# Job Site Evaluation of Corrosion-Resistant Alloys for Use as Reinforcement in Concrete

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# FOREWORD

Economic considerations have historically precluded consideration and widespread use of high-performance (corrosion-resistant) reinforcements such as stainless steels in bridge construction. However, with the advent of life-cycle cost analysis as a project planning tool and of a requirement that major bridge structures have a 75–100 year design life, the competitiveness of such steels has increased such that enhanced attention has now focused in recent years upon these materials.

This investigation was a component of the Innovative Bridge Research and Construction (IBRC) Program that was authorized by Congress in the Transportation Equity Act for the 21st Century (TEA-21) legislation. The project objective was to evaluate and provide a historical record of approved State bridge construction projects throughout the United States that employed corrosion-resistant reinforcement. The study involved site visits, documentation of attributes and any problems associated with the various reinforcement types, and acquisition and testing of reinforcement samples.

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Director, Office of Infrastructure
Research and Development

## Notice



## Quality Assurance Statement

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16. Abstract

Premature deterioration of the Nation's concrete highway and bridge structures as a consequence of chloride (salt) exposure and resultant corrosion of reinforcing steel has evolved during the past four decades to become a formidable technological and economic problem. In response to this, epoxy-coated reinforcing steel (ECR) was adapted in the mid-1970s as a proactive measure to control this problem. Premature corrosion-induced cracking of marine bridge substructures in Florida indicated, however, that ECR is of little benefit for this type of exposure; and while performance of ECR in northern bridge decks has been generally good to date (30-plus years), still the degree of corrosion resistance to be afforded in the long term to major structures with design lives of 75–100 years is uncertain. Corrosion-resistant reinforcements, including stainless steels, are an alternative for such applications, and a component of the Federal Highway Administration (FHWA) Innovative Bridge Research and Construction Program addressed incorporated of such reinforcements into approved State bridge construction projects. The present project evaluated a selected number of these in terms of the type of reinforcement used and difficulties and advantages that were encountered. Of the 27 approved State projects for which information could be gathered; 20 were either completed as planned or utilized an alternate corrosion-resistant reinforcement. The different reinforcements types were solid Types 316 (3 projects), 2201LDX (1 project), and 2205 (5 projects) stainless steels, Type 316 stainless clad black bar (3 projects), MMFX-II (13 projects), and galvanized steel (3 projects). In some cases, more than one corrosion-resistant reinforcement was used on a single project. The various State projects demonstrated that, subject to availability, corrosion-resistant reinforcing steel can be incorporated into bridge construction with relative ease and placed with less difficulty than ECR. Thus, these reinforcements are a viable technical alternative to ECR. Realizing the full benefit of this IBRC program, however, will depend upon individual States acquiring performance data and maintaining records on these structures for decades into the future.



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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oF$ | Fahrenheit | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius | $^oC$ |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oC$ | Celsius | 1.8C+32 | Fahrenheit | $^oF$ |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# BACKGROUND AND INTRODUCTION

For a Nation to be productive, its transportation system must be efficient and reliable. While deterioration of highway structures over time is a normal and expected occurrence, the rate at which this has occurred for bridges in the United States, since the advent in the 1960s of a clear-roads policy and the use of roadway deicing salts in northern locations, has been severe and posed significant challenges, both economically and technically. Also important is the accelerated deterioration of bridges that has occurred in coastal locations, both northern and southern, as a consequence of exposure to sea water (chlorides) and sea spray. In both cases (deicing salts and marine exposure), the deterioration is a consequence of the aggressive nature of chlorides in combination with moisture and oxygen.(1) More than half of the total bridge inventory in the United States is of the reinforced concrete type, and these structures have proved to be particularly susceptible. A recent study has indicated that the annual direct cost of corrosion to bridges is $5.9 to $9.7 billion. If indirect factors are included also, this cost can be as much as 10 times higher.(2,3)

In response to this problem, research studies that focused upon the utility of epoxy-coated reinforcing steel (ECR) were initiated. In the early 1970s, ECR was qualified as an alternative to black bar.(4,5) Consequently, for the past 30 years, ECR has been specified by State Departments of Transportation (DOTs) for major decks and substructures exposed to chlorides. At the same time, ECR was augmented by use of low water-to-cement ratio (w/c) concrete, possibly with pozzolans or corrosion inhibitors (or both), and covers of 65 mm or more.(6)

However, in Florida coastal waters, ECR has proven ineffective(7–10) because of the combined effects of higher average temperature and more prolonged moist exposure. Several comprehensive research studies, including evaluations on actual bridges, were conducted that further investigated, first, the suitability of epoxy coatings for reinforcement corrosion control and, second, in-service ECR performance.(11–13) These studies generally found that time-to-corrosion initiation for ECR and black bar are approximately the same but that the propagation period for ECR to cause concrete surface cracking can range from about the same as for black bar, as noted for Florida bridge substructures, to decades in northern bridge decks. Thus, while ECR performance in the latter type application has been generally good to date and results from long-term testing programs indicate that two mats of ECR in bridge decks should provide a 75–100-year service life with minimal maintenance as presently specified for major bridge structures,(13) still this is not known with certainty. In response to this, interest has focused during the past decade upon alternatives that afford more corrosion resistance than ECR—stainless steels in particular. Such corrosion-resistant steels become particularly competitive on a life-cycle cost basis, since the higher initial expense of the steel may be recovered over the life of the structure via reduced repairs and rehabilitations.

The Innovative Bridge Research and Construction Program (IBRC)[1] was authorized by Congress in the Transportation Equity Act for the 21st Century (TEA-21) legislation initially as a 6-year effort (fiscal year (FY) 1998–2003) but was subsequently extended through May 2005. The

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[1] Statutory references: 23 U.S.C. 503(b)(3)(A)(ii) & 503 (b)(3)(B); TEA-21 Section 5103.

program objective was to provide resources whereby States could demonstrate the utility of innovative materials and technology in construction of bridge and highway structures. The majority of the funding ($142 million) was for actual repair, rehabilitation, and replacement of existing structures and for new construction with a lesser amount ($4 million) for research, both based upon innovative materials. Corrosion-resistant reinforcements constitute one component of the program.

## PROJECT OBJECTIVES

As part of IBRC, a three-year study was performed by Florida Atlantic University (FAU) and the Florida Department of Transportation (FDOT) to document the projects that employed corrosion-resistant reinforcements and to provide an evaluation of their use. Specific project objectives were as listed below:

I. Provide a summary of the different alternative reinforcement products that have become available and which are being used in bridge construction.

II. Provide a summary of representative IBRC projects that have employed corrosion-resistant reinforcements.

III. Acquire samples of the alternative reinforcement employed in IBRC projects from the different job sites and characterize these in terms of mechanical properties, uniformity, conformance to specification (where applicable), and performance in accelerated corrosion tests.

IV. Establish a repository for the acquired reinforcement samples and preserve these as an archival record and reference for historical documentation purposes.

# IBRC PROJECTS INVOLVING CORROSION-RESISTANT REINFORCEMENT

## GENERAL

Task I was accomplished in conjunction with a companion research project and resulted in Federal Highway Administration (FHWA) publication.(14) Table 1 lists information that was made available to the project team regarding approved State IBRC projects involving innovative reinforcement (Task II). This shows that 27 State projects were approved; and of these, 20 were either completed as planned or with an alternate innovative reinforcement. These completed projects include seven different types of innovative reinforcements, as listed in table 2.[2] A dual listing is given for clad stainless steel since two very different production methods are involved. Likewise, table 3 lists the number of projects, both as-planned and as-completed, that employed each specific reinforcement type. Those involving ECR and black bar reflect instances where the supplier was unable to meet schedule in providing the specified innovative reinforcement, and so these were used as the fallbacks. Delivery was particularly a problem in the case of stainless clad reinforcement: one producer (Stelax, Inc., steel designated below as “Source 1”) went into receivership during the project time frame; the other (CMC Steel Group, designated as “Source 2”) experienced unexpected technical production difficulties. This was disappointing since stainless clad rebar has the potential of providing excellent corrosion resistance at relatively low unit cost. These two companies are addressing their respective difficulties, and one is now producing again and the second hopes to be in production in 2007. In many of the instances where a specified alternative reinforcement could not be delivered on schedule, MMFX-II served as the replacement. This reinforcement was consistently delivered in a timely manner even though the lead time was sometimes short.

Figure 1 shows the number of projects in each of the table 1 footnote classes. This indicates that the project team visited five of the projects (Note 1 designation) and in each case, acquired samples of the innovative reinforcement. For two additional projects (FHWA Project Numbers MO-00-01 and SC-00-01), one of which was completed prior to the present study, sufficient information was provided by the respective State DOT personnel that a report was prepared. Each of these seven reports is included below as appendixes A–G. In instances where samples of the innovative reinforcement were acquired from a job site, composition and mechanical properties were determined; and in some cases accelerated corrosion tests were performed.

[2] Galvanized steel reinforcement does not strictly qualify as innovative in that it has been available for many years and has been employed on a limited basis in past bridge construction.

**Table 1. Listing of approved IBRC projects involving innovative reinforcing steel.**

| FHWA Project Number | DOT Structure No. | Road | DOT Contact | Reinforcement Specified | Reinforcement Used | Project Type | Comments |
|---|---|---|---|---|---|---|---|
| DE-00-01 | 1-119 | SR 82 | Keith Gray | SS Clad | MMFX-II | Rehab | Note 1 |
| FL-00-01 | 150048 | SR 679 | William Domico | Clad 316 SS | Solid Type 2205 SS | Repl | Note 2 |
| FL-01-01 | 890146<br>890145 | Jensen Beach Causeway | William Nickas | MMFX-II<br>Solid Type 2201 SS | MMFX-II<br>Solid Type 2201 SS | Repl | Note 1 |
| GA-02-01 | 123-00282D-004.00E | SR 282 | Paul Liles | SS Clad | Black Bar | Repl | Note 3 |
| ID-02-01 | 18710 | Westmond Br, U.S. 95 | Luis Zarate | Clad 316 SS | MMFX-II | Repl | Note 4 |
| ID-02-02 | 12871 | SH21 | Ken Classen | MMFX-II | MMFX-II | Repl | Note 5 |
| IL-98-07 | 011-6011 | N 18th St Bridge | Roy Baranzelli | — | Galvanized | New | Note 5 |
| IN-00-01 | I-65-267-5055A & JA | I-65 | Tommy Nantung | SS Clad | ECR | Rehab | Note 5 |
| IA-01-01 | new | Hwy 520 | Norm McDonald | MMFX-II | MMFX-II | New | Note 4 |
| KY-01-02 | 105-1218-C0034 | CR1218 Galloway Rd | Steve Goodpaster | MMFX-II | MMFX-II | Repl | Note 5 |
| MI-01-02 | 33133045000R123 | EBD I-496 | Dave Juntunen | SS Clad | Solid SS | Repl | Note 4 |
| MN-00-02 | 27168 | T.H. 100 under | Erik Wolhowe | SS Clad | — | New | Note 6 |
| MO-00-01 | A6059 | Rte 6 | Ray Purvis | Solid 316LN SS | Solid 316LN SS | Repl | Note 7 |
| MO-02-02 | A6369 | Rte 136 | Ray Purvis | MMFX-II | ECR | Repl | Note 3 |
| MO-01-02 | A6098 | Rte 86 | Ray Purvis | SS Clad | ECR | Repl | Note 3 |
| MT-01-01 | P00001180+0.399-1 | U.S. 2 | Joe Kolman,<br>Nigel Mends | Solid Type 316 or 2205 SS | Solid Type 316LN SS | Repl | Note 1 |
| NC-02-02 | | SR1178 over I-95 | Roger Roschell | MMFX-II | MMFX-II | Deck | Note 4 |
| ND-00-01 | 94-290.803 | I-94 | Clayton Schumaker | SS Clad | SS Clad | New | Note 5 |
| NE-01-02 | SLB00317 | Skyline Drive | Gale Barnhill | SS Clad | ECR | New | Note 3 |
| NH-02-01 | 003501370012300 | I-93 | Mark Whittemore | MMFX-II | MMFX-II | Rehab | Note 5 |
| NH-02-03 | 016101850007700 | I-293 WB over Frontage Rd.<br>I-293 WB over Brown Ave. | Paul Nadeau | Clad 316L SS<br>Type 316L or 316LN SS | ECR (EB) Galvanized (WB)<br>ECR (EB) Galvanized (WB) | Repl | Note 1 |

