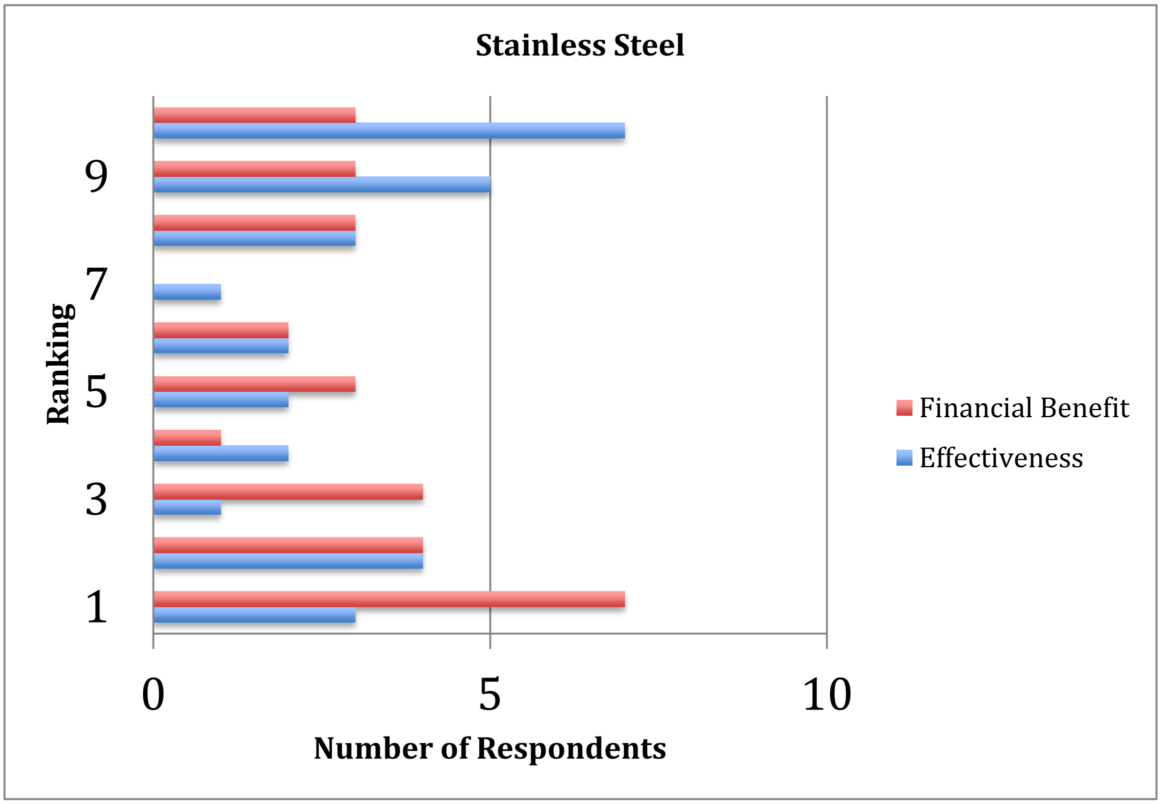

Use of Handling Methods
Ranking
8
7
6
5
4
3
2
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness

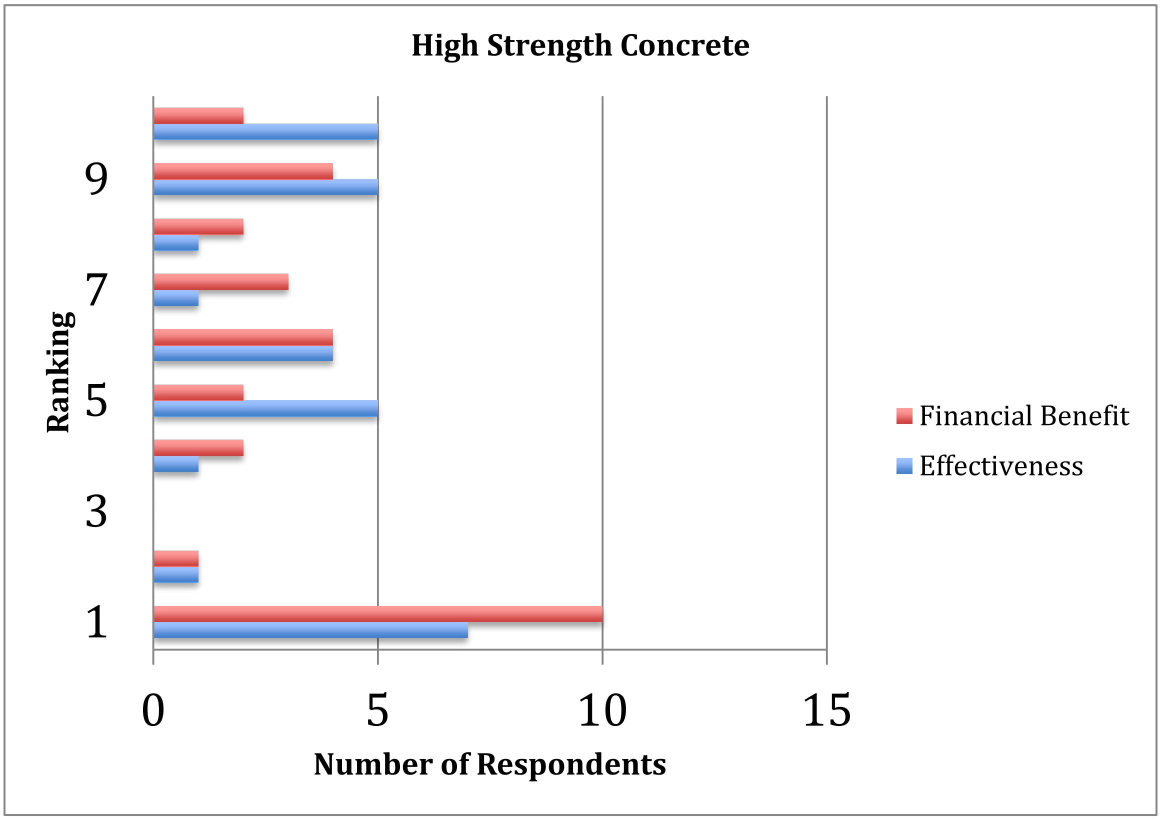
Question 3 Rankings



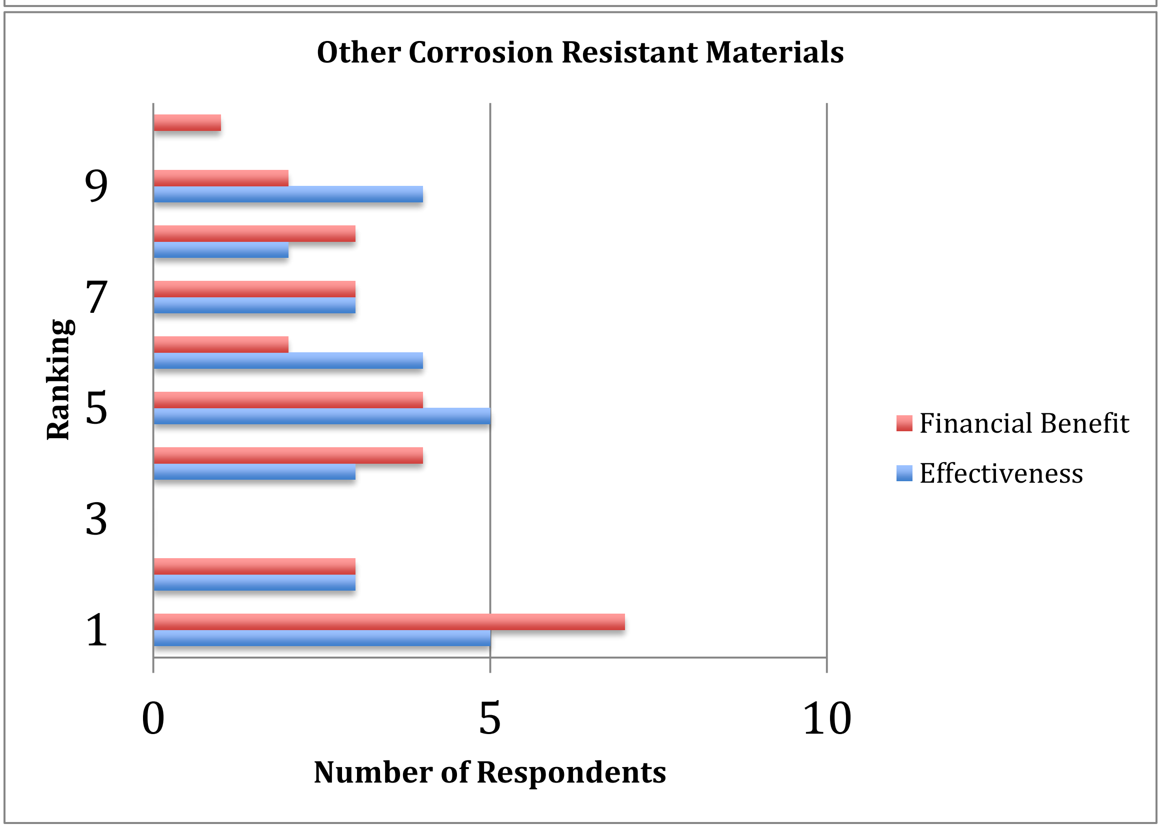



Metallic Coated Reinforcement
Ranking
10
9
8
7
6
5
4
3
2
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness

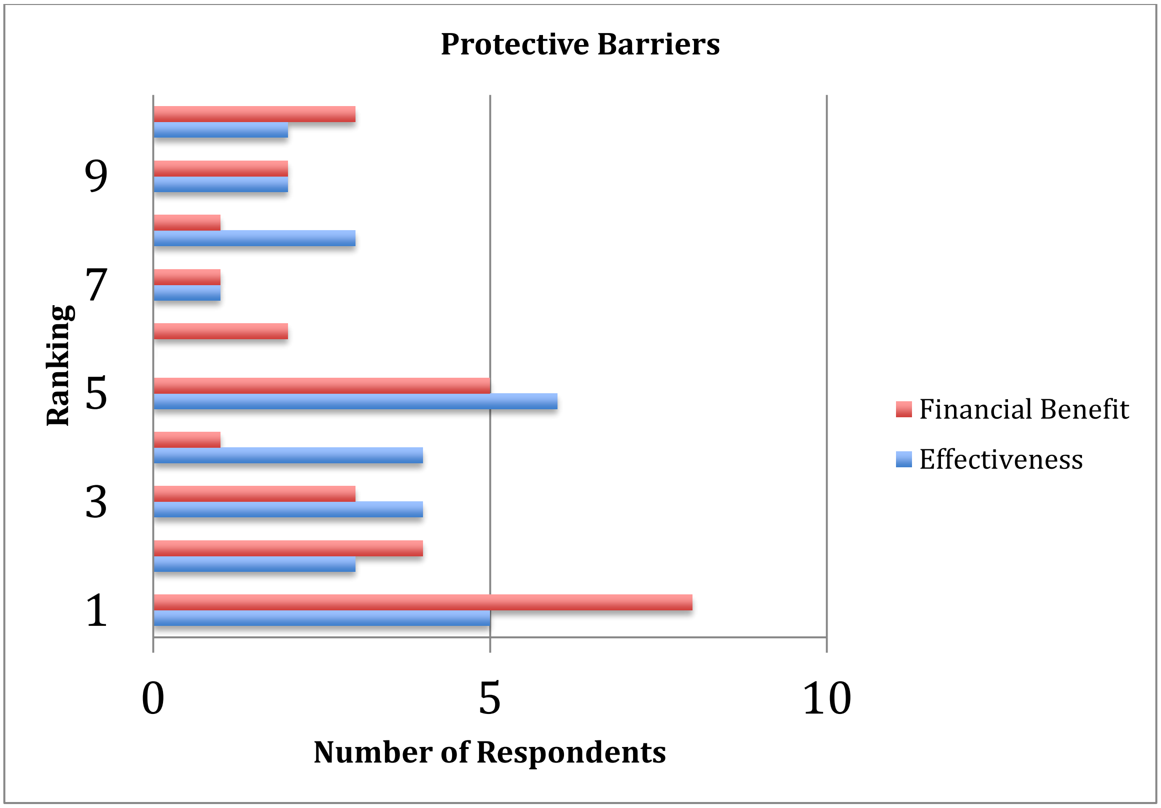

Stainless Steel
Ranking
9
7
5
3
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness



High Strength Concrete
Ranking
9
7
5
3
1
0
5
10
15
Number of Respondents
Financial Benefit
Effectiveness



Other Corrosion Resistant Materials
Ranking
9
7
5
3
1
0
5
10
Number of Respondents
Financial Benefit
Effectiveness



Question 9

If you have used or know someone who has used either stainless steel rebar or strands, then list the company for which the materials were procured and your familiarity with the product. Feel free to also elaborate on any other issues or challenges experienced when using this material.

- North American Stainless, 6870 Highway 42, East Ghent, KY 41045
- Salit Specialty Rebar, 3235 Lockport Road, Niagara Falls NY 14305
- CMC, 10320 South Medallion Drive, Cincinnati, OH 45241

Appendix C: Manufacturer Data