**Table 1. Listing of approved IBRC projects involving innovative reinforcing steel—*Continued***

| FHWA Project Number | DOT Structure No. | Road | DOT Contact | Reinforcement Specified | Reinforcement Used | Project Type | Comments |
|---|---|---|---|---|---|---|---|
| NJ-02-01 | 1604-161 | Rte 23 NB | Harry Capers | MMFX-II | MMFX-II not qualified based upon NJDOT testing. Clad stainless steel then specified but reverted to ECR when clad could not be delivered. | Repl | Note 3 |
| NJ-02-01 | 1604-162 | Rte 23 NB ramp I | | | | | |
| NJ-02-01 | 1604-163 | Rte 23 SB ramp B | | | | | |
| NJ-02-01 | 1604-164 | Rte 23 SB | | | | | |
| NJ-02-01 | 1606-175 | Rte 46 WB, ramp G | | | | | |
| NJ-02-01 | 1609-153 | I-80 ramp B | | | | | |
| NJ-02-01 | 1606-176 | Rte 46 EB, ramp D & E | | | | | |
| NJ-02-01 | 1606-177 | Rte 46 WB, ramp I | | | | | |
| NJ-02-01 | 1604-411 | West Belt Bridge | | | | | |
| OK-01-01 | 14514 | I-35 | John Leonard<br>Jay Gilbreath | SS Clad | MMFX-II | New | Note 1 |
| PR-02 | 0000002061 | PR-102 | Javier E. Ramos | MMFX-II | MMFX-II | New | Note 8 |
| SC-00-01 | 264007300200 | Rte SC73 | Randy Cannon | Clad (Source 2), 2205 SS, and MMFX-II | | Repl | Note 4 |
| SD-01-01 | 07-112-326 | U.S. 281 | Dan Johnston | MMFX-II then Clad 316 SS | Type 2205 SS | Repl | Note 4 |
| SD-02-01 | 50178191 | Russell Avenue | Dan Johnston | MMFX-II then Clad 316 SS | Type 2205 SS | Repl | Note 4 |
| SD-02-01 | 51180180 | Maple Avenue | Dan Johnston | MMFX-II then Clad 316 SS | Type 2205 SS | Repl | Note 4 |
| SD-02-01 | 50181180+50179191 | I-29 | Dan Johnston | MMFX-II | ECR | Repl | Note 3 |
| TX-02 | — | Washington Street under I-40 | — | MMFX-II | — | Deck | — |
| UT-01-01 | 2D653 | EB SR-79 | — | SS Clad | ECR | | Note 3 |
| VA-98-01 | new | WBL Rte 460 | Steve Sharp | SS Clad | SS Clad (Source 1) | New | Note 7 |
| VA-01-01 | 6200 & 6202 | Route 123 bridge over Occoquan | Steve Sharp | SS Clad | MMFX-II | Repl | To be placed in 06 |
| VT-02-01 | 200034006410072 | VT 105 | David Scott | MMFX-II | MMFX-II | New | Note 5 |

**Table 1. Listing of approved IBRC projects involving innovative reinforcing steel—*Continued***

| FHWA Project Number | DOT Structure No. | Road | DOT Contact | Reinforcement Specified | Reinforcement Used | Project Type | Comments |
|---|---|---|---|---|---|---|---|
| WI-00-02 | B-56-153 | US 12 | Gerry Anderson | SS Clad | ECR | New | Note 5 |
| WV-02-01 | 000011A074 | Truss .07 mi E C/R 119-13 | Terry Bailey | SS Clad | Black Bar | Repl | Note 3 |



Note 1: Project visited and inspected. Samples acquired and report issued.
Note 2: Project completed prior to the present study. No report issued but samples available.
Note 3: Project modified. Innovative reinforcement not used.
Note 4: Project not visited or inspected. No samples available.
Note 5: Project completed prior to the present study. No report or material available.
Note 6: Funds diverted to another project that did not involve innovative reinforcement.
Note 7: Project completed prior to the present study. Report issued. No material available.
Note 8: Project not visited. Samples acquired.

**Table 2. Listing of innovative reinforcements employed in IBRC projects.**

| Designation | Common Name |
|---|---|
| — | Clad 316 SS (1) |
| — | Clad 316 SS (2) |
| ASTM A615, Grade 75 | MMFX-II |
| ASTM A955-98 | SS Type 2201LDX |
| UNS-S31603 | SS Type 316LN |
| UNS 31803 | SS Type 2205 |
| — | Galvanized Steel |

**Table 3. Number of projects involving various innovative reinforcement types.**

| | Planned | Constructed |
|---|---|---|
| Solid SS | 4 | 9 |
| Clad SS | 18 | 3 |
| MMFX-II | 24 | 13 |
| Galvanized Steel | 0 | 3 |
| ECR | — | 7 |
| Black Bar | — | 2 |

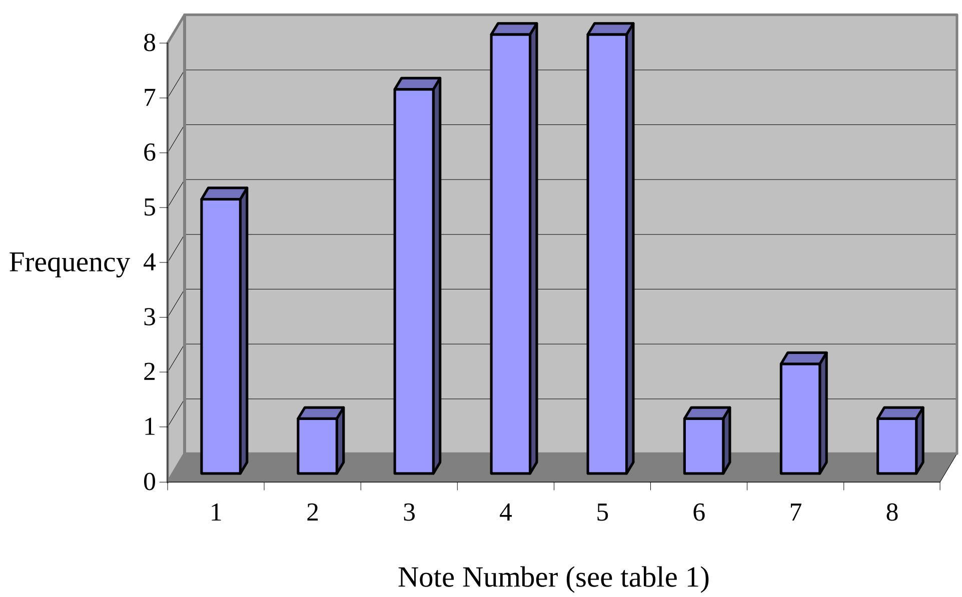


**Figure 1. Distribution of information acquisition and analysis for the IBRC projects.**

## RESULTS AND DISCUSSION

### Hallmark Projects

Two of the projects for which reports were written (MT-01-01 and SC-00-01) merit special comment because of their unique nature. The first involved a replacement bridge across the

Middle Fork of the Flathead River on U.S. 2 in Flathead County, MT. Permitting and closure for repair issues are such that it was desirable to have this bridge in uninterrupted service for as long as possible. With regard to permitting, one end of the bridge terminates on land owned by Glacier National Park and the other on land administered by Flathead National Forest. At the same time, the Flathead River is under jurisdiction of the United States Fish and Wildlife Service and contains several threatened or endangered species. Permitting for this project was complicated because these entities, as well as the U.S. Army Corps of Engineers and various State agencies, were also involved. Consequently, it was reasoned by the Montana Department of Transportation that any future repairs, rehabilitations, or replacement would be complex and difficult. In addition, because of the rural setting and mountainous surroundings, closure of this bridge results in a 480-kilometer (km) (300-mile (mi)) detour for motor traffic. For these reasons, the added initial cost of corrosion-resistant reinforcement was particularly justified.

An additional, particularly noteworthy issue arose in conjunction with project MT-00-01. The specification called for either Type 2205 or 316LN stainless as the reinforcement. It was assumed that the latter would be delivered because it generally is less expensive; however, the bridge engineer subsequently identified the bars as Type 2205 stainless steel. While both materials met specification and were acceptable, this situation points out a potential problem in that different stainless grades are generally not visually distinguishable. Consequently, where stainless reinforcement is employed, an independent determination should be made to confirm that the delivered product conforms to what was specified.

The second project, SC-00-01, was particularly noteworthy because it incorporated five different reinforcement scenarios, (1) black bar with discrete Galvashield XP™ embedded galvanic anodes, (2) black bar without anodes, (3) Type 2205 stainless steel, (4) Type 316 clad black bar (Source 2), and (5) MMFX-II. Individual spans were constructed using one of these five alternatives. It was initially intended that the black bar without anodes span would use 316 clad stainless steel from Source 1; however, the delivery delays discussed above precluded this. As constructed, this bridge affords an excellent opportunity for side-by-side comparison of a variety of reinforcing steel corrosion control alternatives.

A number of other projects also provide the opportunity for future side-by-side comparisons but in these cases between the corrosion-resistant reinforcement and ECR. Thus, in instances of a divided highway, one bridge commonly used ECR and the second, an innovative reinforcement.

### Compositional Analyses of Innovative Reinforcements from Job Sites

Chemical analysis was performed on samples of bars from six job sites, as reported in table 4. The results indicate that composition for all MMFX-II bars is within the specified range for that material. For the Source 2 cladding (SC-00-01), carbon concentration exceeds the upper limit for some 316 grades and is at the upper limit for others. Bars of this composition should not be welded unless special precautions are taken. The MT-01-01 bars are within the specified composition range for 2205 stainless.

**Table 4. Chemical composition for corrosion-resistant rebar samples.**

| Project Number | Reinforcement Type | Composition, weight percent | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C | Mn | P | S | Si | Cr | Ni | Mo | Cu | N | Fe |
| MT-01-01 | Type 2205 | 0.03 | 1.79 | 0.029 | 0.001 | 0.32 | 22.46 | 5.09 | 3.16 | 0.24 | 0.17 | Bal. |
| PA* | MMFX-II | 0.07 | 1.45 | 0.011 | 0.014 | 0.22 | 9.19 | 0.12 | 0.01 | 0.09 | — | Bal. |
| PR-02 | MMFX-II | 0.09 | 1.20 | 0.012 | 0.006 | 0.24 | 9.21 | 0.16 | 0.02 | 0.08 | — | Bal. |
| OK-01-01 | MMFX-II | 0.08 | 0.57 | 0.015 | 0.020 | 0.11 | 8.47 | 0.14 | 0.01 | 0.15 | — | Bal. |
| DE-00-01 | MMFX-II | 0.11 | 1.09 | 0.011 | 0.008 | 0.18 | 9.35 | 0.13 | 0.01 | 0.13 | — | Bal. |
| SC-00-01 | Clad (Source 2) | 0.08 | 1.44 | 0.001 | 0.001 | 0.47 | 16.18 | 10.34 | 2.51 | 0.21 | — | Bal. |

* Not an IBRC project.

## Mechanical Properties of Innovative Reinforcement Samples from Job Sites

Mechanical properties of samples of the same six corrosion-resistant reinforcements that were chemically analyzed (table 4) were determined, and the results are listed in table 5. All bars were #5 and qualified as Grade 60, although the MMFX-II is of considerably higher strength than is normally experienced here. All bars met their applicable standard specification, where one exists.

**Table 5. Listing of mechanical properties for job site acquired bars.**

| Project Number | Reinforcement Type | Yield Point, ksi | Tensile Strength, ksi | Elong., % | Weight, lb/foot | | Cold Bend++ | Deform. Height, in. |
|---|---|---|---|---|---|---|---|---|
| | | | | | Theor. | Actual | | |
| MT-01-01 | Type 2205 | 98 | 115 | 24 | 1.043 | 1.070 | OK @ 180 | 0.043 |
| PA* | MMFX-II | 145 | 162 | 6 | 1.043 | 1.003 | +++ | 0.031 |
| PR-02 | MMFX-II | 140 | 158 | 10 | 1.043 | 1.018 | +++ | 0.037 |
| OK-01-01 | MMFX-II | *** | 159 | 9 | 1.043 | 1.004 | OK @ 180 | 0.036 |
| DE-00-01 | MMFX-II | *** | 173 | 5+ | 1.043 | 1.047 | OK @ 180 | 0.035 |
| SC-00-01** | Clad (Source 2) | 72 | 105 | 15 | 1.043 | 1.059 | OK @ 180 | 0.033 |

ksi = 1000 pounds per square inch

* Not an IBRC project

** Material tested was stainless clad black bar from source 2.

*** No yield point identified.

\+ Did not break in gage area.

++ Pin diameter 2.19 in.

+++ Insufficient length to test.

## Corrosion Testing of Job Site Bars

Type 2201 stainless samples acquired from the job site of Project FL-01-01 and clad bar samples (Source 2), which were from the same production run as those used in Project SC-00-01, were subjected to corrosion testing in conjunction with a companion research project.[15] Several different surface preparations (as-received (rolled), carbon steel shot blasted, silica sand blasted, and stainless steel shot blasted) were used for the former alloy (2201) as a part of an FDOT program to identify the most appropriate condition. Based upon that program, silica sand blasted 2201 was qualified for the project. Accelerated corrosion testing of MMFX-II bars from three job sites (PR-02, OK-01-01, and DE-00-01) as well as the Type 2205 bars from MT-01-01 were also tested.

The accelerated test procedure was modeled after that from an earlier program[16] and involved exposure of triplicate specimens to repetitive cycles of 1.75 hours wet and 4.25 hours dry, for a total of 84 days. The test solution was 0.3N KOH-0.05N NaOH (pH ~ 13.40) simulated pore water with 3.00, 9.00, and 15.00 weight percent NaCl (1.82, 5.46, and 9.10 weight percent $Cl^-$) for each of three successive 28-day periods. Polarization resistance (inversely proportional to corrosion rate) measurements were made periodically during the exposures using a Gamry CMS100 potentiostat with a scan rate of 0.333 millivolts per second (mV/sec) and polarizations of +/-0.020 V referenced to the free corrosion potential. Prior to scanning, potential was monitored for 300 seconds or to a time lapse until any variations were less than 0.1 mV/sec.

Figure 2 shows a plot of polarization resistance (Rp) as a function of exposure time for the various Type 2201 stainless specimens along with data for black bar and Type 316 stainless for comparison. Specimens labeled according to the four surface conditions were provided directly by FDOT (see Appendix C1), whereas the specimens designated “Jensen Beach” (these were silica sand blasted) were acquired directly from the job site, where they had been stored uncovered about one kilometer inland for approximately six weeks. The data show that Rp for the Type 2201 specimens occupy a band about 1–2 orders of magnitude above that for black bar and 1–2 orders of magnitude below the Type 316. Scatter of Rp for the different categories of Type 2201 specimens is about one order of magnitude, with the silica sand and stainless steel blasted materials occupying the upper range. Also, there is a tendency beyond about 50 days for Rp to decrease with time (increasing corrosion rate).

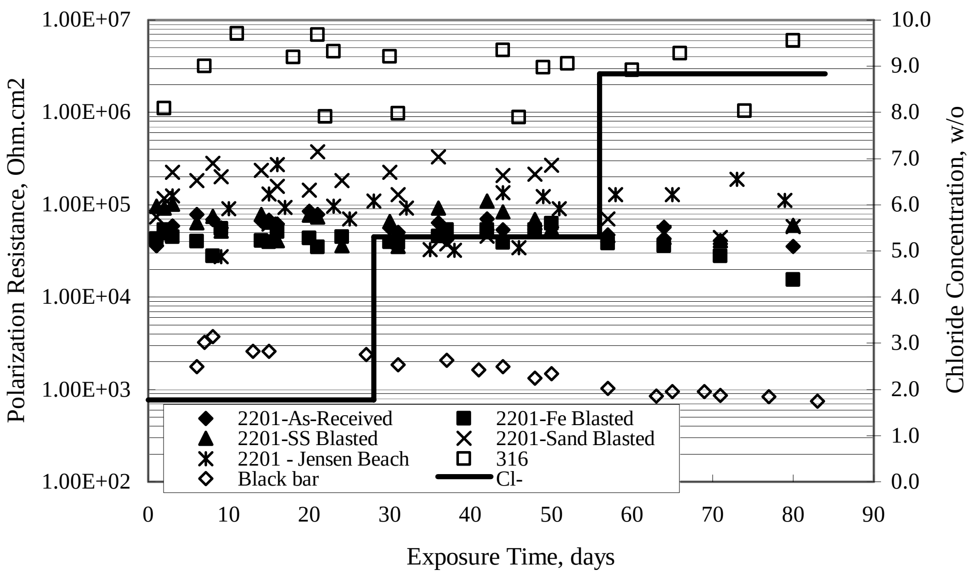


**Figure 2. Accelerated testing data for Type 2201 stainless steel specimens.**

Figure 3 shows a plot of Rp for MMFX-II specimens from three of the job sites compared to data for straight and bent bar specimens of this same steel (labeled “Lab”) that were provided directly to the project by MMFX Steel Corporation of America. Specimens designated MMFX (DE), MMFX (OK), and MMFX (PR) are from project numbers DE-01-01, OK-01-01, and PR-02, respectively (see table 1). The results indicate general consistency between the different job site and lab MMFX-II specimens with Rp for these being 5–10 times greater than for black bar.

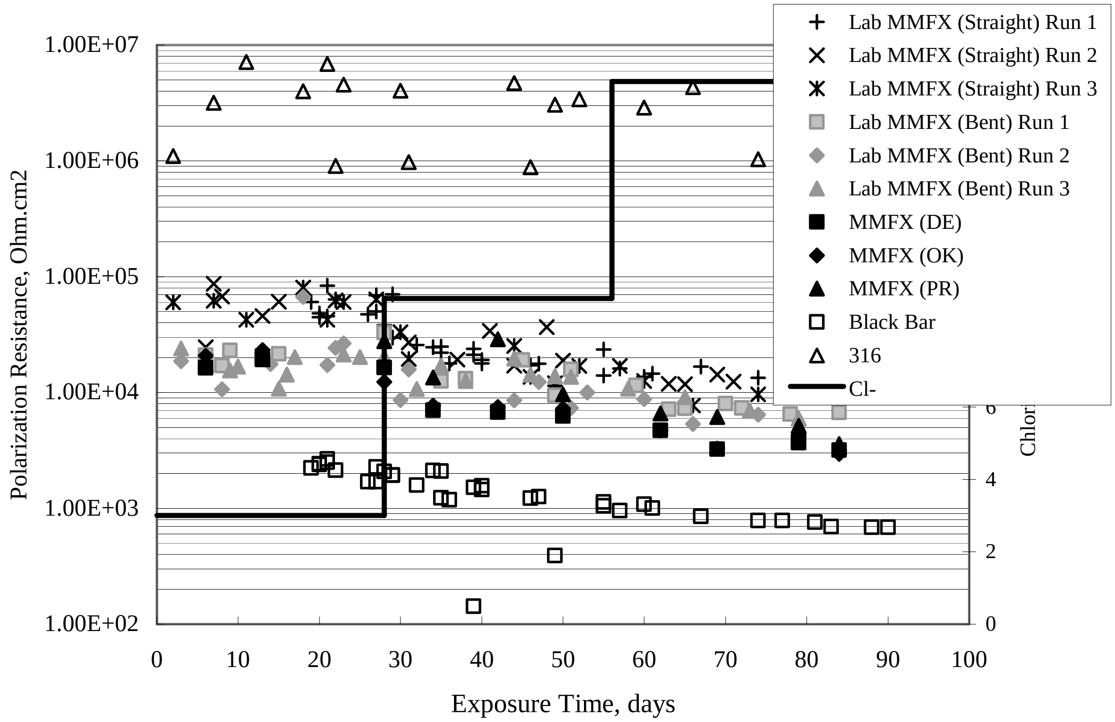


**Figure 3. Accelerated testing data for MMFX-II steel specimens.**

Figure 4 shows Rp versus time data for specimens prepared from project number MT-01-01 job site bars (Type 2205) and clad bars from the same heat as project number SC-00-01 (not actually from the job site). Data for the Type 316 and Type 2205 stainless that was provided directly to the project by a supplier are shown for comparison. Polarization resistance for the SC-00-01 clad bars varies from the lower range to an order of magnitude below that for the solid 316 (higher corrosion rate for the former). Results for the MT-01-01 specimens fall 3–10 times below those for the laboratory Type 2205 specimens. Thus, while data for laboratory received and job site MMFX-II bars are comparable, corrosion rate for the more corrosion-resistant job site bars was higher than for the laboratory received counterpart. These differences are being evaluated in conjunction with the companion activity.(15)

## Conformance of Innovative Reinforcement to Specification

Mechanical properties of specimens prepared from the corrosion-resistant reinforcement samples that were acquired from job sites (table 5) were compared with those listed in the relevant specifications (reference 17 for Type 2205 stainless steel, reference 18 for MMFX-II," and reference 19 for clad stainless steel). All properties of the stainlesses, both solid and clad, conformed to the applicable specification (ASTM A 955/A 955M-06a(16) and AASHTO Designation MP 13M/MP 13-04,(17) respectively). The same applies to MMFX-II (ASTM A 1035/ A 1035M-05(18)) with the exception of elongation, where 6 percent was measured for project

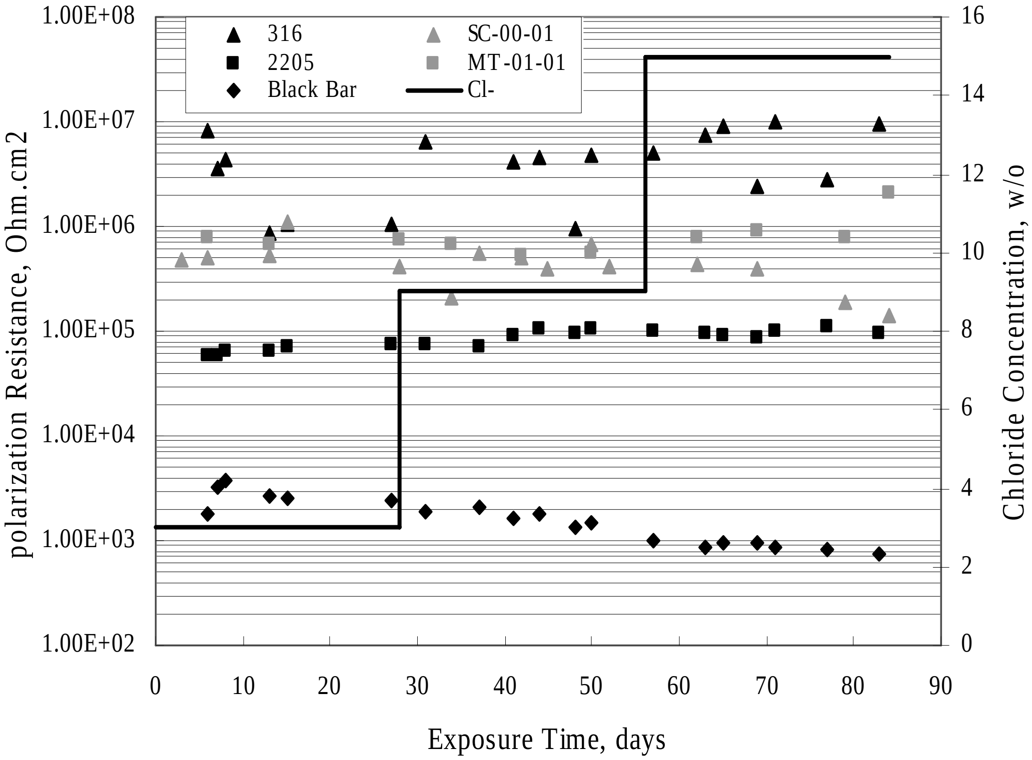


**Figure 4. Accelerated testing data for stainless steel job site bars.**

PA (not an IBRC project) bars (see tables 4 and 5) and 5+ percent for SC-00-01 but with the specification value being 7 percent. It should be pointed out, however, that the ASTM specification pertaining to MMFX-II was only issued in 2004, and the bars in question were produced prior to that date.

## Reinforcement Costs

Economics are an important component of any construction materials evaluation. For the reason of evaluating this within the context of the present study, reinforcement costs were acquired for projects for which reports were issued and are presented in figure 5. This shows that the average cost for the 316 and 2205 stainlesses was $5.34/kilogram (kg) and for the MMFX-II $1.46/kg. These values may be misleading, however, for the following reasons:

1. Reinforcement costs can be expected to decline if the materials become more common.
2. For some unknown reason, the cost for MMFX-II employed in conjunction with project FL-01-01 is unrealistically low (less than for black bar). On the other hand, the MMFX–II™ for DE-00-01 and OK-01-01 was provided on short notice because the originally specified clad bar could not be delivered in a timely manner. This could have elevated the cost.

3. The listed unit cost is not necessarily the lowest that was available, as material costs were often lumped into the contractor's bid. In the case of project MT-01-01, the bid unit costs ranged from $4.10 to $5.27/kg. Apparently, by going with the lowest overall contractor bid, a premium was paid for the reinforcing steel.

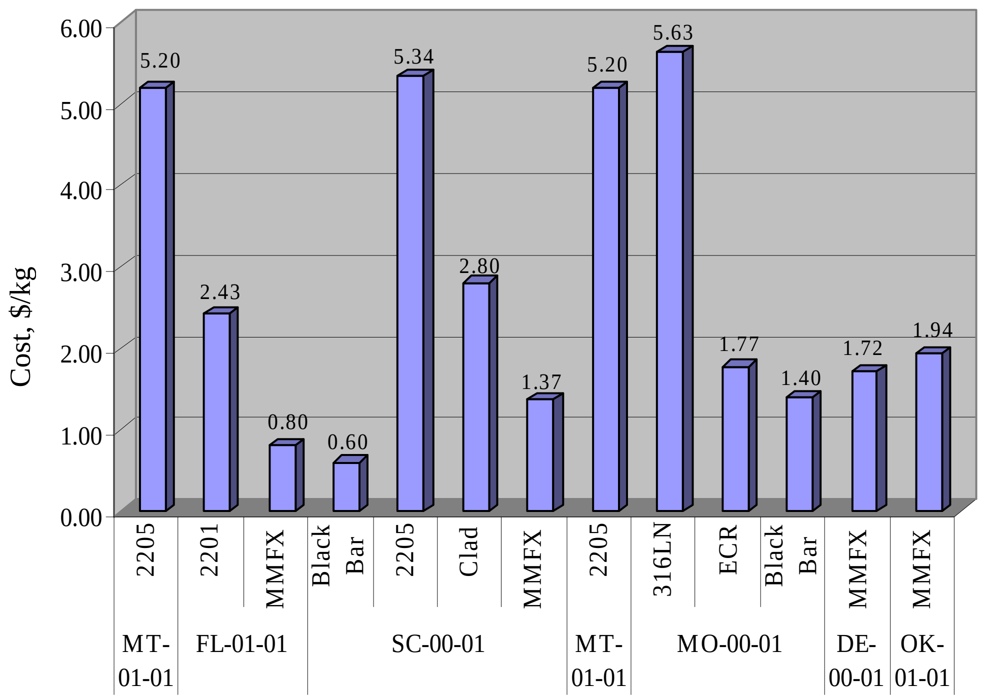


**Figure 5. Cost comparison of the various reinforcements.**

## CONCLUSIONS

The various IBRC projects demonstrated that, in most situations and subject to availability, corrosion-resistant reinforcing steel can be incorporated into bridge construction projects with relative ease. Construction personnel at several job sites indicated that corrosion-resistant reinforcement placement was more straightforward than for ECR because of the care that must be exercised to avoid coating damage on the latter. Further alloy development, particularly in the case of stainless clad, should be encouraged. Attempts should be made to compare results from ongoing laboratory studies, wherein methodologies for projecting long-term performance of corrosion-resistant reinforcement from short-term tests are being developed, with data from the IBRC bridges as the latter become available. This will require, however, that states maintain records for the respective bridges and commit to a long-term monitoring and data acquisition program.

**APPENDIX A**
**FHWA PROJECT NUMBER DE-00-01**
**TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM**
**Evaluation Report[3]**

**State:** Delaware.

**State DOT Contact:** Mr. Keith Gray [(302) 760-2327].

**Bridge Number:** 1-119.

**Project Type:** Deck Replacement.

**Location:** Bridge on SR 82 crossing Red Clay Creek in Ashland, New Castle County, DE.

**Innovative Material:** MMFX-II reinforcing steel.

**Bridge Description:** The bridge is a relatively short, historical, single span structure on a secondary roadway. As such, no deicing salts have normally been employed. Deterioration of the old deck involved concrete cracking and other distress that was apparently a consequence of freeze-thaw damage. The reinforcing steel (conventional black) was said to have been in good condition. Initially, stainless steel clad reinforcement was specified; but because of delivery problems, this was changed to MMFX-II. The project consisted of a full deck replacement and painting of the existing steel girders. The approach roadway was repaved, and new steel beam guardrails (polyester coated brown) were placed. The guardrail was attached to new barrier walls that were constructed adjacent to the existing barrier. This was designed to match the historic architecture of the existing barrier. The existing alignments and roadway widths were maintained. Figure 6 shows a side view of the bridge and of Red Clay Creek, while figure 7 is a photograph of the deck prior to concrete pouring but with the MMFX-II reinforcement in place.

**Figure 6. Side view of Bridge No. 1-119.**

[3] The description for this bridge utilizes English and not metric units since the project documents and specifications were so based.

**Figure 7. Photograph of the bridge deck with MMFX-II reinforcement in place.**

**Innovation Justification:** The bridge is subject to application of deicing salts, and chloride levels in the old deck were extremely high. It was considered that specification of a corrosion-resistant reinforcement in the replacement deck would reduce maintenance costs and extend the life of the bridge.

**Construction Sequence:** The contractor's construction sequence for the deck replacement involved the following sequential steps:

1. Removal of the existing deck.
2. Partial removal of the backwalls and construction of new joints.
3. Sandblasting the steel girders.
4. Placement of welded on shear studs.
5. Painting.
6. Placement of the reinforcing steel and monitoring devices (the monitoring devices were placed by the University of Delaware to assess load-deflection behavior).
7. Construction of formwork including a longitudinal bulkhead.
8. Pouring of the south side of the bridge deck.
9. Pouring of the north side.
10. Construction of the longitudinal joint.
11. Pouring of curbs and safety walk.
12. Mechanically grooving the bridge deck.

Figure 8 shows a general view of the in-place reinforcement, including that for the curb along one of the railings. Also shown are the girders and welded shear studs. Figure 9 provides a view of forming for the bulkhead at the other bridge end. A closer view of reinforcing bars and a girder with welded shear studs is shown in figure 10. The longitudinal and transverse bars are #5s, with spacing for the former being 10 inches and the latter, 12 inches. Figure 11 is also a closeup view of the in-place reinforcement showing superficial rusting. The steel had been onsite for approximately 20 days with rain having occurred during much of this time. This corrosion was judged to be less than what would have occurred with conventional uncoated black steel.

**Figure 8. General view of in-place reinforcement, girders with studs, curb, and bulkhead.**

**Figure 9. Closeup view of reinforcing steel, girder with shear studs, gusset plate, and forming for bulkhead.**

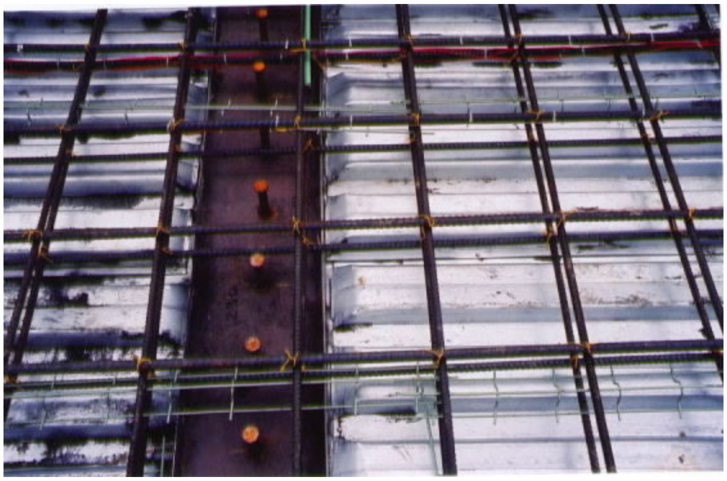

**Figure 10. Photograph of reinforcing steel and a girder with studs.**

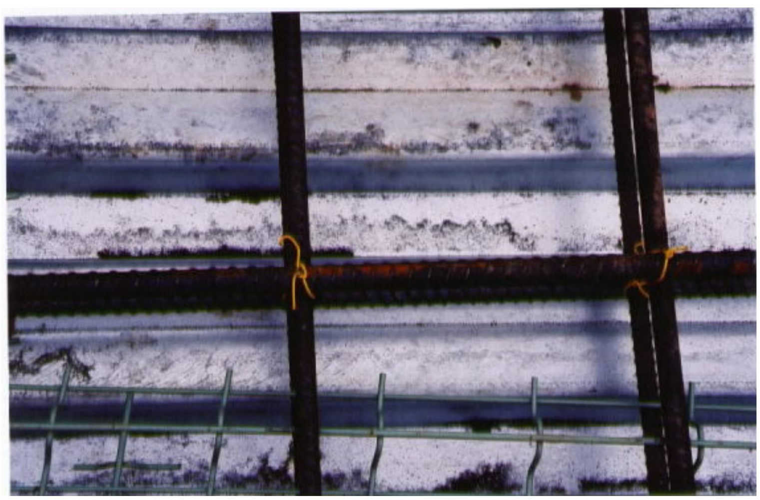

**Figure 11 Closeup view of in-place reinforcing steel showing superficial corrosion.**

**Reinforcement Specification:** Delaware DOT (DelDOT) did not have a material specification because, first, the use of MMFX-II steel was a field change and, second, the product is new. The design was based upon properties of conventional steel, and it was considered that the higher strength of MMFX-II would provide a further factor of safety.

**Concrete Specification:** The concrete was DelDOT Class D, “Deck Concrete,” the mix design for which is given in table 6. Slab thickness varied from 10.5 inches at the center to 8.5 inches at the outside. Design cover over the reinforcement was 2.5 inches.

**Table 6. Concrete mix design.**

| | |
|---|---|
| Cement Content (Type I), pcy* | 458 |
| Slag/Fly Ash, pcy | 247 |
| Fine Aggregate, pcy | 1,051 |
| Coarse Aggregate, pcy | 1,846 |
| Water Content, gal/cy** | 33.9 |
| Water-Cement Ratio | 0.4 |
| Water Reducer Admixture (Sikament-MP), 1 oz/94 lbs cementitious material | 40–80 |
| Air Content, percent | 5–8 |
| Polypropylene Fibers, pcy | 1.5 |

*pcy = pounds per cubic yard; **cy = cubic yards

**Job Contractor:** Greggo and Ferrara, Inc.
4048 New Castle Avenue
New Castle, DE 19720
(302) 658-5241

**Steel Supplier:** MMFX Steel Corporation of America, Inc. Subsequent to FHWA approval for substituting MMFX-II for stainless steel clad reinforcement, the contractor contacted MMFX-II directly to determine cost and availability. Straight bars were shipped to the contractor's steel fabricator (ReSteel) where cuts and bends were made. ReSteel then shipped the bars directly to the job site. There were no delays or delivery problems in acquiring the MMFX-II reinforcing steel.

**Material Cost:** The MMFX-II material cost for 8.79 metric tons was $15,120 for a unit price of $0.78/lb ($1.72/kg). The in-place reinforcing steel cost was $2.95/lb ($6.49/kg).

**Job Site Storage:** The reinforcing steel was delivered elevated on a flatbed truck and stored elevated and uncovered on the ground.

**Material Acquisition:** Six bent bar details were made available from the job storage site for testing by FAU and FDOT. Figure 12 shows a photograph of these.

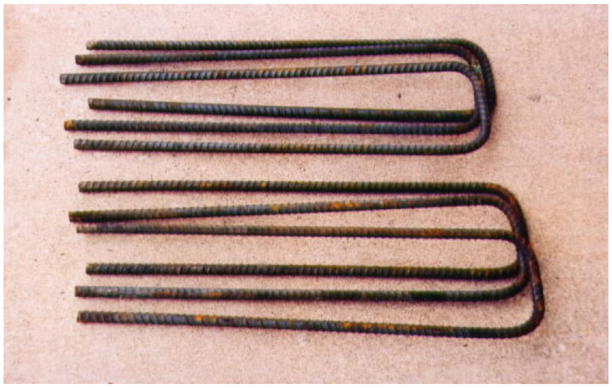

**Figure 12. Photograph of MMFX-II reinforcement details acquired from the job site.**

**APPENDIX B**
**FHWA PROJECT NUMBER FL-00-01, PART 1**
**TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM**
**Evaluation Report**

**State**: Florida.

**State DOT Contact**: Mr. Randall Scott [(772) 225-1888].

**Bridge Number**: 890146 (East Relief Bridge).

**Project Type**: Replacement.

**Location**: Bridge crossing the St. Lucie River at Jensen Beach, FL.

**Innovative Material**: MMFX-II Reinforcing Steel.

**Bridge Description**: This bridge is the eastern of two four-lane structures[4] in a causeway between Jensen Beach and Stuart in southeast Florida. It replaces a 50-year-old, low-profile, two-lane bridge that has badly deteriorated because of the combined effects of brackish water, near-ocean exposure, and age; it is now functionally obsolete. Figure 13 shows a perspective of what will be the two northern lanes (westbound). Construction of the southern (eastbound) lanes will start once the northern is completed. The project is scheduled for completion in March 2004. Each bent consists of four 0.6-m (24-inch) square prestressed pilings, conventionally reinforced pile caps, and 16 deck spans. These components, plus barrier and parapet walls, are reinforced with conventional steel except for eight deck spans (numbers 9–16), reinforced with MMFX-II. The deck spans are formed cap-to-cap using an assembly of plywood on transverse and then on longitudinal I-beams. The framing is pulled subsequent to concrete setting and is reused.

**Figure 13. Perspective view of replacement Bridge Number 890146.**

[4] The second or western bridge (Frank A. Wacha Bridge of Bridge Number 890145) is addressed in a companion IBRC report.

**Innovation Justification:** The bridge is subject to a marine exposure in a semitropical south Florida coastal environment. It is anticipated that MMFX-II reinforcement will provide improved corrosion resistance and thereby facilitate achieving a 100-year design life.

**Construction Sequence:** The contractor's construction sequence involves the following steps:

1. Driving of conventional prestressed piles.
2. Forming, steel placement, and pouring of pile caps. Figure 14 shows a view of piles and pile cap for a specific bent.
3. Deck forming, steel placement and pouring of the deck. The deck is being placed from west to east with each span being formed and poured as a separate unit.

Figures 15 and 16 show photographs of the MMFX-II steel in place on the deck.

**Figure 14. Photograph of substructure components prior to decking.**

**Figure 15. Photograph of MMFX-II deck steel in place.**

**Figure 16. Second view of MMFX-II deck steel in place.**

**Reinforcement Specification:** At the time of construction, no national standard existed for MMFX-II reinforcing steel. In lieu of this, the manufacturer's "Product Bulletin" dated September, 2001 was employed. The eight MMFX-II deck spans require a total of 145,004 kg (319,734 pounds) of reinforcement. All longitudinal bars for both mats are #32 (metric designation) and are spaced at 165 mm in the top mat and 200 mm in the bottom. All transverse bars are #16 (metric designation) and are spaced at 300 mm in the top and 255 mm in the bottom mat.

**Concrete Specification:** The concrete was specified as conforming to Class IV of Section 346 of the FDOT State Specifications Office. Table 7 provides a listing of required properties.

**Table 7. Concrete mix design.**

| | |
|---|---|
| Min. Cementitious Content (Type II + pozzolans), kg/m$^3$ | 390 |
| Maximum Water-Cement Ratio | 0.41 |
| Target Slump, mm | 75 |
| Air Content Range, percent | 1–6 |
| Minimum Compressive Strength (28d), MPa* (ksi) | 38 (5.5) |
| Water-Cement Ratio | 0.41 |

*MPa = megapascal; 1 MPa = 20.885 ksi

**Job Contractor:** Archer Western, Inc.
Jacksonville, FL

**Steel Supplier:** MMFX Steel Corporation of America, Inc.

**Material Cost:** The contractor indicated the in-place cost for MMFX-II as \$0.80/kg (\$0.36/pound). This is an abnormally low figure, particularly in view of the fact that the corresponding cost for black steel was \$1.00/kg (\$0.45/pound).

**Job Site Storage:** The bars were stored wrapped with polyethylene and elevated. Figure 17 shows a photograph of this. This specific measure was considered important because there was a single delivery of all reinforcement. Consequently, bars for the southern (eastbound) bridge for which construction has not yet commenced will be on site for a number of months prior to placement.

**Figure 17. Photograph of stored MMFX-II reinforcing steel at the job site.**

**Construction Difficulties:** No construction difficulties have been encountered.

## APPENDIX C
## FHWA PROJECT NUMBER FL-00-01, PART 2
## TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM

### EVALUATION REPORT

**State:** Florida.

**State DOT Contact:** Mr. Randall Scott, P.E. [(772) 225-1888].

**Bridge Number:** 890145 (Frank A. Wacha Bridge).

**Project Type:** Replacement.

**Location:** Bridge crossing the St. Lucie River at Jensen Beach, FL.

**Innovative Material:** Type 2201 Stainless Steel Reinforcement.

**Bridge Description:** The bridge is the center of three two-lane structures[5] that serve as a causeway between Jensen Beach and South Hutchinson Island on the southeast Florida coast. It is replacing a 50-year-old, low-profile, two-lane bascule bridge that has become badly deteriorated because of the combined effects of brackish water exposure and age, and is now functionally obsolete. Figure 18 shows a perspective photograph of the project which is scheduled for completion in March 2005 (note the old bridge in the background). The substructure design involves conventional, driven prestressed piles, cast-in-place footers, columns and cast-in-place hammerhead column caps. The superstructure is constructed with precast Florida bulb-tee beams and a cast-in-place deck. Unlike northern areas that employ deicing salts such that deterioration from embedded steel corrosion and concrete cracking and spalling is largely confined to the deck, it is the substructure of coastal bridges in Florida that typically experiences the greatest distress. While most of the reinforcement in this bridge is conventional bar or prestressing strand, the footer and column of two piers (numbers 11 and 12, which are just to the right of the leftmost crane in figure 18) are being constructed using Type 2201 stainless steel. The eastern bridge, the construction of which is of longer duration, will have MMFX-II reinforcement in eight deck spans.

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[5] The second or eastern bridge (East Relief Bridge or Bridge Number 890146) is addressed in a companion IBRC report.

**Figure 18. Perspective photograph of the Jensen Beach Causeway Bridge under construction.**

**Innovation Justification:** The bridge is subject to a marine exposure in a semitropical south Florida coastal environment. It is anticipated that 2201 stainless steel (ss) reinforcement will provide improved confidence that structures of this type can achieve a 100-year life.

**Construction Sequence:** The contractor's construction sequence involved the following sequential steps:

1. Driving of conventional prestressed piles. Figure 19 shows a photograph of these, as driven, for the number 12 pier.
2. Cut prestressed pilings to grade.
3. Placement of 203-mm (8-inch) thick seal slab and associated footer formwork.
4. Placement of footer reinforcement. Figure 20 shows a photograph of this in progress for the footer of pier number 11, and figure 21 does the same for pier number 12.
5. Pouring of footer concrete.
6. Placement of prefabricated column reinforcement cage.
7. Placement of column formwork.
8. Pouring of column concrete.
9. Placement of hammerhead cap form.
10. Placement of cap steel.
11. Pouring of cap concrete.
12. Placement of Florida bulb-tee beams.
13. Deck placement.

**Figure 19. Photograph of driven, cut-off prestressed piles for pier 11.**

**Figure 20. Photograph of formwork, piles, and reinforcement being placed in the footer of pier number 12.**

**Figure 21. Photograph of formwork, piles, and reinforcement being placed in the footer of pier number 12.**

Figure 22 shows a closer view of the in-place 2201 bars at the bottom of the footer for pier number 12. The threaded conventional steel bars and support I-beams upon the piles remain in place, but the black bars will be isolated from the 2201 prior to concrete pouring. The tie wire is also stainless steel (type unknown).

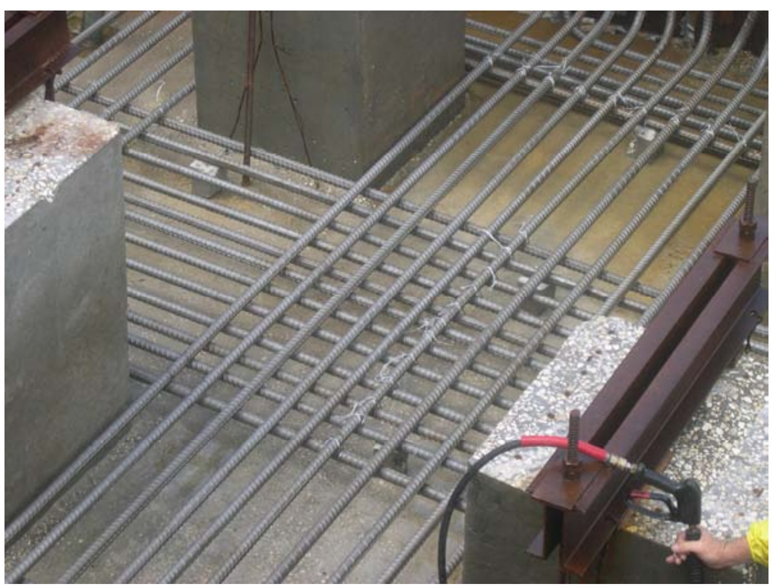

**Figure 22. View of 2201 ss in place at the base of the footer formwork.**

Figure 23 shows a perspective view of the reinforcement cage for column number 11 as fabricated prior to placement. At the time of this photograph, the cage had been in this position for approximately six weeks. Figure 24 is a closeup view of a portion of the cage showing the bars to be generally excellent condition. Figure 25 shows a conventional bar reinforcing steel cage for a hammerhead column cap that had been exposed for approximately the same length of time as the column cage (figures 23 and 24). Here, rusting over the whole surface is apparent.

**Figure 23. Photograph of 2201 ss reinforcement cage for the column of pier number 11.**

**Figure 24. Closeup view of a portion of the 2201 ss reinforcing bars in the column cage prior to placement in pier number 11.**

**Figure 25. Photograph of the conventional bar reinforcement cage for a hammerhead column cap.**

Figure 26 shows a photograph that was taken several weeks after the ones above of the column steel and forms of pier number 11 in place.

**Figure 26. Photograph of pier number 11 column formwork and 2201 ss cage in place.**

**Reinforcement Specification:** The column and bottom mat footer bars are #36 (metric designation) and the top mat footer bars are #19 (metric designation). A total of 8,048 kg (17,746 lb) of reinforcement was required for each footer. The column of pier number 11 required 10,422 kg (22,981 lb) of reinforcement and for pier number 12, 9,741 kg (21,479 lb), with the difference resulting from the difference in height. Clear cover in both cases is specified as 115 mm (4.5 inches).

**Concrete Specification:** The concrete was specified as conforming to class IV of section 346 of the FDOT State Specifications Office. Table 8 provides a listed of required properties.

**Table 8. Concrete mix design.**

| | |
|---|---|
| Min. Cementitious Content (Type II + pozzolans), $kg/m^3$ | 390 |
| Target Slump, mm | 75 |
| Air Content Range, percent | 1–6 |
| Minimum Compressive Strength (28d), MPa (ksi) | 38 (5.5) |
| Maximum Water-Cement Ratio | 0.37 |

MPa = megapascal; 1 MPa = 20.885 ksi

**Job Contractor:** Archer Western, Inc.
Jacksonville, FL

**Steel Supplier:** Gerdau Ameristeel, Inc., as supplied by Avesta Sheffield in Sweden.

**Material Cost:** The delivered cost was \$2.43/kg (\$1.10/lb).

**Job Site Storage:** The column cage fabrication commenced shortly after bars were delivered. Consequently, the bars were stored elevated but uncovered per FDOT Specification 415.

**Special Considerations**: Prior to delivery of the steel, the supplier (Gerdau Ameristeel, Inc.) expressed concern that the as-rolled 2201 would develop surface rust as a consequence of the use of carbon steel rolling and handling equipment. A test program was performed by the FDOT Corrosion Laboratory in Gainesville, FL, to assist in selection of an appropriate surface treatment. A copy of the report issued by FDOT is attached as appendix C1. Based upon this, blasting with silica sand was selected with the specification for this, as is described in appendix C2. From the appearance of the stainless steel at the job site (see figures 20–24), this treatment accomplished what was intended.

During construction, ground leads were installed to the 2201 column steel. The purpose of these was to facilitate subsequent continuity and corrosion test measurements. The work was performed by Concorr Florida, Inc., under direction from the FDOT Corrosion Laboratory in Gainesville, FL.

**Construction Difficulties:** The 2201 column and footer cages were fabricated on the construction site. Because the source of replacement reinforcement was in Sweden, possible delay resulting from mistakes raised concerns. However, the fabrication occurred without incident; and so this concern did not materialize.

## FLORIDA DEPARTMENT OF TRANSPORTATION CORROSION RESEARCH LABORATORY

Four sets of 16-mm bars of alloy 2201 stainless steel furnished by Gerdau Ameristeel, Inc., were received for testing per ASTM G85, “Standard Practice for Modified Salt Spray (Fog) Testing.” The four sets received had different surface condition per table 9:

**Table 9. Listing of reinforcements and surface condition for each.**

| Set # | As Received Surface Condition |
|---|---|
| 1 | Carbon Steel Shot Blasted (Fe blasted) |
| 2 | Plain (As received) |
| 3 | Sand Blasted |
| 4 | Stainless Steel Shot Blasted  (ss blasted) |

Half of the bars for each set were pickled per ASTM A380, “Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems,” Table A1.1 “Acid Descaling (Pickling) of Stainless Steel,” Code B, followed by scrubbing with plastic fiber brush in hot running tap water. The bars were exposed in salt spray tank for 3 days positioned horizontally as shown in figure 27.


**Figure 27. Bars positioned in salt fog chamber.**

The photographs in figures 28–31 show the condition of the bar samples after salt spray exposure.


**Figure 28. Bars 1A and 1B.**

- Bar 1A: Shot blasted with carbon steel, 98 percent area corroded, heavy corrosion
- Bar 1B: Shot blasted with carbon steel and pickled, 3 percent area corroded, light corrosion.


**Figure 29. Bars 2A and 2B.**

- Bar 2A: Plain, 98 percent area corroded, heavy corrosion.
- Bar 2B: Plain pickled, 2 percent area corroded, light corrosion.


**Figure 30. Bars 3A and 3B.**

- Bar 3A: Sand blasted with silica sand, 5 percent area corroded, light corrosion.
- Bar 3B: Sand blasted with silica sand and pickled, 1 percent area corroded, light corrosion.


**Figure 31. Bars 4A and 4B.**

- Bar 4A: Shot blasted with stainless steel, 50 percent area corroded, light corrosion.
- Bar 4B. Shot blasted with stainless steel and pickled, less than 1 percent area corroded, light corrosion.

GERDAU AMERISTEEL

Jacksonville Mill
217 Yellow Water Road
Jacksonville, FL 32234

# Stainless Blasting Procedure

Work to be performed at Blast Tech.

1. Rod Powers, State Materials Office, will be notified prior to blasting. 352–337–3134 work, 352–334–1649 fax, Rodney.powers@dot.state.fl.us e-mail.
2. Bars will be placed on work stands approximately one-third full. This will depend on the diameter of the bars. Bars will be blocked if the blasting causes them to roll.
3. The bars will be hand blasted with silica sand covering approximately one-half the diameter. Blasting sand will not be reused.
4. The bars will then be rotated one-third of a turn.
5. The bars will be hand blasted with silica sand covering approximately one-half the diameter.
6. The bars will then be rotated another one-third of a turn.
7. The bars will be hand blasted with silica sand covering approximately one-half the diameter.
8. The blasters will then remove their hoods and inspect the bars, touching up as needed. The bars shall be free of mill scale and red rust.
9. The bars will then be tied with 9-gauge [polyvinyl chloride] PVC coated wire using eight ties.
10. The bundles will then be handled using a spreader beam and nylon straps to load on a spare trailer. The bars will be maintained upon wooden or padded cribbing during transport and storage.
11. Bill Stephens will visit and inspect loads prior to shipping.

**APPENDIX D**
**FHWA PROJECT NUMBER MO-00-01**
**TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM**
**Evaluation Report**[6]

**State:** Missouri.

**State DOT Contact:** Mr. John D. Wenzlick [(405) 521-2606].

**NBI Bridge Number:** 6059.

**Project Type:** Replacement Bridge.

**Location:** Bridge crossing Medicine Creek and an adjoining field runoff stream on SR 6 near Galt, MO (~100 miles northwest of Kansas City, MO).

**Innovative Material:** Solid Type 316LN Stainless Steel.

**Bridge Description**: The new bridge is one of a sequential pair, where the companion bridge (Bridge Number A6060) is approximately 600 feet east of the bridge in question. Bridge Number A6059 consists of a reinforced concrete slab that was formed conventionally. Bridge Number A6060, on the other hand, employed permanent precast prestressed structural form panels and a cast-in-place topping between the external girders. The slab overhang from the external girders was conventionally formed. ECR was employed for the companion bridge. Roadway width and girder spacing are the same for the two bridges, but span length and skew differ. Both bridges were opened to traffic in June 2001. Figure 32[7] provides a perspective view of the two bridges, and figure 33 shows a profile of one of the two. Figure 34 provides a view of the stainless steel reinforcement, as placed in the deck of Bridge Number A6059. A report detailing the bridges and planned comprehensive evaluation program is available from Missouri DOT (MoDOT).[(20)]

**Figure 32. General view of the Route 6 bridges.**

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[6] The description for this bridge utilizes English and not metric units since the project documents and specifications were so based.

[7] All photographs courtesy of Mr. John Wenzlick, MoDOT.

**Figure 33. Side view of Bridge Number 6059.**

**Figure 34. View of bridge deck with stainless steel in place.**

**Innovation Justification:** The anticipated good corrosion resistance of the Type 316LN stainless reinforcing steel compared to ECR and certainly to black steel should result in reduced maintenance and life-cycle cost for the bridge.

**Construction Sequence:** Unknown.

**Reinforcement Specification:** The Type 316LN stainless steel met the specification of ASTM A955M Grade 420 deformed bars that were called for in special provisions.

**Concrete Specification:** Unknown.

**Job Contractor:** Unknown.

**Steel Supplier:** Empire Specialty Steel, Inc., Dunkirk, NY.

**Material Cost:** Material cost for the stainless steel for Bridge Number A059 was $2.55/lb ($5.63/kg). The ECR material cost for Bridge Number A6060, on the other hand, was $0.80/lb ($1.77/kg). Black steel priced at $0.64/lb ($1.40/kg).

**Job Site Storage:** No information available.

**Problems:** No information available.

**Material Acquisition:** No steel from the job site was available for evaluation.

**APPENDIX E**
**FHWA PROJECT NUMBER MT-01-01**
**TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM**
**Evaluation Report**

**State:** Montana.

**State DOT Contact:** Mr. Nigel Mends [(406) 444-9221].

**NBI Bridge Number:** P00001180+0.399-1.

**Project Type:** Replacement.

**Location:** Bridge crossing the Middle Fork of the Flathead River on U.S. 2 near Essex, Flathead County, MT.

**Innovative Material:** Solid Stainless Steel Type [American Iron and Steel Institute] AISI 316LN or 2205 reinforcement and related hardware.

**Bridge Description:** The new bridge is replacing an older one that is structurally obsolete. It is 190 m long with four spans of lengths 43, 52, 52, and 43 m. The two-lane roadway width is 12 m. Alignment is tangent across the bridge except for the last span which lies on a 5-degree spiral. Four welded plate weathering steel girders, each with a 900x22 mm web and 400 mm wide flange which varies in thickness from 19 mm at midspan to 64 mm over the piers, support the deck. The cast-in-place deck has a constant 2 percent superelevation. The specified deck thickness is 215 mm and the concrete cover over the top reinforcement 60 mm.

**Innovation Justification:** One end of the bridge terminates on land owned by Glacier National Park and the other on land administered by Flathead National Forest. The Flathead River that the bridge crosses is under jurisdiction of the United States Fish and Wildlife Service. Permitting was complicated because these, as well as the U.S. Army Corps of Engineers and various State agencies, were involved. Consequently, it was reasoned by the Montana Department of Transportation (MDT) that any future repairs, rehabilitations, or replacement would be complex and difficult. The bridge was anticipated to require relatively high maintenance if it were built using conventional reinforcement (ECR) because it is in a heavy snow area that experiences wintertime applications of $MgCl_2$ (liquid form) and numerous freeze-thaw cycles. In addition, because of the rural setting and mountainous surroundings, any bridge closure involves a 480-km (300-mile) detour. For this reason, extra expense that promoted longevity with minimal maintenance was considered justified.

**Construction Sequence:** The four piers were formed and poured during the second half of 2001, and the deck was placed in June and July 2002. The site was visited on June 24, 2002, at which time approximately two-thirds of the reinforcement had been placed. Figure 35 shows a photograph of the deck at that time.

**Figure 35. View of deck with stainless steel reinforcement placement in progress.**

**Reinforcement Specification:** The reinforcement for both mats was specified as pickled AISI Stainless Steel Type 316LN or 2205 which was to be delivered to the construction site free of any rusting.

**Concrete Specification:** The concrete was termed, “Special Deck,” with properties as specified in table 10.

**Table 10. Concrete mix design.**

| | |
|---|---|
| Cement Content (minimum), $kg/m^3$ | 390 |
| Water Content (maximum), $kg/m^3$ | 155 |
| Slump Range, mm | 40–80 |
| Air Content, percent | 6±1 |
| Maximum Coarse Aggregate, mm | 19 |
| Compressive Strength (minimum), MPa | 34 |

**Job Contractor:** Frontier West, Inc.
P.O. Box 16295
Missoula, MT 59808

**Steel Supplier:** Empire Steel. The reinforcing steel was acquired from Spain and shipped to the United States. Cutting and bending, where necessary, were performed in Colorado; and the steel was then shipped to the job site. Guard angles were provided by Watson Bowman Acme Corp. in New York.

**Material Cost:** The reinforcement cost was estimated as \$3.50/kg (\$1.60/lb). Five bids were obtained that ranged from \$4.10/kg (\$1.86/lb) to \$5.27/kg (\$2.39/lb). The lowest bidder for the overall project was awarded the contract, with the reinforcement cost being \$5.20/kg (\$2.36/lb). A total of 106.5 tons of reinforcement was required.

**Job Site Storage:** Two truckloads arrived at the job site on June 13, 2002, and the remaining three truck loads during the week of June 17. These were off-loaded onto wooden 2-ft by 4-ft supports on the ground. Figure 36 shows a photograph of this storage. The storage time was short, as placement commenced shortly after delivery. Packaging and covering are described below. No problems were encountered in connection with delivery and storage.

**Figure 36. Photograph of bundled/wrapped bars at the job site.**

**Presence of Carbon Steel:** Shear studs on the top girder flanges are carbon steel. Figure 37 shows how these penetrate the bottom mat of stainless steel. The specification requires that there be no contact between the studs and reinforcement. This was accomplished using plastic caps over the studs. These had not been placed at the time on this site visit, and so they do not appear in figure 37. Stainless steel in the structure backwalls is tied to black bar.


**Figure 37. View showing carbon steel shear studs protruding through bottom mat of stainless steel reinforcement.**

**Problems:** The following difficulties were encountered when incorporating stainless steel into this project.

1. MDT personnel indicated that industry was very encouraging with regard to using stainless steel reinforcement but was less than enthusiastic when specialized treatment and handling became involved. As one example, the supplier’s pickling bath was 10 m long; and they would not invest in lengthening this to accommodate longer bars. Consequently, longer bars had to be cut for pickling and unnecessarily spliced when placed. This increased cost because of the additional material required for the lap splices.
2. The bars were processed and packaged in Spain using Teflon-coated stainless steel bands and a water-repellant, heavy paper-like wrapping. This wrapping can be seen in figure 36. When these bundles were opened at the job site, the reinforcement was clean and bright, and no rust spots were evident. However, bundles that were opened in Colorado for cutting and bending exhibited rust spots. Figure 38 shows examples of these. Such corrosion apparently resulted because carbon steel (nonstainless) handling and bending equipment was used in conjunction with the cutting and bending operations. This is in spite of a preconstruction meeting with the supplier, at which time the need for special handling was discussed and agreed to. The bent bar details were repackaged in cardboard boxes only, as shown in figure 39. MDT is requiring that rusted bars be retreated in place according to ASTM Specification A380-94a.

(a)

(b)

**Figure 38. Examples of rust spots on reinforcement:**
**(a) bundled bent bars in opened cardboard container and**
**(b) straight reinforcement in place.**

3. Procurement of the expansion joint guard angles was expensive because, first, the manufacturer treated this as a special order and, second, they were not used to fabricating stainless steel. The guard angles arrived at the site packaged with carbon steel bands. Figure 40 is a view of a guard angle in place.
4. Placement of the stainless steel rebar was estimated to have taken 1.5–2 times longer than for conventional steel. This resulted because stainless steel chairs were not available as epoxy-coated ones are for ECR, and reinforcement had to be tied with

**Figure 39. View showing cardboard packaged bent reinforcement details.**

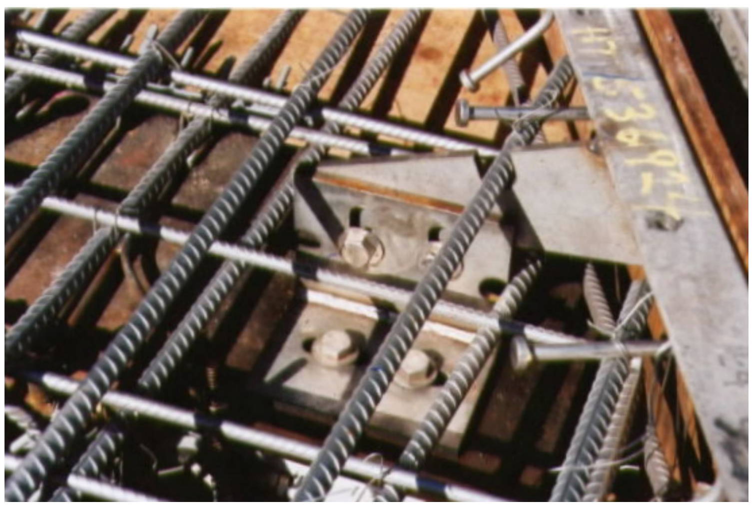

**Figure 40. View of a guard angle adjacent to an expansion joint.**

wire individually to each plastic chair. Figure 41 shows an array of chairs on the deck in preparation for placement of the top mat (see figure 35 also), and figure 42 shows a closeup view of a completed placement area where both the top and bottom bars are tied with wire to a chair. This difficulty should be overcome as stainless steel reinforcement use becomes more common, at which time stainless steel or plastic chairs should be available.

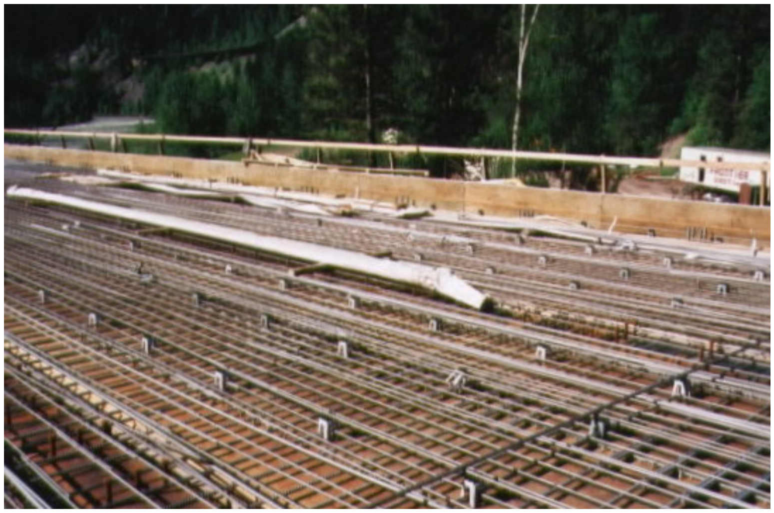

**Figure 41. Array of plastic chairs to which bars from both mats are tied.**

**Figure 42. Closeup view of a plastic chair to which bars are tied.**

5. MDT personnel assumed that the reinforcement would be AISI 316LN rather than 2205, which was also allowed, because the former is less expensive. Compositional analyses subsequent to placement revealed, however, that the reinforcement was 2205. While this, in and of itself, was not a problem, it does point out a need for identity confirmation of as-received stainless steel reinforcement.

6. Mass of the #22 (metric designation) stainless steel bars averaged 2.80 kg/m$^3$, whereas the specification requires 2.85 kg/m$^3$. Consequently, the bar mass was 98

percent of what was required. The reduced mass was subtracted from payment to the contractor based on the bid price per kg.

7. The specification deformation height for the #13 (metric designation) bars was 0.51 mm, whereas the actual height was approximately 0.33 mm (65 percent of what was required). A percentage reduction of payment to the contractor, based upon the bid price, resulted.

**Material Acquisition:** Four bent bar details were made available from the job site for testing by FAU and FDOT. Figure 43 shows examples of these.

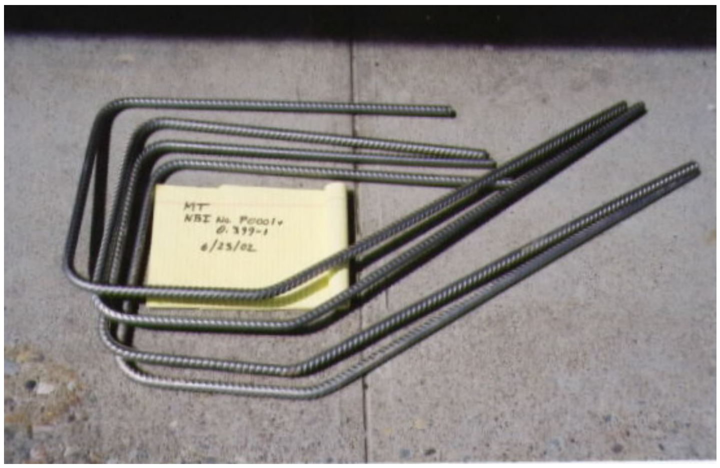

**Figure 43. Examples of stainless steel reinforcement details acquired from the job site.**

**APPENDIX F**
**FHWA PROJECT NUMBER NH-02-03**
**TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM**
**Evaluation Report**

**October 27, 2004**

**State:** New Hampshire.

**State DOT Contact:** Mr. Paul Nadeau [(603) 645-1760].

**NBI Bridge Number:** 016101850007700.

**Project Type:** Replacement.

**Location:** Bridges on I-293 over Frontage Rd. and Brown Ave., Manchester, NH.

**Innovative Material:** Galvanizing reinforcing steel.

**Bridge Description:** These two bridges are discussed in a single report because of construction and innovative reinforcement commonalities and their proximity to one another. In each case, there are two-lane east- and westbound bridges that are part of a number of bridge reconstructions and replacements along I-293. The Frontage Road Bridge is about 300 mi east of the Brown Avenue Bridge. Figure 44 shows a perspective view of the latter bridge where the girders are set but the deck formwork has not been placed. Note job site storage of the galvanized reinforcement (circled) to the right of the in-place girders. Figure 45 provides a closer view. The deck specifications call for longitudinal #5 bars with 8-inch spacing and transverse #6 at 6-inch spacing. While a pavement overlay is normally employed for New Hampshire bridges, this is not being called for on the Frontage Road or Brown Avenue Bridges.

**Figure 44. General view of the Brown Avenue Bridge under construction.**

**Figure 45. View of the in-place girders on the Brown Avenue Bridge. Note ECR extending from the top of the backwall.**

Classification of galvanized reinforcement as innovative is conjecture, since this material has been available for decades, although its use as reinforcement in bridge construction has been limited. The fact that results from both research and field experience have been mixed from the corrosion performance standpoint, however, warrants its being included in this program.

**Construction Sequence:** At the time of the site visit (May 6, 2004), only the girders were in place on the Brown Avenue Bridge as noted above in conjunction with figures 44 and 45. Construction was more advanced at Frontage Road as explained below. Figure 46 shows a general view of the galvanized bar placement on the Frontage Road deck.

**Figure 46. In-place galvanized reinforcement on the Frontage Road Bridge deck.**

**Reinforcement Specification:** Initially, Type 316L or 316LN reinforcement conforming to AASHTO M 31M (M31) in accordance with ASTM A-955M-96 was specified for both Brown Avenue Bridges and 316L clad black bars (AASHTO M 31M (M31)) for the Frontage Road ones. The two east bound bridges were replaced in 2003; but because suppliers were unable to provide the stainless steel, ECR was substituted. This same supply problem arose for the clad reinforcement in 2004, and galvanized reinforcement was used as a substitute here.

**Material Cost:** Table 11 lists the as-bid costs for both the originally specified stainless and stainless clad reinforcement and for the replacement galvanized reinforcement for both bridges.

**Table 11. Reinforcing steel costs.**

| Reinforcement Type | Bridge | Est. Quantity, kg | Unit Price | Est. Cost |
|---|---|---|---|---|
| Type 316L or 316LN | Brown Avenue | 59,977 | $5.15/kg | $308,882 |
| Galvanized | | | $2.92/kg | $175,133 |
| Clad Type 316L | Frontage Road | 51,340 | $4.15/kg | $213,061 |
| Galvanized | | | $3.54/kg | $181,743 |

**Concrete Specification:** The concrete mix design is shown in table 12. This requires a minimum 30 MPa (4,000 psi) compressive strength at 28 days.

**Table 12. Concrete mix design.**

| | Sat'd Weight | Surface Dry Yield, $m^3$ |
|---|---|---|
| Cement Quebec Type II | 173 kg | 0.055 |
| Blue Circle NewCem | 173 kg | 0.059 |
| Manch. S&G Fine Aggr. | 700 kg | 0.264 |
| Manch. S&G 0.75 inches | 864 kg | 0.327 |
| Manch. S&G 0.375 inches | 211 kg | 0.080 |
| Water | 155 liters | 0.155 |
| Total Air | 6.0% | 0.060 |
| | Total | 1.001 |

| | |
|---|---|
| Daracem-100 | 3460 ml |
| Micro Air | 2.0 ml |
| Water/cement ratio | 0.45 |
| Slump | 127–203 mm |
| Unit Weight | 2274 kg/$m^3$ |

**Prime Job Contractor:** George R. Cairns & Sons
8 Ledge Road
Windham, NH 03087
(603) 421-1888

**Subcontractor:** E.D. Swett, Inc.
8 Industrial Park Dr.
Concord, NH 03301
(603) 224-7401

**Steel Supplier:** Barker Steel Company, Inc.
55 Sumner Street
Milford, MA 01757

**Job Site Storage:** The galvanized steel for both bridges was delivered in plastic wrapping just prior to the placement schedule for the Frontage Road Bridge. Figures 47 and 48 show views of bar storage at this latter site. A distant view of bars at the Brown Avenue Bridge was indicated in figure 44, and figures 49 and 50 show closer views of straight and fabricated bars, respectively, at this location.

**Figure 47. Bundled/wrapped bars at the Frontage Road job site.**

**Figure 48. Fabricated galvanized bars at the Frontage Road Bridge job site.**

**Figure 49. Stored galvanized bars at the Brown Avenue Bridge job site.**

**Figure 50. As-delivered galvanized bars at the Brown Avenue site after pulling back the plastic wrap.**

**Presence of Carbon Steel:** Shear studs on the top girder flanges are carbon steel. A distant view of these can be seen in figure 46, and figure 51 provides a closer view. While no instances of electrical contact between the two metal types were apparent, this could inadvertently occur. Because potential of galvanized steel can be active to passive black steel, a corrosion cell could be established.

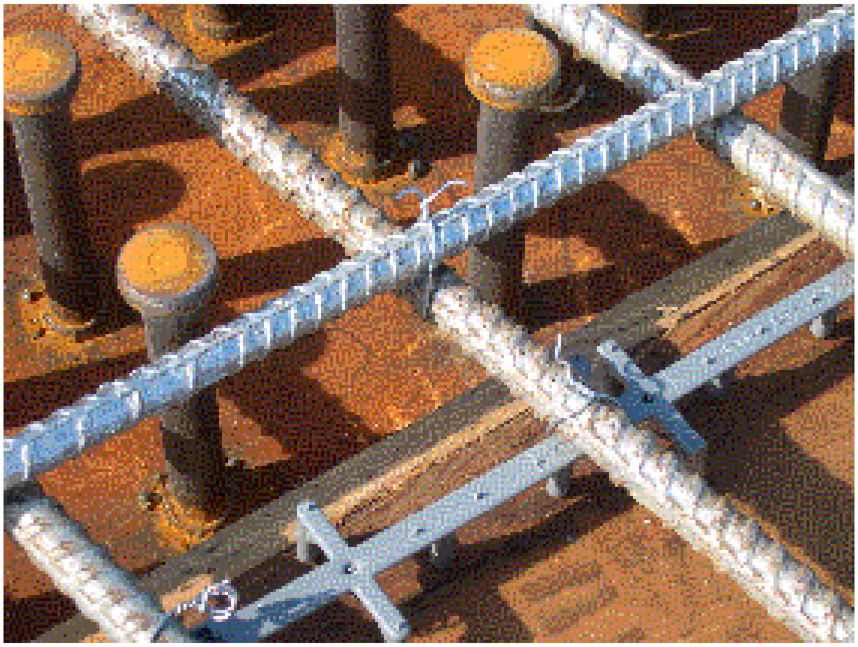

**Figure 51. Closeup view of the in-place galvanized reinforcement relative to carbon steel studs.**

**Innovation Justification:** Northern bridge decks in New Hampshire endure heavy winter precipitation and deicing salt use. Innovative reinforcements that provide enhanced corrosion resistance relative to that of black steel are being increasingly recognized as competitive on a life-cycle cost analysis basis.

**Problems:** The following difficulties and potential difficulties were cited for these two bridge projects:

1. The problems associated with acquisition of both the 316L/316LN stainless steel reinforcement (Frontage Road Bridge) and clad 316L stainless reinforcement (Brown Avenue Bridge) were noted above.
2. The potential galvanic corrosion problem that could arise from the galvanized reinforcement contacting the carbon steel studs that project from the top of girders was mentioned above.
3. Many of the as-delivered galvanized bars had a brown-greenish surface deposit. Examples of this can be seen on some of the bars in figure 51, and a closer view is shown in figure 52 This caused delays and additional effort in that the contractor was told to remove the deposits to the extent possible. It was later determined that the deposits were residuals from a chromate pretreatment. It is not unexpected for such "lack of prior experience" problems to arise with innovative reinforcement.
4. A concern was expressed that concrete cracking along the plastic mat spacers could occur because the openings in these may be too small to pass the coarse aggregate as the concrete is placed. Figure 53 shows a spacer in place. This, of course, is not related to the use of innovative reinforcement.

**Figure 52. Deposits on galvanized reinforcing bars.**

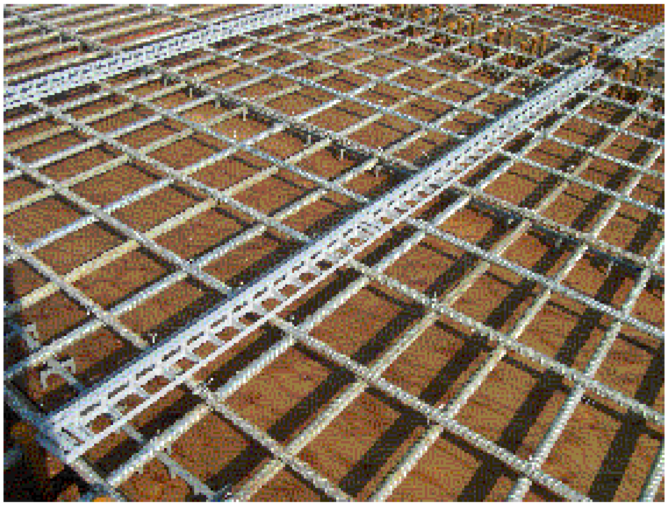

**Figure 53. In-place bottom galvanized rebar mat with plastic mat spacer.**

5. Fabricated bars for the Brown Avenue Bridge, in particular, exhibited areas of disbonded zinc coating. This apparently resulted when bars were bundled together as the galvanized layer dried and the bars were subsequently pulled apart. Zinc layer dendrites (or icicles) were also present. Examples of the former are shown in figure 54 (circled regions) and of the latter in figure 55.

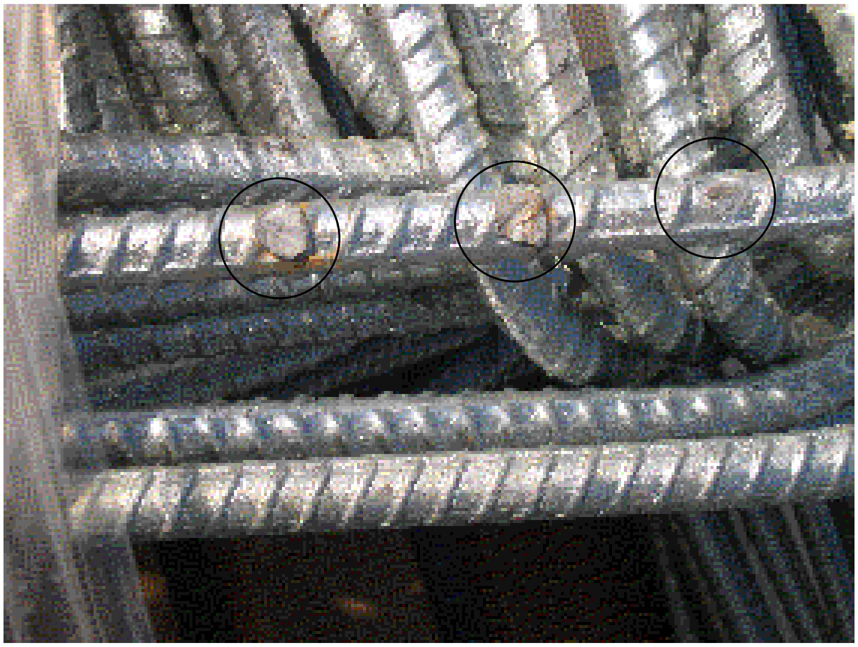

**Figure 54. Examples of disbonding of the galvanized layer on fabricated bars for the Brown Avenue Bridge.**

**Figure 55. Galvanized layer disbonding and icicle on reinforcing bars. Examples of disbonding are also apparent.**

**Material Acquisition:** The project team was able to acquire samples of the galvanized bars from the job site for analysis.

**APPENDIX G**
**FHWA PROJECT NUMBER OK-01-01**
**TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM**
**Evaluation Report**[8]

**State:** Oklahoma.

**State DOT Contact:** Mr. John Leonard [(580) 336-7374]
Mr. James Gilbreath [(580) 336-7374].

**NBI Bridge Number:** 26415.

**Project Type:** Replacement Bridge.

**Location:** Bridge crossing Chickaskia River on I-35 in Kay County, OK.

**Innovative Material:** MMFX-II Reinforcing Steel.

**Bridge Description:** The new bridge comprises the two northbound lanes at the above location. The southbound bridge of the same design was completed one year earlier and employed epoxy-coated reinforcing steel. Overall length of the bridge is 200 m (657 ft) and total width 12.3 m (40.4 ft) and consists of five spans on four piers with 1.80 m (5.90 ft) diameter drilled shafts with cast-in-place caps and bulb-tee prestressed concrete beams. Deck design was by the empirical method. Initially, stainless steel clad reinforcement was specified; but because of delivery problems, this was changed to MMFX-II. Figure 56 shows a general view of the bridge at the time when the deck was being formed.

**Figure 56. General view of the I-35 northbound bridge.**

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8 The description for this bridge utilizes English and not metric units since the project documents and specifications were so based.

**Innovation Justification:** The anticipated good corrosion resistance of MMFX-II reinforcing steel is anticipated to result in reduced maintenance and life-cycle cost for the bridge.

**Construction Sequence:** The deck was placed from south to north with each span being formed and poured as a separate unit. Figure 57 shows a perspective view of the as-formed deck reinforcing steel as seen from east to west across span 1. Figure 58 provides a closer view, including an ECR spacer that separates the two mats and reinforcing steel from a girder. Figure 59 shows the tie-in of the parapet wall reinforcing steel to the deck. Slab thickness is 8 inches and the reinforcement is comprised of #4 and #5 bars. Cover over the top steel is 2.4 inches.

**Figure 57. In-place deck reinforcing steel.**

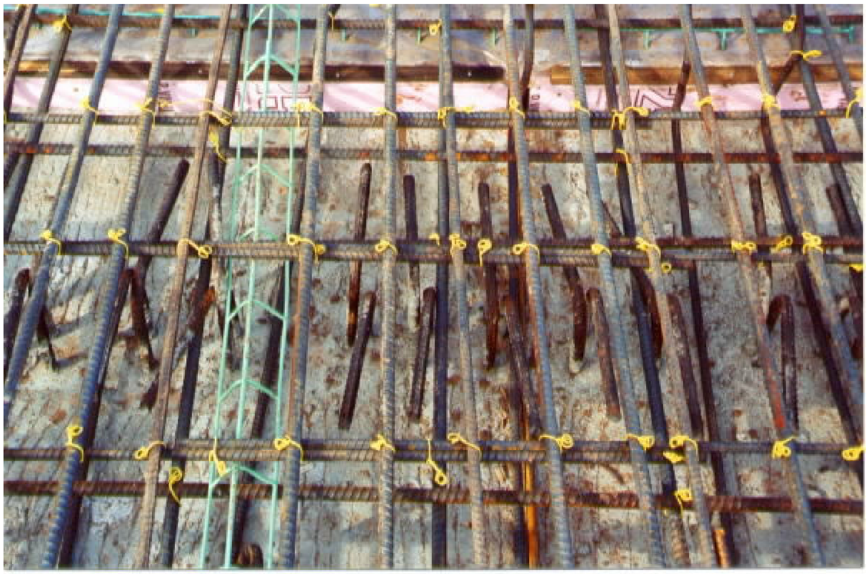

**Figure 58. Closeup view of MMFX-II deck reinforcing steel.**

**Figure 59. Reinforcing steel as placed in the deck and parapet wall.**

**Reinforcement Specification:** At the time of construction, no national standard existed for MMFX-II reinforcing steel. In lieu of this, the manufacturer's "Product Bulletin" dated September 2001 was employed.

**Concrete Specification:** The concrete was termed, "Special Deck," with mix design as specified in table 13. Because MMFX-II was anticipated to be less corrosion-resistant than the clad stainless steel, the admixture IPANEX®, which has corrosion inhibiting attributes, was added via a change order.

**Table 13. Concrete mix design.**

| | |
|---|---|
| Cement Content (Type I), pcy | 559 |
| Slag/Fly Ash, pcy | 133 |
| Fine Aggregate, pcy | 1,272 |
| Coarse Aggregate (#67), pcy | 1,710 |
| Water Content, gal/cy | 33 |
| Water-Cement Ratio | 0.40 |
| Air Entraining Agent, oz. | 6 |
| Air Content, percent | 5 |

**Job Contractor:** Muskogee Bridge Co., Inc.
P.O. Drawer 798
Muskogee, OK 74402
(918) 683-3051

**Steel Supplier:** MMFX Steel Corporation of America, Inc. The steel was produced by Birmingham Steel, 3630 Fourth Street, Flowood, MS 39208.

**Material Cost:** A total of 167,790 pounds of MMFX-II reinforcing steel was ordered for the project. The unit material cost was $0.88/lb for a total cost of $146,863.

**Job Site Storage:** The steel was delivered via truck and stored uncovered outdoors on timbers. A crane was employed to move the steel to the deck, where it was placed by hand. Figure 60 shows a perspective view of the storage location, and figure 61 provides a closeup view.

**Figure 60. Perspective view of steel storage site.**

**Figure 61. Closeup view of stored bars on timbers at job site.**

**Problems:** Difficulties that were encountered with the companion, southbound bridge, which do not relate to the reinforcement but rather to structural problems, led to doing away with the elastomeric pads at piers 1 and 4 and installing expansion joints at these locations. Closure pours were not made here; and instead, these areas were poured with the adjoining slabs. The longitudinal steel was shortened to allow for expansion devices.

There was a 5-week period between the time the order for MMFX-II was placed and the steel was delivered. Because the change from clad stainless steel to MMFX-II reinforcement was anticipated ahead of time, no project delay resulted.

**Material Acquisition:** Several lengths of reinforcing steel were made available from the job site for testing by FAU and FDOT.

**APPENDIX H**
**FHWA PROJECT NUMBER SC-00-01**
**TEA-21 INNOVATIVE BRIDGE CONSTRUCTION PROGRAM**
**Evaluation Report**[9]

**October 27, 2004**

**State:** South Carolina.

**State DOT Contact:** Mr. Clay Bodiford [(843) 740-1574].

**NBI Bridge Number:** 107005400100.

**Project Type:** Replacement.

**Location:** Bridges on S-54 (Chisholm Road over Tidal Creek), Charlestown County, SC.

**Innovative Material:** Stainless steel Type 2205, Type 316 clad black bar, and MMFX-II.

**Bridge Description:** The bridge is two lanes with the substructure consisting of six conventional prestressed piling bends with cast-in-place pile caps. These support five 28- by 30-ft reinforced concrete deck spans (total length 150 feet). Figure 62 provides a perspective view of the bridge under construction. The five spans, designated 1–5, extend generally from north to south and, along with the barrier parapets, were placed with, respectively, black bar with discrete


**Figure 62. General view of the bridge under construction.**

[9] The description for this bridge utilizes English and not metric units since the project documents and specifications were so based.

Galvashield XP embedded galvanic anodes, Type 2205 stainless steel, Type 316 clad black bar, black bars,[10] and MMFX-II. This combination of reinforcement types provides a unique opportunity to assess the relative long-term performance of these materials in an actual service environment.

The deck slabs are 19 inches thick with 1) #5 longitudinal and transverse top mat bars on 16-inch centers and 2) #5 transverse bars with 12-inch spacing and staggered #5 and #9 longitudinal bars with 6-inch spacing in the bottom. Bar supports are plastic.

**Reinforcement Specification:** As noted above, innovative reinforcement was used in spans 2, 3 and 5, in addition to incorporation of discrete galvanic anodes on the black bars in span 1. Table 14 gives details for the different reinforcement types.

**Table 14. Reinforcement requirements and suppliers.**

| Reinforcing Steel | Specification | Supplier | Grade |
|---|---|---|---|
| Black Bar | ASTM A706 | — | 60 |
| Type 2205 SS | ASTM A955 | Talley Metals | 75 |
| Type 316 stainless Slad | ASTM A615 or A706 | CMC Steel Group | 60 |
| MMFX-II | Company Spec. | MMFX Steel Corp. | 100 |

**Material Cost:** Table 15 lists the as-bid costs for the different reinforcement types.

**Table 15. Cost data for the different types of reinforcement.**

| Reinforcement Type | Quantity, lbs. | Unit Cost per lb. | Total Cost |
|---|---|---|---|
| Black Bar | 22,529 | $0.27 | $6,083 |
| Type 2205 Stainless Steel | 10,990 | $2.42 | $26,500 |
| Type 316 Clad Stainless | 10,990 | $1.27 | $14,000 |
| MMFX-II | 11,107 | $0.62 | $6,900 |

**Steel Supplier:** All reinforcement was purchased through CMC Steel Group although producers of the Type 2205 stainless and MMFX-II are as indicated in table 14.

**Concrete Specification:** The concrete mix specification was for Class 4000 concrete (4,000 psi minimum compressive strength at 28 days). This was supplied by Van-Smith Concrete Company in Charleston according to the mix design in table 16.

**Prime Job Contractor:** Cape Romain Contracting, Inc.
660 Cape Romain Road
Wando, SC 29492
(843) 884-5167

[10] It was originally planned that span 4 would utilize stainless clad bars from a second source; however, these could not be delivered according to the construction schedule.

**Table 16. Concrete mix design.**

| Material | Source | Amount, cy |
|---|---|---|
| Cement | Holman Type I | 541 lbs. |
| Fly Ash | | 140 lbs. |
| Fine Aggr. | Palmetto | 1,093 lbs. |
| Coarse Aggr. | | 1,810 lbs. |
| Air | | 4.50% |
| Water-Cementitious Ratio | | 0.40% |
| WRDA-35 | WR Grace | 26 oz. |
| Darex II | WR Grace | 6 oz |
| Weight per cf | | 142.8 lbs. |

**Construction:** Figures 63–67 show various aspects of the deck steel placement and concrete pouring.

**Figure 63. View of MMFX-II placement in span 5.**

**Figure 64. View of 2205 stainless steel placement in span 2.**

**Figure 65. View of in-place clad stainless in span 3.**

**Figure 66. View of in-place black bars (span 1) along with discrete galvanic anodes.**

**Figure 67. Closeup view of discrete galvanic anodes on in-place span 1 black bars.**

**Presence of Carbon Steel:** Carbon steel A25 dowels extend into the deck slabs from the backwalls. An example of these can be seen in the right foreground of figure 64. The specification calls for these to be wrapped with roofing felt, rubber, or another seepage-proofed compressible material to allow 0.25 inches of compressible material between the concrete and dowel. As such, electrical contact between the dowels and reinforcement was avoided.

**Innovation Justification:** The salt water climate of coastal South Carolina can result in shortened service life for bridge substructures and for decks in cases where profile is low. This project provides an excellent opportunity to investigate and compare various innovative, corrosion-resistant reinforcement options in side-by-side, actual bridge comparisons.

**Problems:** As noted above, the original bridge specification called for Stelax clad 316 black core bars in span 4. The company was unable to deliver these according to the project timing, and plain black bars were substituted.

## ACKNOWLEDGMENTS

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